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VIRTUAL BALKAN POWER CENTRE FOR ADVANCE OF RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

WORKSHOP 1.2: TECHNICAL DESIGN OF RES-PLANTS FOR ISOLATED REGIONS

AGENDA

Faculty of Electrical Engineering and Computing, Zagreb, Croatia
23 – 24 May, 2005

Monday, 23rd of May

$9^{30} – 10^{00}$	Registration	
$10^{00} - 10^{15}$	Welcome and Introduction	
$10^{15} – 10^{45}$	Renewable Energy Sources in Croatian Power System	Dr. sc. Željko Tomšić, Ministry of Economy, Labour and Enterpreneurship
$10^{45} - 11^{15}$	Technical Design of Micro Hydro and Small Hydro Plants	ETF, INTRADE
$11^{15} – 11^{45}$	Increasing Penetration of RES in Island Energy Systems	Dr. sc. Neven Duić, Faculty of Mechanical and Naval Engineering, Zagreb
$11^{45} - 12^{00}$	Discussion	
$12^{00} – 14^{00}$	Lunch Break	
$14^{00} - 14^{30}$	Technical design of photovoltaic & wind power for a tourist centre at an Adriatic island	Maja Božičević Vrhovčak, Faculty of Electrical Engineering and Computing
$14^{30} – 15^{00}$	Technical design of wood pellet fired micro CHP	ISTRABENZ
$15^{00} - 15^{30}$	Technical design of wood chip fired Steam engine/generator at district heating plant	DMSG
$15^{30} – 16^{00}$	Wood chip fired ORC-plant for CHP-production for rural village	TUS
$16^{00} – 16^{30}$	RES application in the Kynthos Island	NTUA
$16^{30} – 17^{00}$	Discussion	
20^{00}	Official dinner	

Tuesday, 24th of May

$09^{00} - 09^{30}$	Legislative Framework for Renewable Energy Use in Croatia	Igor Raguzin, Ministry of Economy
$09^{30} - 10^{00}$	Absorption Cooling System Based on Wood-waste Biomass	UNTZ
$10^{00} - 10^{30}$	Technical Design of a Geothermal Driven ORC-Plant	CRES
$10^{30} - 10^{45}$	Coffee break	
$10^{45} – 11^{15}$	Technical Definition and Current Status Of RES in Greek Islands	NTUA
$11^{15} – 11^{45}$	Discussion	
$11^{45} – 12^{30}$	Future activities	
$12^{30} - 14^{00}$	Lunch	
14^{00}	End of workshop	

Participants

ACRONYM	Institution	Participant
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Virtual Balkan Power Centre for Advance of
Renewable Energy Sources in Western Balkans

Balkan Power Center Report

Technical design of RES-plants for isolated regions

Workshop T.1.2, WP 1

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INDEX

1 Technical design of micro hydro and small hydro power plants

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1.1 Micro and small hydro power plants - General

We can distinguish two principals of using the water energy:

- Actional
- Reactional

The actional principle is based on using the energy of water flow, and reactional on using the potential water energy.

There are several various types of water wheels. With so-called hitting water wheel, the spades dive horizontally into the water and, in that way, they use the water flow energy and turn it into useful mechanical work. Out from the hitting working wheel the “under channel” working wheel was developed in time. Besides the water flow energy it uses the water pressure too, created from the height difference when water enters the wheel.

Contrary to that, “over channel” working wheel uses exclusively the potential water energy. Water comes from above and hits the spades and turn them using its weight. Besides the stated, there are the working wheels where water is brought to the middle of the spades, which is the combination of the first two.

Figure 1. Hitting wheel

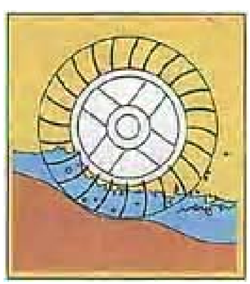

Figure 2. “Under channel”

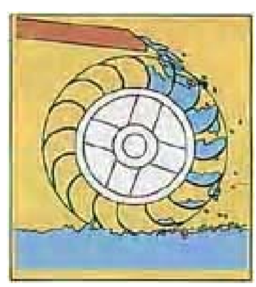

Figure 3. “Over channel”

There is no strict bordering line between the mentioned drives, but we can take that:

- Small drives with power of 100 kW – 5 MW,
- Medium drives of 5 MW – 25 MW,

- Large drives of 25 MW and more.

Besides the stated, there are smaller, so called micro drives with the power of 0,5 kW to 100 kW.

1.2 Small and Micro Electric Power Plants – principals and types

Small and micro hydroelectric power plants are built on the current flows whose characteristics are suitable for the building of those. It is mainly about the mountains current flows with small quantity of water and big falls. It is also possible to build this type of electric power plants on the bigger current flows, where only the smaller part of available current flow is taken for production. This however is done rarely since bigger current flows are, in principal, used for building bigger plants. To make the project of building one micro or small power plant justified from the techno-economic aspect, it is necessary to decide two basic parameters, defining the type of facility and its feasibility. They are:

- Water flow of the current at place of water taking,
- Altitude difference between the place of water taking and the facility where the turbine is.

Based on these parameters bit also on the configuration of the terrain, environmental aspects and some other local circumstances, we can define the type of the hydroelectric power plant, the type of turbine and other equipment.

There are two basic types of electric power plants:

- The ones that use derivational channel and/or the ones that use the pressure water pipe line to bring the water to the turbine,
- Turbine is next to the small dam – dam facility

To reach the optimal solution we use the techno-economic analysis where all necessary parameters are taken in consideration.

1.3 Small Hydropower Plant

Each small hydropower plant, regardless of the type, consists of three basic elements:

- Water intake structure,
- Derivational channel and/or the pressure water pipe line or in taking pipe line,
- Engine facility with adequate equipment.

Depending on the project solution, we can also have, as additional facilities or equipment, the water bed or hydro mechanical equipment at law dams, like a lid.

1.3.1 Intake Structure

At the place of water take, the redirection or smaller accumulation is done, in order to bring it to the water pipe line or directly to the turbine, if we are talking about, so called, dam facility. There are two basic types of intake structure:

- Water intake with law partition profile and sand sedimentary,
- Law or medium dam.

The first variation of intake structure, where we include *Tyrolean intake and direct intake*, is the one that has shown in practice as the most suitable from several reasons:

- More simple workmanship
- Shorter building time,
- Lower costs,
- Easier to live with environment,
- Less ecologic influence to the environment.

Out of the two mentioned solutions, the practice proved the Tyrolean intake more suitable. It consists of:

- Law partition profile with not overflowing and water taking part,
- Sand sedimentary,
- Adequate hydro mechanical equipment,
- Incoming segment at the end of sand sedimentary.

Tyrolean intake

It is used with typical mountain water flows which have uneven current flow during the year, big waters in short periods (during sudden snow melting or after intensive falls) and big quantities of huge pulled drifts. Law partition profile is made out of concrete which has to satisfy the criteria of hydro building facilities. It is a concrete of MB 30 quality, so called hydro technical concrete. The purpose of partition profile is to stop the water flow which is done at on a part of over flowing profile, and redirect it to the water taking part of profile where there is a collecting channel with the net. The purpose of this net at the collecting channel is to stop the income of huge drifts. It is made in decline of cca 10% in the direction of water flow to make the cleaning easier. Decline of the bottom of collecting channel is 5 %, although it can be different. At the end of collecting channel, at the entrance into the send sedimentary, there is panel lid. The collecting channel with the net is of dimensions to intake the installed quantity of water. The evacuation of the surplus of water and prevention of in taking of huge drifts and floating objects is done over the whole length of profile. Sand sedimentary continues after collecting channel. Its basic function is to remove the tiny drifts that went through the rough net at the in taking part of profile. The sedimentary is hydraulically and technically of dimensions that guaranty removal of particles that could damage the work of turbine. The size of the particles that have to be removed depends also on type of turbine. For the Francis turbine, those particles can be bigger, while for Pelton turbine they are considerably smaller. At the entrance of the sedimentary, at the same side but under the angle of 90^{o} there is, so called, the winter opening with panel lid. This opening is useful for low temperatures in the winter months (the matter of location of the plant) and the possibility of freezing of the net at the collection channel. However, due to its law position, the drifts can easily close this opening, so its application is useful but not necessary. The practice has shown that this opening can also have a function of letting the water out when cleaning the sedimentary. Considering that the water when the opening is opened, hits directly the sedimentary, it is very efficient for cleaning it. At the end of the sedimentary is the opening for mud that serves to take away the sediments from the sedimentary. It is possible to do the cleaning in mechanical and hydraulic way. By opening the open on the winter open and at the mud open, with closing the lid at the end of collecting channel, it is possible to clean the sedimentary, quickly and efficiently. At the very sedimentary, the side overflow is predicted and it serves for the evacuation of the surplus of water over Q_{inst}. Between the sedimentary and incoming chamber, there is a fine net, and at the beginning of the pipe line, there is a panel lid. The basic dimensions of his buildings and equipment are the matter of calculation.

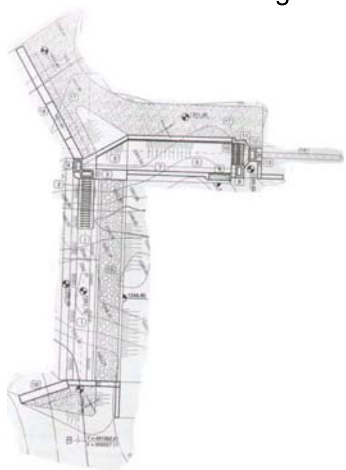

Figure 4. Water intake structure

Figure 5. Water intake – 3D

The direct water intake

The second mentioned variant of intake, the direct intake, is applied at the current flows that do not have stressed problem of huge drifts and do have relatively even annual water flow. We are talking about simple concrete building consisting of entering basin or channel incorporated in the very current flow, where the water falls directly into it over the net, which serves to prevent the huge drifts to come in. The sedimentation of mud and send is also done in the basin, after which the water, over the fine net, enters the pressure pipeline.

The dam

The practice knows the application of law and medium dams. In one case, the dams serve to make smaller accumulation and to redirect water through the pressure pipeline to the engine facility, while in the other case the engine facility is next to dam – dam facility. In this case it is possible to use the water multi functionally from the accumulation for i.e. irrigation of the arable land. From the techno – economic aspect it is very rare that this type of in taking structure is built, since it is very expensive because of the construction costs and later of monitoring and maintenance costs. Besides, the ecological aspect is very important because the building of the dam with accumulation, even the temporary one, influences the microclimate of environment.

1.3.2 Pressure water pipeline

Pressure water pipeline serves for bringing the water from the intake to engine facilities. It is often that, before the pipeline, the derivational channel is built. It is in the shape of concrete basin that serves to bring the water to the pressure pipeline. Derivational channel is used, among other things, due to the building costs, since it is much cheaper than the pressure pipeline. Every pressure pipeline is dimensioned to receive and transport water for turbine. Pressure water pipeline is made of:

- Steel
- Non steel materials

Out of non steel materials the most common in use are plastic pipes made of special types of plastic. Besides, it is possible to make the pipes out of wood, but it is very seldom used in practice. Pressure water pipeline can be divided by the way of building to:

- On the ground,
- Underground.

On the ground pressure pipelines are installed at the terrain which allows it with its configuration, but at the locations where it is possible too. For instance, if the route of pressure pipeline goes alongside the road, it is hard to imagine installing on the ground pressure pipeline, since it would be exposed to various dangers. The level of the pipeline, in both installing cases, in height and situational is laid in a way that the works are reduced to minimum with respecting certain principles, such as:

- The level of the pipeline is under the piezometrical line with all regimes of the electric power plant work,
- Because of empting the pipeline the level has parallel decline in all its length, and in direction of flow.

Pressure pipeline is dimensioned to bring the water for maximal power production of turbine. Diameters ranges from Ø100 to Ø2500 or even higher. Based on diameter, the wall thickness of pipes will be defined to satisfy the pressure requirement. Pressure ranges from 1 to cca 50 bar or even higher.

Underground or dug in pipelines

When the pipeline is laid underground, which is more often variant, it is necessary to make the construction works in digging the channels and laying the pipeline. Depending on the calibre pipes that the pipeline is made of the types of normal transversal profiles of the route. Before laying the pipeline, it is necessary to make fine levelling of the bottom of the trench according to the established levelling system. At the bottom of the trench, regardless of the material of the pipeline, the small-grained stone material is poured. Under the very pipes, the base of small-grained material of certain thickness is laid and stamped. Around the pipe and cca 20 cm above the top of the pipe, the adequate material is laid. It can be the material dug out from the trench, or the material brought from aside. When it comes to the pipes made of special plastic materials, it is necessary that the fines of this material are better than with the steel pipes. Material around the pipes is stamped to the certain firmness, which is controlled by, so called, dynamic plate. The pouring above the pipe up to certain height is done in layers with the repeated stamping. Only the layer of cca 20 cm above the very pipe is not stamped due to possibility of damaging the pipe in the form of making initial cracks on the outer layer of the pipe. The rest of the trench above the pipe, in height of 50 cm above, is poured by the trench material without stamping. The summary layer above the top of the pipeline depends of several factors but it varies from 0,5 to 1,2 m. Digging in is done in forming the layers of 15-20 cm so that it is levelled by subsiding the surface of terrain, later on. If it is needed, and if the subsiding is stronger, the pipeline can be poured on later.

Figure 6. Steel pipeline – "underground" Figure 7. GRP pipeline – "underground"

On the ground pipeline

If the terrain and some other conditions allow, it is possible to lay the pipeline on the ground. In principal, the on the ground pipeline is relatively right construction. Pipeline is laid on so called saddles which are placed on the concrete anchor blocks. The arrangement of anchor blocks and saddles depends on pipe calibre, configuration and geology of the terrain.

Each pipeline has several main characteristics, like:

- materials,
- length,
- diameter,
- dynamic pressure,
- inner pressure,
- width of the wall.

Regarding materials, it has already been mentioned that steel and non steel, that is, the pipes of special plastic materials are installed. As one of the most quality and economically the best cost efficient solutions is the usage of, so called, GRP (Glass reinforced plastic) pipes. These pipes have the following advantage over the steel pipes:

- only 25% of the steel pipes weight (or 10% of concrete pipes weight),
- quick and simple installing,
- no need for heavy and expensive equipment,
- transport is more simple and cheaper at the same distance, since the pipes can be transported one within the others (if there are pipes of different calibres),
- excellent hydraulic characteristics, less coefficient of roughness of the pipe inside which enables the bigger water flow,
- ecologically examined and safe,
- no need for ante corrosion and cathode protection,

Joining the individual segments of the steel pipes is done by welding, while GRP and other steel pipes are joined by joints, which can be separate elements or integral parts of the pipes. While welding two pipes together the most important thing is that the weld of the root is done in a quality way since it is the part that suffers the highest burden. The welded joint must be rayed radio graphically in order to confirm its quality. In case that some mistakes are discovered, they have to be removed which is mostly done by grinding and repeated welding. This is especially important when high pressures are in question, over 20 bars, which is often the case in practice.

1.3.3 Power house

To put it simply, the engine facility is considered to be a building where the necessary equipment is placed. Technological space in the facility consists of working-operational and mounting part of the facility and they together make one unity. The engine facility should satisfy the following criteria:

- To be of optimal size to facilitate the safe accommodation of the equipment,
- That it is on a location close enough to let the water into the initial current flow,
- Not to be to close to inhabited settlements because of the noise.

In practice, the engine facilities are mostly on the ground, but there are examples where they are dug into the ground. The main reason for such construction is the closeness of inhabited settlements and the underground setting reduces the negative effects of noise.

It is especially important to mention that it is needed to pay special attention to the foundations for turbine and generator when building the facility. Since those are the parts exposed to great forces that cause vibrations and they are very heavy, the foundations must be done out of high quality concrete and in a very expert way. Two mentioned elements, turbine and generator, are initially placed on, so called, primary concrete, after which they are centred and poured by the secondary concrete.

It is necessary to plan the crane path in the facility, which is placed on the ceiling and serves for installing the equipment, and later on, for maintenance works. It is made out of steel I-profiles and should be defined to endure the burdening of the heaviest element, which is usually the generator. The crane is installed on the crane path. Besides, in the basic slab of the facility, it is needed to predict channels for various kinds of cables so that they are not exposed to the outside influences.

Figure 8. Powerhouse

Figure 9. Founding of generator

1.3.4 The equipment of the hydro power plant

Each power plant must possess:

- Turbine with adequate equipment,
- Generator with adequate equipment,

- Energetic transformer,
- Managerial, measuring cells,
- Other equipment according to the needs,

1.3.4.1 Turbine

Turbine represents the heart of the power plant and based on turbine, all other equipment is decided. Turbines are engines where potential and kinetic energy of flowing water transforms into mechanically useful work considering the way of bringing water to the working wheel of the turbine we distinguish:

- Reactional,
- Impulse turbines.

With the reactional turbines in the flowing elements before the working wheel, the pressure is transformed into kinetic energy and the other part of suppressed energy is transformed on the way into kinetic energy in the working wheel. With this turbine, the water pressure is significant immediately in front of the working wheel, and therefore we call them reactional turbines. Those turbines have immobile conducting wheel or the aperture with mobile wheel or the aperture with mobile spades and the working wheel that rotates with the turbine's axis.

If the total part of suppressed energy of the working wheel transforms into kinetic energy and it is brought to the very wheel, than we are talking about impulse turbine that is the turbine of equal pressure. The suppressed energy is transformed into kinetic energy in the spout, and therefore we call it the impulse turbine. In reactional turbines we include Francis, Kaplan and propeller turbines and in impulse we include Pelton and Bianki, that is Crossflow turbines as the most applied in practise. There are also some sub variants but they will not be included in this text. The integral part of this equipment for turbines is a flywheel (if needed), lid in front of turbine, hydraulic generator and turbine regulator (which are the integral part of the equipment for managing and regulating).

Flywheel

If it is necessary, and in order to compensate the inert generator masses deficit (turbine + generator), the flywheel is used, and it's mass must be compatible with other part of generator. It is in a shape of disc, which must be concentric and balanced together with other rotating parts of generator.

The lid in front of turbine

Between the pressure pipeline and turbine, more accurately, in the very pipeline the lid in front of turbine or the valve is placed. Its function is to close the pipeline during installing or maintenance works and to close the pressure pipeline when the engine does not work. It can be ball or butterfly valve which depends on the pressure in the pipeline and the flow, and on the type of turbine. It must be constructed in a way that, in a case of danger, it can be closed during the full flow. It is opened by hydraulic pressure and closed by knocking off the weight. The time of closing is adjusted, so that sudden rise of pressure within the pressure pipeline is prevented, and with it, the return hydraulic hit. The return hydraulic hit can be rather unpleasant because there are the pressures up to 50% higher than the hydrostatic, which can create many problems. This return hydraulic hit is especially expressed with Francis turbines, while with Pelton turbines it is insignificant. The integral part of the in front of turbine valve is a by-pass valve.

The turbine regulator

The regulator must be suitable for parallel work with the network (often in practice), but also for the island propulsion (rarely in practice) and the safe protection independently from outside conditions. It does its function by closing quickly the inflow of water and redirecting the jet and closing the in front turbine lid in the case of malfunctioning of the network, mechanical or electrical mistake and run away. It also has to secure the control of opening of conducting mechanism (with Francis turbine, ie.) or spurt (with Pelton turbine) depending on level of the upper water. It consists of hydraulic and electrical part with the following functions:

- managing the speed,
- managing the opening and
- stoppage in the case of danger.

Francis turbine

Francis turbine is also reaction, radial-axis turbine. It is because the water enters the turbine and the working wheel radially and leaves it axially, as it is shown at *picture x*. Parameters, for which those turbines are built, are single rate work 120 J/kg and flow through 0,45-25 m^3/s. Such a solution decreases the price of turbine up to 20% compared to all other solutions. Turbine wheel redirect water from radial to axial direction. They are made for falls from 10-350 m and have the specific number of turns from several tens to 1000 per minute. Water is brought to Francis turbine by a conveying wheel who's spades (that can be opened and closed) regulate the water quantity in the working wheel – the rotor. From the working wheel, water flows to diffuser whose role is to convey water further without whirling. In that way, the power can be regulated as well as the quantity of produced energy.

It can be of horizontal or vertical construction. Rotor is installed on the axle of the turbine and it has to be statically and dynamically balanced. The material out of which the rotor is made must be resistant to wearing out, ie. CrNi 13.4. The conveying aperture with adjustable spades is also made of quality material.

The axle can be bedded in several ways. One of the ways is with the help of two bearings at the ends of axle, while the other is by using combined bearings. This bearing is better but also the more expensive so one must make the analysis of the needs for its usage. The practice has often shown that this bearing needs additional oil-pressure device for cooling the oil in the bearing.

The Francis turbine belong to the type where water evenly inflows all over the working wheel, which means that each spade contributes, all the time, to reaching the rotating moment at the axle of the turbine. Since that the pressure difference is created between the enter and the exit of the water from the working wheel, this turbine is called overpressure.

Figure 10. The lid in front of turbine

Figure 11. Francis turbine - installation

Caplan turbine

Caplan turbine is reaction axial turbine used for single rate work from 15-50 J/kg and for through flows 0,01-50 m^3/s. depending on single rate work the number of spades can be from 3-10 (less number for lesser falls), in the shape of propeller. The conveying apparatus can be made as cylindrical conveying one, when the conveying apparatus circular motion axe of the spades is crossed with the axe of working wheel axel. The basic characteristic of Caplan's turbine is, the working wheel spades are mobile around its axes depending on turbine working regime. They are made with a vertical axel, while the pipe Caplan turbines are made with a horizontal axel. They are usually applied at low-pressure power plants (3 m < H < 55 m), where the flow through are relatively big. Caplan turbine can have 3 to 7 spades, depending of initial conditions: current flow and water decline.

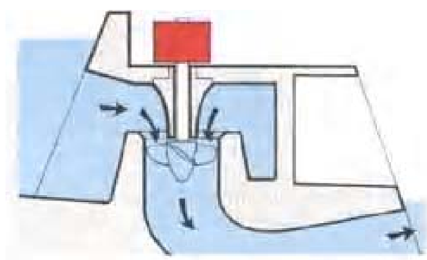

Figure 12. Caplan turbine - principle

Pelton turbine

Pelton's impulse working turbine is most frequently used in small hydro power plants. The advantage of it is that Pelton turbine is relatively the simplest, in constructive and hydraulic way. The application range for small hydro power plants is from the falls of 300 m and more, and are made for specific number of turns from 10-30 turns per minute, and flows through from 0,01-2 m^3/s. In a Pelton turbine water is brought through, so called, nozzle (mouth-piece), directed on spoon shaped spades which have nozzles on its ends. Working water is brought in under a pressure. The number of spouts is from 1-4. By the position of needle in the nozzle, the quantity of water is regulated. They are often built with horizontal axel. Pelton turbines work on the principal of active hit of water stream on working wheel spouts. The water stream from spout hits the spade tangential and rotates the turbine by that pressure. So the water hits directly the working wheel, reflects under the angle of almost 180 and flows away without pressure. The potential water energy is completely transformed into kinetic energy in the muzzle. The outer side of the spade does not contact the water. It is used with the high-pressure power plants where the flow through is relatively small. The application scope is in the range of declines of

300 m and more, the rotating number is from 1000 to 3000 r/m, and a flow through of 0,01 to 2 m3/s. the Pelton turbine belongs to the most efficient turbines from the aspect of efficiency, that is usage, with η = 90-95 %.

Figure 13. Pelton turbine

Figure.14. Entering mechanism of Pelton turb. and his inventor

1.3.4.2 Generators

Generator transforms the mechanic energy got from the axle of the turbine, into electric energy. Generators for three-phase alternating current are in use nowadays, although the earlier hydro electric systems used to give one-way current to serve the needs of earlier commercial electric systems. Depending on a network supply characteristics, the producers may choose between synchronised and unsynchronised generators.

Synchronized generators are more expensive than unsynchronised and are used in energetic systems where the exit from generator is in accordance with a burden of energetic system.

Synchronized generators

Synchronized generators is supplied with a stimulating system (rotational or statically) together with a voltage regulator which gives a voltage frequency and angle control phase before the generator is connected with a generator. It also supplies reactive energy, which requires current system when the generator is connected with a network. Synchronized generators can work isolated from network and produce current, since the stimulation does not depend on a network.

Synchronized generators for small hydro power plants:

Power: from 10-500 kVA,

Voltage: 400/230 V,

Frequency: 50 and 60 Hz,

Power factor: 0,8 cos φ

Rotation number: 1500 o/m

Ventilator as the integral part, is installed on the side of generator connected with the turbine. The switchboard is placed in a way that enables installing the power transformers and voltage regulators, as well as simple electric connection. Connections for electric cables must be vibration resistant and can be standard 4 or 6 wired.

Since the generator is an element exposed to great powers, it must be cooled so the ventilator must be predicted. Ventilators can be mechanical, when installed on the axis of the generator, or electric one that has the speed regulator to reduce the loses during the small burdens on the generator. Frequently, the hot air from the generator is taken out of the facility through additional out taking channels. It is important because it prevents additional heating of bearings, which is especially stressed during the summer months and in the wormer climates. Each generator is equipped with the air filter that can serve in n normal and special circumstances. Stator wind-ups are equipped with temperature sensors with the function to indicate, among other things, the foulness of the air filter. In principal, generators are made with rolling bearings with greasing, with the life time of at least 100.000 working hours. They are greased with the high quality greases with the wide range of temperature. Each bearing must be equipped with the miniature sonds for temperature measuring. One of the important characteristics of each generator is over speed. In the moment of sudden unburdening of the generator, that is, when the machine is no longer at the network from any reason, we have a short over speed that can go up to 70% of nominal rotation number. Therefore, before installing of generator, it is necessary to test the over speed in the very factory. Beside the stated, it is important to do the following for each generator:

- Winding resistance test,
- No load test,
- Short circuit test,
- High voltage test and insulation resistance,
- Load test,
- Current overload,
- Phase voltage comparison,
- Phase sequence,
- Winding test (600 V, 3 min),
- Vibration test,
- Voltage regulator test.

Unsynchronised generators

Unsynchronised generators are simple inductive engines without possibility to regulate voltage and they work with the speed directly connected with a frequency of system. They spend stimulating current from the network, absorbing reactive energy from their own magnetism. They cannot generate when they are disconnected from the network because they are unable to supply themselves with stimulating current. These generators are cheaper and are used with big networks where their exit is insignificantly proportional to the burden of energetic system. Their efficiency is from 2-4% lower than the efficiency of synchronised generators in the scope of work.

Lately, system of changeable speed and constant frequency, where the fluctuation of a turbine speed is allowed in a wide range, while voltage and frequency stay constant, entered the market. This system can even synchronize units to the network before it starts turning. The key of the system is the use of transformer with serial resonance, which is connected with the machine with double power supply.

Working voltage of generator varies with power. The standard voltages are 380 V or 430 V up to 1400 kVA. The stated voltages allow the usage of standard distributing transformers as well as exit transformer and the usage of generated power supply within the power plant system.

Unsynchronised generators for small hydro power plants:

Power: from 15-315 kVA

Voltage: 3x380 V,

Frequency: 50 Hz,

Power factor: from 0,8-0,9 cos φ

Tolerance: np = 2 nn

Rotation number: from 600-1500 o/m

1.3.4.3 Energetic transformer

To transport the electric energy produced in generator through the distributive network to the user, it is needed to adjust the voltage of it to the voltage of distributive network, which can be done in the transformer. It is said for the transformer to represent immovable electric machine. The reason: the alternating voltages of different and big units can be produced in transformers, and doing it is not necessary to start a single mechanical element. Transformer consists of the iron core where there are the electric wind-ups around. When we let the alternating electric power through the wind-ups, the magnetic flows initiated by the currents constantly change the direction and intensity. Consequently, in each wind up certain voltage is induced. The ratio of numbers of entering and exiting wind ups, roughly represents the ratio of entering and exiting voltages:

$W_1 / W_2 = U_1 / U_2$

This is true in case of empty walk of transformer, while there are smaller discrepancies in case of secondary burdening. If the exiting voltage, during the burdening of transformer insignificantly changes, it means that the transformer has the high voltage short circuit. Such transformers are called law-voltage ones and the stated formula can be used. The cooling is done by mineral oils, natural air current through the coolers and wind-ups (inner cooling) and natural current (outer cooling). Transformers can be with the conservers (dilatation dish) or without it. The magnetic wheel is made out of the materials of high magnetic permeability. Transformer’s dish (armour) and lid are made out of quality materials, resistant to deformations due to making the openings and installing the equipment.

1.3.4.4 Other equipment

Beside the stated, the main machinery for the successful work of small hydro power plant in the engine room are:

- Own consumption transformer,
- Medium voltage machinery,
- Management system,
- Signalization and alarms,
- System of one-way supply,

- Grounding system,
- Other.

1.3.4.5 Concrete example of a small hydroelectric power plant

The small hydroelectric power plant Jezernica, at the river Jezernica nearby Fojnica in the middle Bosnia:

1. Construction facilities consisting of:

a) Intake with sedimentary, length of partition profile is cca 12 m, width 60 cm, height down stream towards the river cca 1,5 m. Intake part of the profile is 5m long, and non intaking 7 m. sedimentary is cca 10 m long and 2,5 m wide. Intake is placed at the place 1345 m altitude.

b) Pressure pipeline is totally 2.850 meters long, out of that 2150 m is done by GRP pipes a 700 m out of steel pipes. The reason is a huge gross drop of the facility of 380 m and consequent pressure of 32 bars. Since that GRP pipes can bare pressures of 32 bars, it was necessary to use the steel pipes for the pressures above mentioned. Calibres are from Ø 500 at the beginning, over Ø 450 to Ø 400 mm at the entrance to the facility. At the very entrance to the turbine there is a pipe of Ø 300 mm with in front of turbine round lid DN 300, NP 50.

c) The engine facility is of dimensions 10x7 m next to which the transformer box of dimensions 3x2,5 m is located. It is located at 965 m altitude next to the river flow.

2. Equipment: in the engine facility there are:

a) Pelton turbine of nominal power of 1376 kW, with the number of rotations of 1000 o/min. the stated power can be reached when the nominal current flow of 360 l/s is available.

b) Generator is three-phase synchrony of nominal power 1500 kVA, nominal voltage 0,4 kV and frequency 50 Hz. It was meant for work parallel with the distributive network 20 kV, as well as possibility for isolated, that is, island work.

c) Energetic transformer is of nominal power 1500 kVA, nominal voltage 10(20) kV/0,4 kV (foldable) and frequency 50 Hz. Therefore, wind-ups of higher voltage are 10(20) kV while wind-ups of lower voltage are 400 V.

d) 24 kV engine facility: serves for connecting the power plant with the electro-energetic system at the level of distributive network. Besides that, the facility is a part of electro power plant, at the same time it is part of electro-distributive network, because the distributive lead (in this case cable) runs through the power plant.

e) The managing system, equipment 0,4 kV of generator voltage, its own consumption and continuous expenditure and continuous supply with power: the stated equipment is used for connecting electro mechanical equipment of the electro power plant into the functional unity. The facility 0,4 kV of generator voltage serves for distribution of electric power where the generator switch is a part of it. Managing system predicts installing of the system of local management, but the SCADA system of distant managing as well.

Pictures from the project!!!

1.3.5 The economic reasons for building small hydro power plants

The building of small hydro power plants is distinguished by:

- Relatively high initial investment per installed kW,
- Long life time of the facility,
- Great availability and reliability,
- Small running and maintenance costs (in normal case 1-2 % of investment expenditures),
- No need for fuel, consequently no costs.

Therefore, majority of costs are made during the realisation, that is, at the very beginning of the project, after which period, during the exploiting of the electric power plant, there are no major expenditures. Exceptions are eventual damages at the facilities and general overhaul after cca 15 years, when some elements may need to be changed (like working wheel of turbine, ie.)

1.4 Micro electric power plant

As stated previously in the text, under the micro electric power plants we understand the ones with the installed power of 0,5-100 kW, although, there is no strict division. Every micro electric power plant has all the construction facilities previously mentioned with all accompanied facilities. Of course, from the aspect of dimensions, micro electric power plants possess very modest facilities. The equipment is, in principle, alike to those for small hydroelectric power plants, adapted to this type of facilities, with some peculiarities.

Micro electric power plants are mainly built at the localities where it is not possible to build any other energetic facility, nor there any other source of electric energy. Such micro electric power plant can supply the island distributive network with the electric power where they can regulate the voltage and the frequencies of it.

Micro electric power plant consists of:

- Turbine,
- generator,
- Resistor for measuring the surplus of energy,
- Dispensator with the adequate equipment.

Electro-components need to be projected in a way to fit in small building, and at the same tome, not to influence the quality, that is, parameters of delivered electric energy. The programmed automats are used for managing the micro electric power plants.

Managing forms can be:

- Automatic adjustment of the own power,
- Work on its own network (island work),
- Parallel facility with the network.

In the first case, the automatic security of real possible power of the aggregate, and with it, the requests for agitating the generator. In the second case, the electric power plant works in the island facility as an independent producer of electric power. It is possible to correct the exit voltage ± 10%, to manage the frequency and energy distribution in the resistor, as well as maintaining the frequency at ± 10%.

If it is needed, micro (but small one too) electric power plant can be constructed for the work in parallel facility with the local distributive network.

1.5 Micro and small electric power plants in isolated areas

In the previous passage, the working principles of the power plants in isolated areas are partly explained. The stated is valid for micro electric power plants, as well as for the small ones. Mainly, the practice shows us that it is much cost efficiently to make a small or micro electric power plant (if there are conditions for it).

The reasons can be the following:

- Non existence of distributive network in certain area,
- Bad distributive network, especially in remote areas,
- If the techno-economic analysis shows that it is cost efficient to built some such facility.

Such facilities can be built for the supply of electric energy to some industrial facilities, like saw mills, health and recreation centres and smaller settlements in the remote areas. Today, there are such solutions that can provide quick and simple transfer of complete equipment of one micro electric power plant from one location to another.

2 Technical design of photovoltaic and wind power for a tourist centre at an Adriatic island

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2.1 Abstract

Basic data on Croatian islands with an emphasis on islands energy consumption have been presented. A national energy programme aiming for increasing energy efficiency, alternative energy use and environment protection on Croatian islands – CROTOK – has been introduced. A pilot project of an autonomous tourist resort at the island of Brač has been described. The project proposes the use of hybrid solar/wind/hydrogen plant for energy supply, desalinization plant and sustainable agriculture.

2.2 Basic information on Croatian islands

Croatian islands are the second largest archipelago of the Mediterranean Sea. The archipelago consists of 718 islands, 389 sounds and 78 reefs [1]. They define the territorial sea of the Republic of Croatia, which makes 37 per cent of its overall territory. The total surface of the archipelago is 3,300 km2, which is 5.7% of the total national land territory. 66 islands are inhabited, with a population of 110,953. About 95% of the population lives on 15 islands.

The islands are situated in the area with the Adriatic type of Mediterranean climate. Summers are hot and dry, winters are mild and wet, and the insolation degree is high. July average temperature range from 23,7ºC to 25,6ºC. Croatian islands are among locations the most exposed to the sun in Europe: the annual average of insolation ranges from 2200 to 2650 hours, which means over 7 hours of sun daily. The regime of precipitation is typically Mediterranean. There are 266 to 1141 mm of precipitation. Adriatic Sea belongs to the group of warm seas. The sea surface temperature in winter period does not drop bellow 10ºC and during summer season it can reach up to 25ºC.

2.3 The national energy programme CROTOK

Croatian islands are a specific natural resource of the Republic of Croatia and their geographic and economic characteristics demand a special approach in management of energy generation and consumption. Because of these reasons, the Croatian government has started a national energy programme CROTOK – a particular organization of ten other national energy programs whose goal is to provide conditions for increasing energy efficiency, alternative energy use and environment protection on Croatian islands.

The preliminary results of CROTOK programme [0] show energy consumption in the year 1996 and predictions of future energy demands until 2020. The year 1996 has been taken as a reference year for which detailed energy consumption data by energy form and energy use are available. Projections of future energy demands have been made according to the general development projections, infrastructure development, the protection of the human environment, the development of the economic activities as well as the development of social activities. Energy system on islands is analysed through three consumer categories: households, services and industry. Agriculture is not developed, so its consumption, compared to others sectors, is not significant.

Households are the major energy consumers on islands, with an overall consumption of 1842 TJ. The total number of island households is 39,643, but this number increases during the summer period when people form mainland come to their holiday houses. On average, one household consumes 46,4 GJ per year for its thermal and non-thermal purposes as well as for cooling. The most widely used energy source is fuel wood and its share in overall consumption is 50 percent. Electricity has very high share of 36 percent as a result of its intensive use for thermal purposes (heating, cooling and hot water). The share of light oil and LPG is less than 10 percent.

The service sector on islands comprises tourism and catering, trade, health, education public administration and others. Due to the fact that tourism is the most developed branch on islands this subsector is the largest energy consumer in service category. Total accommodation capacity on islands is 129,305 beds, and 29 percent of that number belongs to the hotels. Total energy consumption in services in 1996 was 477 TJ. 54% of that energy is used for thermal purposes, 38% for non-thermal purposes and the rest for cooling. Fossil fuels are mainly used for thermal purposes while other demands are covered by electric energy.

Industry on islands is very poorly developed, but there is shipbuilding, textile industry, plastic production, salt industry and stones extraction. In 1996, 250 TJ of energy was consumed, mostly fuel oil and electricity.

Prediction of future energy demand on islands until 2020 are given in Table 2.1. Increasing trends for all three categories of consumption can be observed.

Table 2.1 End-use energy consumption prediction on islands until 2020, TJ

	1996 **TJ**	**2000** **TJ**	**2005** **TJ**	**2010** **TJ**	**2015** **TJ**	**2020** **TJ**
HOUSEHOLDS	**1204.68**	**1435.00**	**1673.00**	**1890.00**	**2060.00**	**2228.39**
	1.00	1.19	1.39	1.57	1.71	1.85
SERVICES	**419.04**	**640.00**	**900.00**	**1150.00**	**1420.00**	**1707.38**
	1.00	1.53	2.15	2.74	3.39	4.07
INDUSTRY	**166.81**	**220.00**	**285.00**	**320.00**	**330.00**	**333.62**
	1.00	1.32	1.71	1.92	1.98	2.00
TOTAL	**1790.53**	**2295.00**	**2858.00**	**3360.00**	**3810.00**	**4269.39**
	1.00	1.28	1.60	1.88	2.13	2.38

Total end-use energy demand on islands in the year 2020 will be 2,38 times larger than in 1996. The highest increase will occur in the service sector because of the planned intensive development of tourism as a leading economy branch on islands. Energy consumption in households will also rise. Until 2020 their demand will increase about twice. It is predicted that the number of island inhabitants will rise. A rise in the living standard is expected and, related to this, the average yearly consumption per household will grow as well. Also, energy consumption in industry and agriculture will rise, however their share in total energy consumption will stay the same.

2.4 Renewable energy sources in island energy supply

When planning future energy supply of an island, several island-specific factors must be taken into the account. In general, island energy systems are small, resulting in higher energy and electricity costs in comparison to the mainland. Higher energy costs make renewable energy sources more economically viable in small island energy systems than on the mainland which makes islands a promising starting point for a wider penetration of renewables.

The higher penetration of renewable energy sources in islands is limited with their intermittent nature, which makes the use of energy storage necessary [0]. The excess energy could be stored in a water reservoir for later hydropower production, or an electrolysing unit could be used together with a hydrogen storage unit and a fuel cell or batteries. In islands there is also often need for desalination of seawater, which might be a good destination of dumped load, or water pumps, or refrigeration units. In case the island grid is connected to the mainland grid, the surplus electricity could be stored in it.

A promising accumulation technology is based on storing the energy in its chemical form, in hydrogen, from where it can be retrieved by a fuel cell, or that can be used for other uses, including transport.

2.5 The proposed pilot project

In Croatia, all the inhabited islands are connected to the mainland electric grid via 35 kV or 110 kV sea cables and there are no significant population centres without access to electricity. There are several smaller unelectrified villages primarily in the islands' inland, but they are mostly being heavily depopulated with inhabitants migrating to larger towns. Although the higher share of renewable energy sources in the islands' energy mix is envisaged, there are no plans for an energy autonomous island. Nevertheless, a pilot project of an energy autonomous tourist settlement on the island of Brač has been proposed [0].

The proposed system would function as following:

- thermal energy supply by solar collectors and hydrogen;
- power supply by wind and solar power plant;
- transformation of unused power into hydrogen by using electrolysis;
- storing hydrogen and oxygen into containers under high pressure;
- major part of produced hydrogen would be used directly as a substitute for fossil fuels, and a smaller part would be used for transformation into electric energy by means of fuel cells.

As a practical demonstration, the island of Brač and the planned eco-tourist village in the bay of Smrčeva luka are proposed as the first hybrid (hydrogen/solar/wind) demonstration project on the islands (Figure 2.1).

Figure 2.1 The location of the proposed eco-resort

Smrčeva luka is located on the southern coast of Brač, about 10 kilometres from the town of Bol which is a popular tourist destination. Availability of solar and wind energy at the proposed location are shown in Figure 2.2.

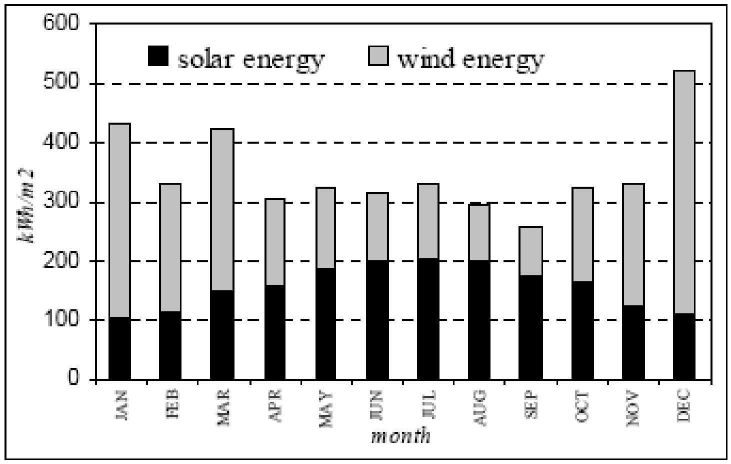

Figure 2.2 Availability of solar and wind energy

As shown in Figure 2.2, availability of solar and wind energy varies throughout a year – the available solar energy is the highest during the summer months, as opposed to the wind availability, which is the highest during winter.

Table 2.2 lists the major parameters of the pilot eco-resort.

Table 2.2 Major parameters of the pilot eco-resort

The number of eco-tourist households	8
Number of objects	8
Surfaces of individual objects for the residence:	100 m^2
Number permanent settled inhabitant in the resort:	32
Maximal number tourist in the resort:	32
Agricultures:	
olive grove	2 ha
vineyard	2 ha
fig	1 ha
garden plots	0.5 ha
consumption sanitary warm water in the settlement winter (minimal)	24,8 m^3/month
Consumptions sanitary warm water in the settlement during the summer (maximal)	119 m^3/month

temperatures sanitary warm water	60 °C
Degree-day heating, Tu = 20°C	1438 K

The layout and architectural design of eco-resort are being planned for the best passive use of solar energy. All buildings are planned as low-energy consumption houses where their heat demand should not be in excess of 150 MJ/m^{2}a. The architectural design shall prevent any summer overheating of buildings. Good design of passive ventilation systems will significantly reduce daily air-conditioning loads in summer.

Figure 2.3 presents the thermal energy needed for the resort, for hot water preparation, heating and cooling.

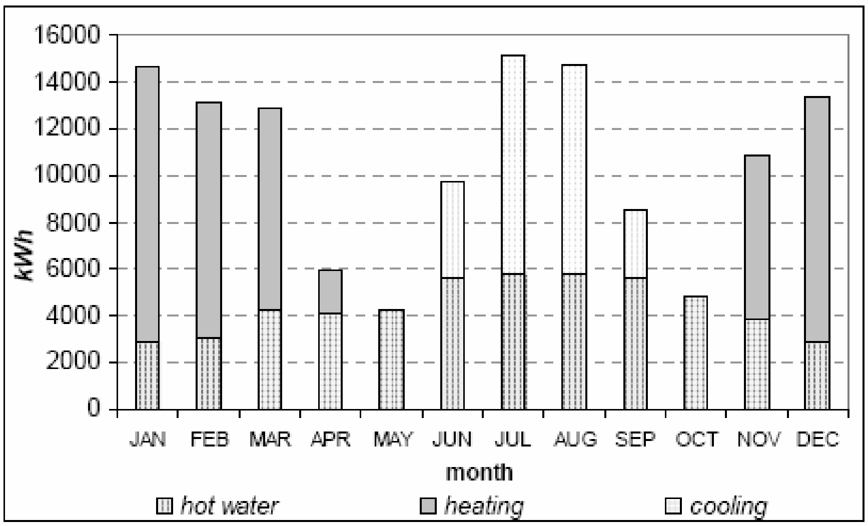

Figure 2.3 Thermal needs of the resort

The thermal energy of 112.5 MWh/a has been estimated for the eco-resort in Smrčeva Luka, with the peak cooling needs of 25 kW (Figure 2.3). The electric energy demand of 4.2 MWh/a has been estimated [0].

The thermal and electric energy needs are envisaged to be covered by a hybrid system, containing solar thermal collectors, solar photovoltaic and wind power plants. Surplus of electrical power generated by solar and wind power plants will be converted into hydrogen via water electrolysis. Water for electrolysis, water for the eco resort, including water for agriculture will be prepared in the reverse osmosis desalination plant. Hydrogen will be stored and used to supplement solar heating, to generate electricity via fuel cells when solar and wind power is not available, and to power the utility vehicles for local transportation. Figure 2.4 illustrates the proposed model of the energy system. A similar system may be applied on any location without energy and water infrastructure.

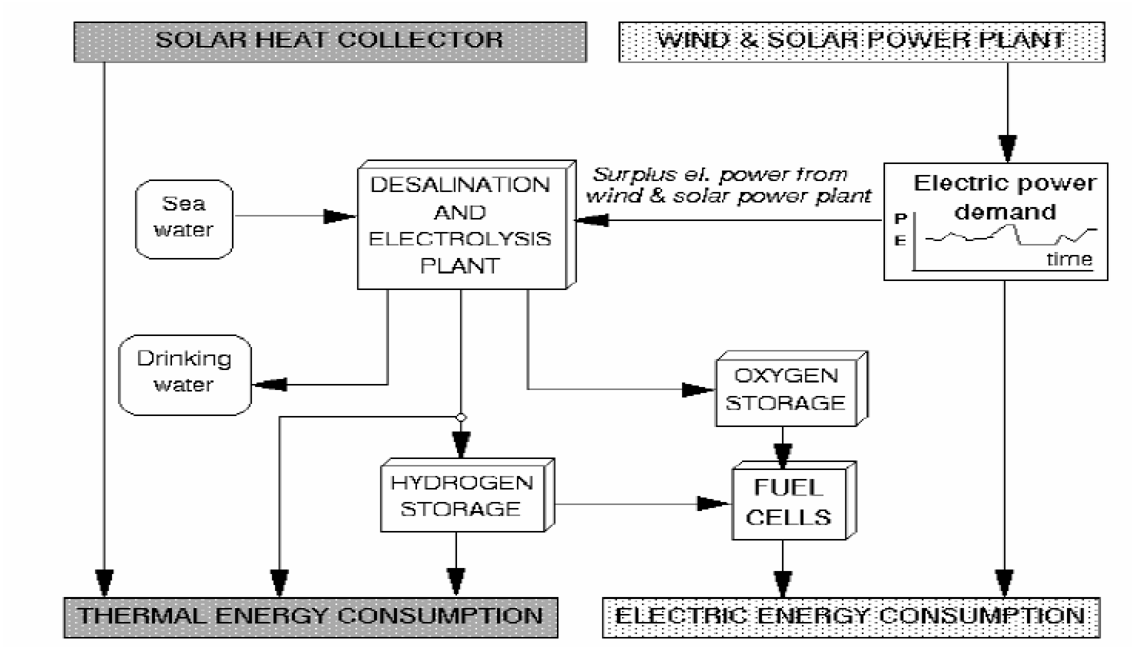

Figure 2.4 Model of a hybrid energy system for an autonomous resort

Electricity production by using wind and solar energy today is well known and widely used. Therefore more attention in this article will be put on reverse osmosis desalinization technology and fuell cells technology.

The reverse osmosis process diagram is shown in Figure 2.5.

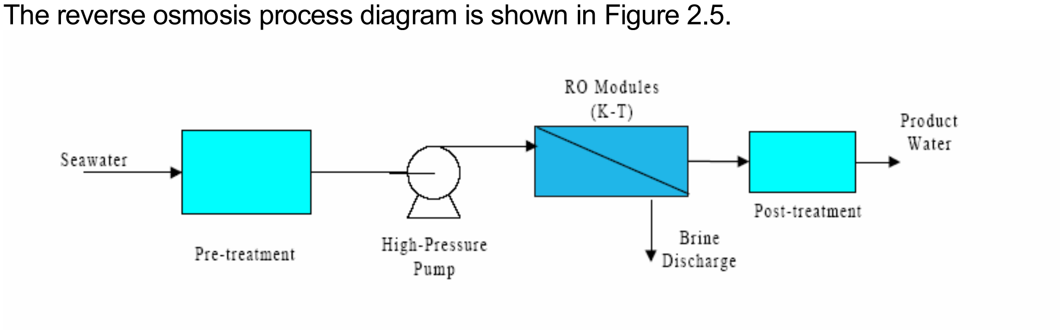

Figure 2.5 Process diagram for a reverse osmosis plant

In reverse osmosis, hydrostatic pressure is applied to force sea water through a semi-permeable membrane, which will filter the salt from the water. Pressure is applied to intake water, forcing water through semi-permeable membrane. Salt molecules do not pass through membrane and the produced water is potable. The amount of electrical energy consumed for preparation of one cubic meter potable water varies from 4.7 to 5.7 kWh [0]. This does not include energy required for pre-treatment, brine disposal and water transport.

The excess electricity produced by wind driven generator and PV panels is used for the desalinization plant, described above, and for hydrogen production by means of electrolysis. Hydrogen is used for thermal power production in cases when solar heat collectors are not able to collect the needed amount of thermal power, and for electric energy production via fuel cells.

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. The fuel cell concept is shown in Figure 2.6 [Figure 2.6].

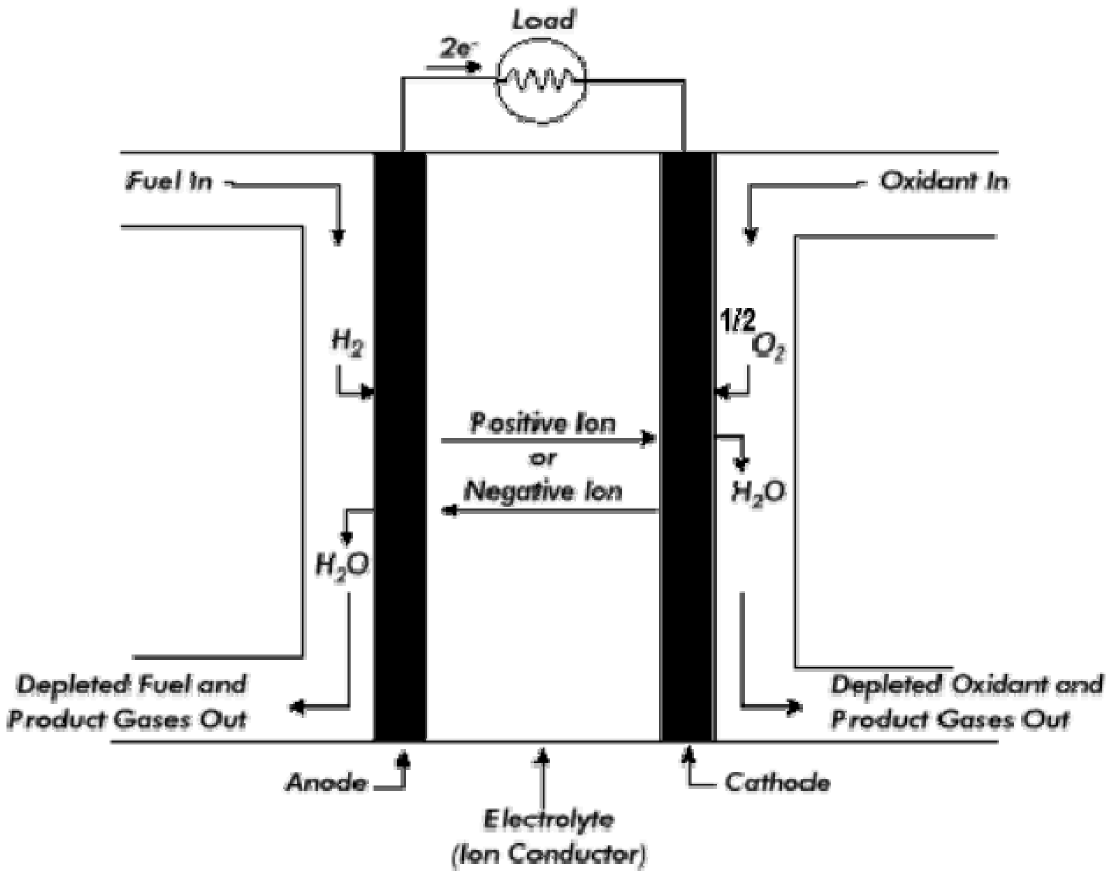

Figure 2.6 Fuel cell schematic

In a fuel cell, gaseous fuels are fed continuously to the anode (negative electrode) compartment and an oxidant (i.e., oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electric current.

An advantage of such concept of distributed solar/wind/hydrogen power is that the expected thermal and electric demand growth could be matched by simple extension of fuel cells, solar and wind power systems, all of which are modular.

By matching the available solar and wind resources to the requirements, the following values for the eco-resort Smrceva luka have been calculated:

- peak load of electric energy system of the eco-resort is 75 kW;
- total installed wind power plant capacity is 200 kW;
- total installed photovoltaic cells capacity is 5 kW;
- solar collector array of 52.5 m^2;
- total installed fuel cells capacity is 100 kW:

- RO desalination plant of nominal capacity of 100 cubic metres per day.

Simulation of solar and wind energy availability, and expected thermal and electrical energy demand enabled sizing of the individual subsystems and components. An example of the simulation is Figure 2.7, which shows the thermal energy supply for the proposed eco-resort by month and by source.

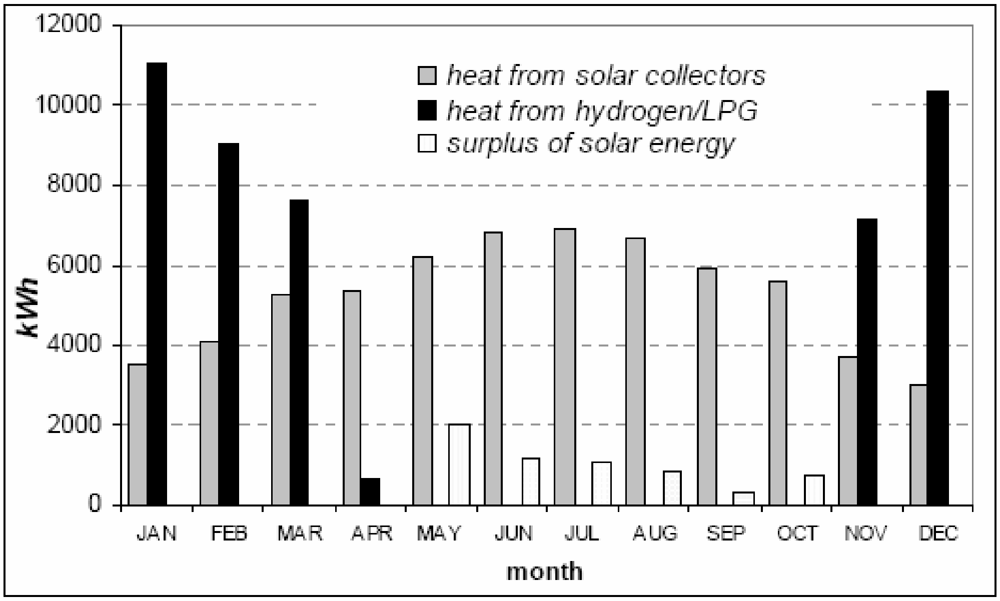

Figure 2.7 The relation of produced heat from the solar collectors and needs for the sanitary hot water and heating

The demand for sanitary hot water and heating is the highest in winter, when it is mainly covered by hydrogen. The availability of solar energy is the highest in summer when needs for thermal energy are lower, so the entire thermal consumption can be covered by solar energy use.

Traditionally, agriculture has been one of the most important economic activities in this area. Lately, tourism has become, but agriculture continues to be an important segment. These two activities have an important role in the plans for revitalization and economic development of the islands, and actually complement each other, although they may compete for some resources such as water and work force. It is important for both of these activities that economic development is carefully planned so that it preserves the environment as the common and the most important resource.

The programme of regional development calls for raising and cultivation of plantation vines, figs and olives, as the original autochthonous cultures. Table 2.5 shows the labour and water requirements, and Table 2.6 shows the cost of establishing and maintaining the plantation of these products, to support the proposed eco-resort.

The traditional way of production in these climate and ecological conditions has been ecologically balanced and organic, without the use of any chemicals. The ground is inclined, facing south, forming a natural solar collector. Because of the terrain this kind of agriculture is very labour intensive. It is crucial for the success of this program to ensure sufficient water supply. The annual volume of water needed for the planned plantations is shown in Table 2.3.

Table 2.3 Water requirements for the planned plantations

Plantation	Water, m^3/annual
Olive grove -2ha	8000
Vineyard -2ha	6000
Fig -1ha	4000
TOTAL	18000

The sufficient amount of water can be produced by the proposed reverse osmosis desalinization plant using the excess energy from the solar and wind power plant.

2.6 Conclusion

According to all predictions, energy demand on Croatian islands will rise, primarily due to growth in tourism. The Croatian government has started a national energy programme devoted to sustainable development of islands energy sector called CROTOK. Its goal is increasing energy efficiency, alternative energy use and environment protection on Croatian islands.

Because of their isolation and small energy markets, islands are ideal polygons for demonstration of new renewable technologies. The most promising renewable energy sources for Croatian islands are wind and solar energy technologies. However, due to their intermittent nature, energy storage must be included in an isolated energy system. In the article a demonstration project for energy and water supply of an isolated tourist eco-resort has been described. The energy system consists of a photovoltaic solar power plant and a wind power plant for electricity production and solar thermal collectors for thermal energy production. The excess electricity is used for hydrogen production and for sea water desalinization. The water is used in households and in agriculture. Data retrieved by modelling of energy and water needs of the resort show that energy and water requirements of the settlement could be met by the proposed system.

The objective of the proposed demonstration project is not only to gain a necessary experience insight in order to further implement the system but also to contribute to the island economy and stop the processes of depopulation.

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3 Wood pellet fired micro CHP

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3.1 Abstract

Pollution and global warming are becoming more and more the everyday concern of the modern society. That is why various efforts were made by environmentally conscious individuals towards more efficient and sustainable energy sources as the struggle for energy will probably be the key to the brighter future.

Pellet fired micro CHP is one of the efforts in that direction. Holding the benefits of pellets burning at high temperatures and Stirling engine producing energy from an external heat source it is also ideal for implementation in isolated regions.

Due to relatively high investment cost, this application is not yet enough cost effective to penetrate the grid connected residential applications' market, but has many advantages for isolated regions, where electricity cost is considerably higher and no network connection exist.

Techno economic analysis is made for a 15-20 kW residential heating system with a mounted Stirling engine. The results from the economic evaluation show that the such a micro CHP is economically viable only if the electricity price exceeds 17 € cents per kWh,

3.2 Introduction

During the oil shock in 1970's mankind started considering about alternative energy sources and energy independence. Investments into research of promising Stirling engines were made, but the falling oil prices stopped further investigations.

Then the Stirling engine is being noticed now for the following reasons:

- High thermal efficiency,
- A great variety of the fuel,
- Low emission and low pollution.

Recently, the energy and environment problems have become the most serious social problems. Wood pellet fired CHP seems the right solution for the coming challenges as it holds the benefits of the Stirling engine, biomass burning as well combined with comfort comparable to any fossil fuel:

Micro CHP combine a few characteristics that make them very attractive from the energy supply and environmental point of view.

They can represent an independent source of electricity, which can be of a big importance in isolated areas or in areas with bad grid connection or electricity supply insufficiencies.

Improved energy efficiency of the whole system is also very crucial. It represents and advantage from the economic as well as from the environmental point of view. Better energy efficiency lowers primal energy consumption, thus lower costs and less emissions.

With a decentralised and distributed electricity production in isolated areas the electricity supply becomes more stable and reliable.

Moreover the environmental impact of electricity generation is even reduced, due to the utilization of biomass. State of the art pellet boilers have extremely low particle and NO_x emissions. Since sulphur is practically absent in wood, also there is no mentionable SO_x emission. One of the most important advantages of biomass utilization is however the CO_2 neutrality of biomass burning. Utilization of biomass does not represent any green house gases emission.

3.2.1 State of the art

Since the end of 80's the co-generation of heat and power has been on the and in many countries is expected to rise to outputs as high as 8 GW. There has been a growing trend in recent years, though, for the production of more efficient, smaller, personal units that are capable of supplying the energy needs of single industries and residences. Although the manufacturing industry has traditionally been the largest user of this technology (around 5 GW), smaller systems have been developed and installed in large buildings such as schools, offices, and blocks of flats. These units are called 'mini-CHP' and have an electrical output of around 5 kW.

L smaller 'mini-CHP' systems was usually the four-stroke single-cylinder gas engine, which has a capacity of 583 cm3, an electrical output of 5·5 kW, and can provide central heating systems with up to 12 kW of heat, recovered from the cooling water. This system, controlled and monitored by an on-board computer, can achieve efficiencies as high as 90%.

This gas engine mini-CHP system has been successfully implemented in offices, swimming pools, sports facilities, and larger residential units. However, due to the size and price of the system, it is not cost effective to install mini-CHP units in residences of fewer than fifteen homes.

With the advancement of technology and materials, the rediscovery of the Stirling engine revolutionised the combined heat and power industry and is now leading the field of micro-CHP. The Stirling micro-CHP unit has a power output of around 800 W, which is at a level suitable for use by a single dwelling. The high efficiency (up to 98%), low cost, versatility of fuel sources, and relatively simple design gives the system the potential to be implemented on a pan-European scale.

The Stirling engine is powered through external combustion. This means that anything that produces heat can be used as a power source, e.g. wood, straw, petrol, kerosene, alcohol, propane, natural gas, methane, biogas, bio-oil, etc. It also allows for non-carbon heat sources to be used, such as solar energy, geothermal energy or waste heat from industrial processes.

This diversity of fuel sources has allowed the Stirling engine to lead the way in renewable micro-CHP and allows the units to be used in all parts of the world, from highly developed areas to isolated rural communities.

3.3 CHP in isolated regions

The operation of the system normally implies export of electricity to the grid, the system must be connected to the mains network of the electricity supplier. Transparent and fair arrangements must be found with network operators in order not to jeopardise security of both systems. However, there are no major technical obstacles to connection of micro-cogeneration systems to grids and the issue is more a commercial one since it involves defining buy-back rates for the exported electricity and the potential back-up supplies from the electricity supplier. Such issues are now well known and are common to most cogeneration businesses.

In general, heat and electricity demand at user premises have quite different load shapes. It is quite a challenging task to serve two types of demand, which are not varying simultaneously. And the challenge is much more pronounced when co-producing heat and electricity for isolated region.

In case a CHP device is connected to the grid operation modes might be:

- Thermal load following,
- Electrical load following,
- Cost minimisation/revenue maximisation.

In case of isolated operation, the electricity demand drives the system operation – electricity should be produced in time of its demand. In time of production only slight modulation of electricity load shape can be achieved by other means as demand side management and/or direct load control. Also load shifts, which can be achieved in case electricity storage is in a system, should be very limited and costly.

For that reason all CHP systems designed to operate in isolated regions need to have high flexibility at its thermal part. Auxiliary boilers to cover thermal peak load are almost obligatory. Thermal storage is much more economical option as the electricity storage is. Quite large load variation can be offset by it.

Various CHP technologies have its own flexibility to change vary the level two products. As the ratio between electrical output and thermal output is almost fixed for gas motors and turbines and for backpressure steam turbines, the extraction condensing steam turbines allows significant changes of electricity outputs at same heat production.

3.3.1 Impacts on the electricity system and security of electricity supply

Even in small isolated areas the micro CHP can operate in connection to the grid. In such a case there are some issues that have to be addressed.

In contrast to large centralized power plants, micro CHP plants have the important advantage that they are located directly at the consumer site. This has beneficial effects on the system, as currents in transformers as well as transmission and distribution lines are lowered. As a consequence, transmission and distribution losses are avoided and upgrading of the transmission or distribution system might be deferred or suspended. In this way, micro CHP plants could help Distribution Network Operators to overcome local bottlenecks in the distribution system, saving costs for expensive upgrades (IEA 2002).

In the existing power system, central steam power plants have the responsibility to provide ancillary services required to operate the electricity system and to maintain a high power quality. These ancillary services comprise reserve power control, voltage and reactive power control as well as certain fault behavior requirements. To maintain high power quality and system reliability in an electricity system with a large share of distributed generation, distributed power plants should be designed to provide some of these ancillary services.

For micro CHP plants, heat demand is the most limiting factor in providing power control services. In winter, large heat demand involves continuous power generation by micro CHP plants. In spring and autumn, micro CHP plants are typically operated for a couple of hours per day. In summer, overall power generation is restricted by hot water demand, limiting power generation to approximately one hour per day.

Power generation can be decoupled from heat demand to a certain extent by means of hot water storage tanks. Appropriately operated and controlled, hot water storage tanks enable micro CHP plants to increase or decrease their power generation for a limited time span. This allows a shift in power generation towards the peak hours in the system, if corresponding economic incentives are provided. This is particularly useful in summer, when the power generation potential of micro CHP plants is most limited. As feed-in tariffs for electricity are significantly lower than electricity purchase prices, micro CHP plant operators already have certain incentives to optimize the time match between CHP operation and on-site electricity demand.

3.4 Technical description

3.4.1 Energy flow

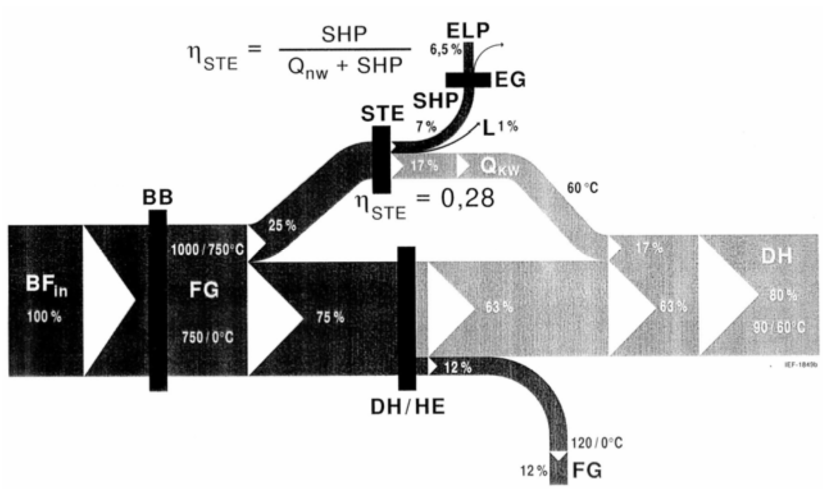

Figure 3.8*: Energy flow diagram of the micro CHP-production (source: Joanneum Research)*

BF_{in} - biomass fuel, **FG** - flue gas, **BB** - pellet boiler, **DH/HE** - heat exchanger for house heating, **DH** - house heating system, **STE** - Stirling engine, **L** – losses, **SHP** - shaft power, **EG** - Electric generator, **ELP** - electric power, **Q_{KW}** - Cooling water of Stirling engine, **η_{STE}** - efficiency of Stirling engine.

Basic energy flow of the biomass fired micro CHP with a Stirling engine is shown above in Figure 3.8 The biomass fuel (pellets in our case) $\mathbf{BF}_{in}$ enter the pellet boiler **BB** where they are subject to combustion. The exiting flue gas exchanges a portion of the heat with the heat exchanger of the Stirling engine(expansion side) **STE** while the rest of the heat is exchanged at the house heating heat exchanger **DH/HE**. The heat at the Stirling engine is converted with 28% efficiency η_{STE} into the shaft power **SHP** and this on with some losses at the electric generator **EG** to electric power **ELP**. Flue gases from the DH/DE heat exchanger leave the boiler at 120°C, which prevents condensation and subsequent corrosion problems. The rejected heat from the Stirling engine is used together with the heat from the DH/HE heat exchanger for domestic heating DE.

The micro CHP production results in 80% thermal efficiency and the electrical efficiency of 6,5%. Only 13,5% of all input energy is lost, most of it due to high flue gas exhaust temperature. Some thermal efficiency could be gained by using the condensation heat of the flue gas, but eventual problems of corrosion would occur instead.

3.4.2 Boiler

3.4.2.1 Boiler types

Modern combustion machines are equipped with process control systems supporting fully automatic system operation thus eliminating the need for manual fuel-feeding, which increases availability, but also results in lower emissions. The following combustion technologies can, in principle, be distinguished:

- fixed-bed combustion,
- fluidised bed combustion,
- dust combustion.

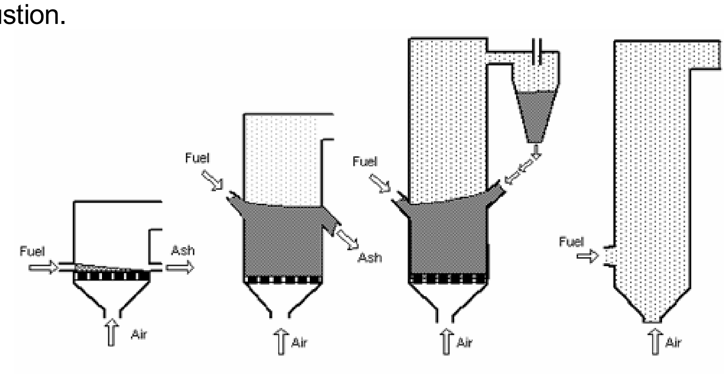

Figure 3.9*: Different boiler types; from left: fixed bed, bubbling fluidised bed, circulating fluidised bed, dust firing*

Due to the simplicity of the technology fixed-bed combustion is widely used for domestic appliances. Fixed-bed combustion systems include grate furnaces and underfeed stokers. Grate furnaces are appropriate for burning biomass fuels with high moisture content, different particle sizes, and high ash content

Underfeed stokers are suitable for biomass fuels with low ash content and small particle sizes (up to 50 mm). As the pellets' size, ash content and moisture is mostly uniform and controlled, underfeed stokers represent a cheap safe technology for small- and medium-scale systems up to about 6 MW_{th}. The fuel is fed into the combustion chamber by screw conveyors from below and is transported upwards on a grate. Underfeed stokers have a good partial load behaviour and simple load control. Load changes can be achieved more easily and quickly than in grate furnaces because there is better control of the fuel supply.

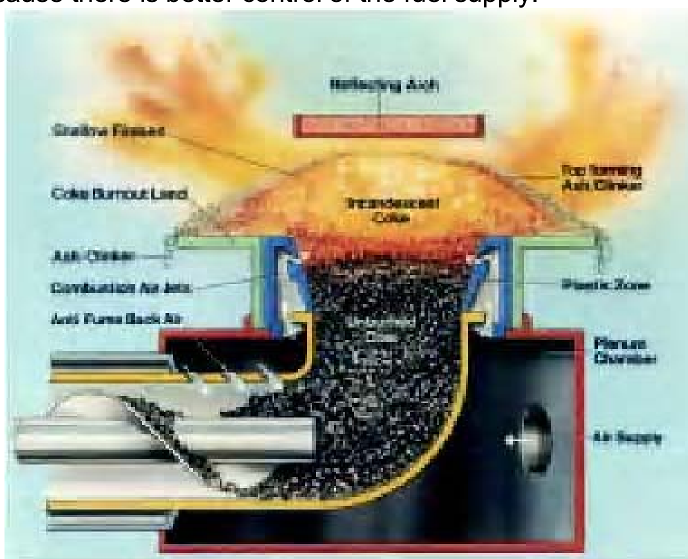

Figure 3.10: Principle of an underfeed stoker (source: Joanneum Research)

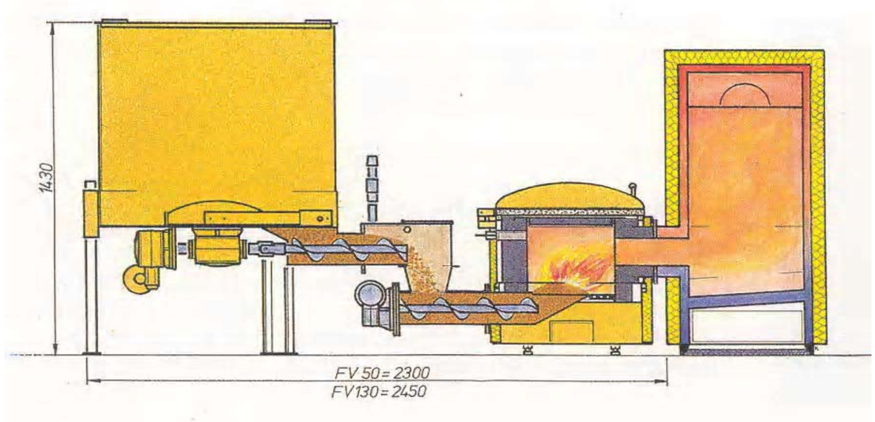

Figure 3.11*: Wood pellet furnace with fixed-bed combustion and underfeed stokers (source: Joanneum Research)*

3.4.2.2 Boiler selection

Boiler selection must be made upon the examination of two decision criteria:

- the peak heat demand of the building,
- possibility of fitting the Stirling engine,
- temperature of flue gas.

The peak heat demand is evaluated through the meteorological data for the region, area and volume of the building and quality of thermal insulation. At the figure below the heat demand distribution is shown on a time scale. Peak thermal power is needed only a few hours in the heating season while the rest of the time the heat demand is significantly lower. Specific energy demand for older residential buildings can vary from 100 kW/m^{2}a up to 250 kW/m^{2}a, so a detailed energy check is needed for the selection of the right boiler dimension.

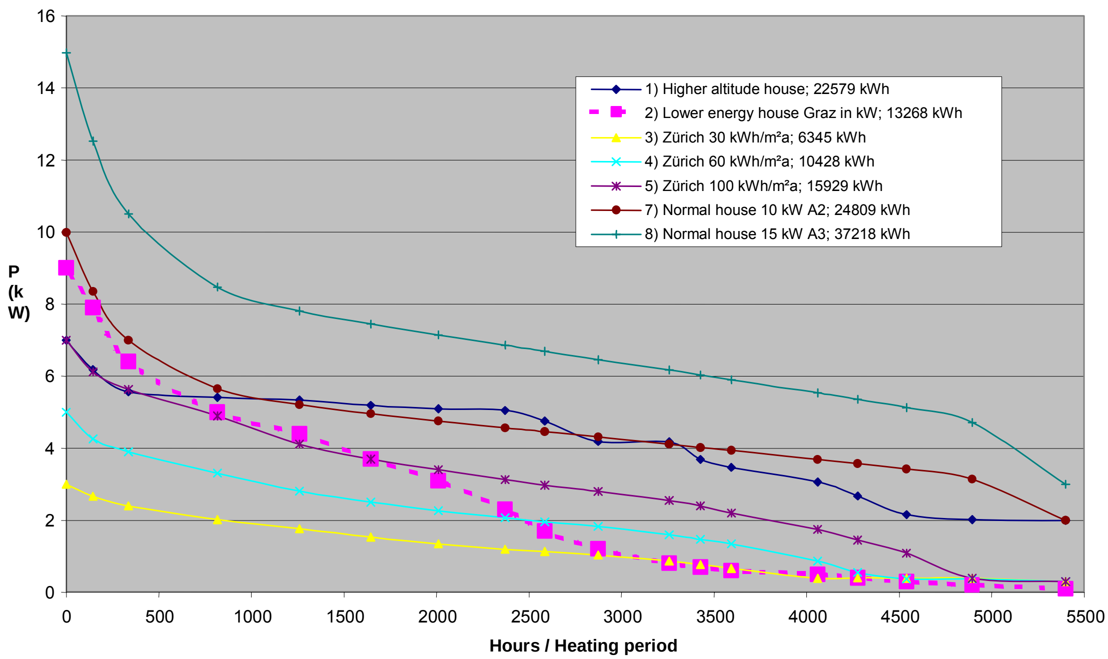

Figure 3.12*: Example of the heat demand distribution during the heating season(source: Joanneum Research)*

Considerate thought should be put into choosing the boiler with a suitable space and possibilities for Stirling engine mounting. If possible, the boiler should allow quick inspection of the Stirling engine heat exchanger and easy access for cleaning purposes.

The temperatures of the flue gas in the boiler should be as high as possible due to higher theoretical efficiency of the Stirling engine. The upper limit is set by the efficiency equation for the ideal Carnot cycle:

$\eta_{th}=1-T_L/T_H$

T_L – lower temperature(environment)

T_H – higher temperature(flue gas)

The flue gas temperature in smaller boilers usually ranges between 800 and 950°C, but can be as high as 1100^{o}C thus reaching the theoretical efficiency of 78,7%. Such high temperatures can be obtained with pellet burning, while they are hardly reachable with other biomass due to much higher water content.

Table 3.4*: Examples of typical boilers in the capacity range of 15 kW suitable for a micro CHP*

	KWB USP 15	KWB USP 20
Thermal output(kW)	14,9	20,4
Minimum output(kW)	4,3	6,1
Thermal efficiency at maximum load(%)	92,7	93,5
Thermal efficiency at minimum load(%)	90,1	90,1
Flue gasses temperature(^oC)	900-1100	900-1100
Length×height×width(mm)	900×1102×1200	900×1102×1200
Weight(kg)	406	406

3.4.3 Stirling engine

Stirling engines are based on a closed cycle, where the working gas is alternately compressed in a cold cylinder volume and expanded in a hot cylinder volume. The advantage of the Stirling engine in comparison to internal combustion engines is that the heat is not supplied to the cycle by combustion of the fuel inside the cylinder, but transferred from the outside through a heat exchanger in the same way as in a steam boiler. Consequently, the combustion system for a Stirling engine can be based on proven furnace technology, thus reducing combustion related problems. The heat input from fuel combustion is transferred to the working gas through a hot heat exchanger at high temperatures. The heat that is not converted into work on the shaft is rejected to the cooling water in a cold heat exchanger.

In our case the engine considered is a gamma(γ) type Stirling engine produced by Energiebig, Innsbruck, Austria. Fixed in a 15 kW heat source it is able to produce 1 kW of electricity.

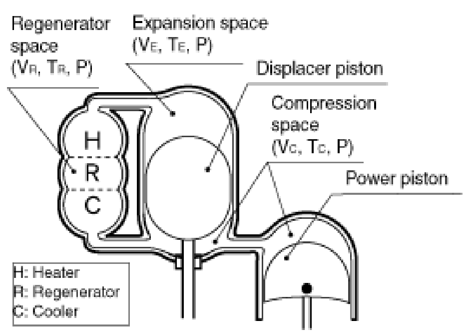

Figure 3.13: Scheme of a typical γ-type Stirling engine

Figure 3.14: 1 kW Biomass gamma type Stirling engine (courtesy of Comp. ENERGIEBIG, Innsbruck, Austria)

1 - power piston with cooled cylinder, **2** - Crank mechanism, **3** - displacer cylinder with cooler, **4** - regenerator section, **5** - hot heat exchanger, **6** - fly wheel with starter

3.4.4 Stirling engine mounting

There are three possible ways for the Stirling engine mounting in the boiler casing, depending on the type of boiler, its cross section, configuration of pellet feeding, design of combustion chamber and also flue gases channels. Basically we can have a top mounting, side mounting and backside mounting. However we must take into deep consideration the future actions connected with Stirling engine maintenance. We should leave enough space for a quick visual inspection and design the mounting for easy access during the cleaning of heat exchanger surface.

Top mouniting

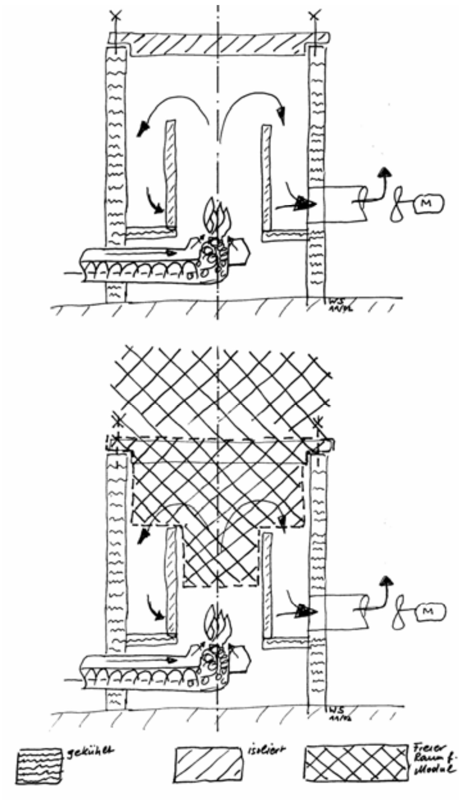

Figure 3.15*: Illustration of top mounting(source: Joanneum Research)*

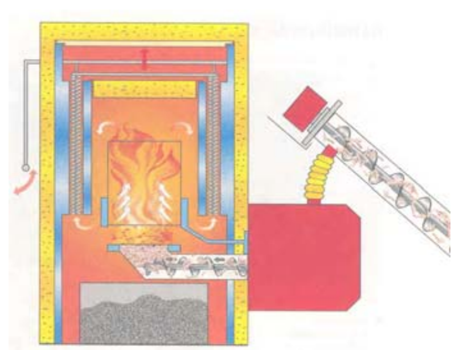

Figure 3.16: *Type of boiler for top mounting(source: Joanneum Research)*

Top mounting is suitable for boilers with side feeding and side designated exhaust channels, but most of all for boiler with a round cross section.

Side mounting

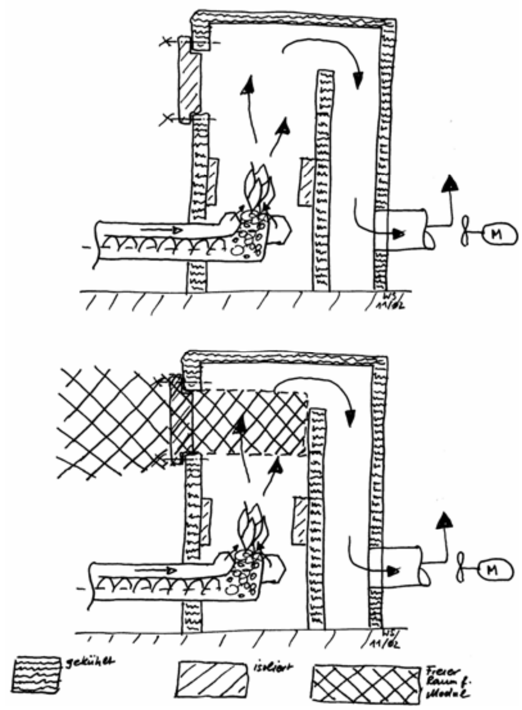

Figure 3.17: *Illustration of side mounting(source: Joanneum Research)*

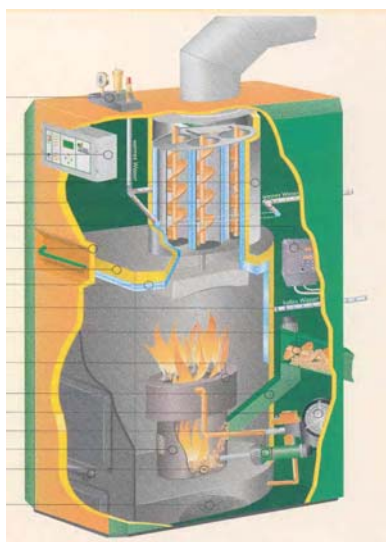

Figure 3.18: *Type of boiler for side mounting(source: Joanneum Research)*

Side mounting is suitable for boilers with rectangular cross section. It is also much easier to mount the engine on the side when we have flue gases exhaust top mounted.

Backside mounting

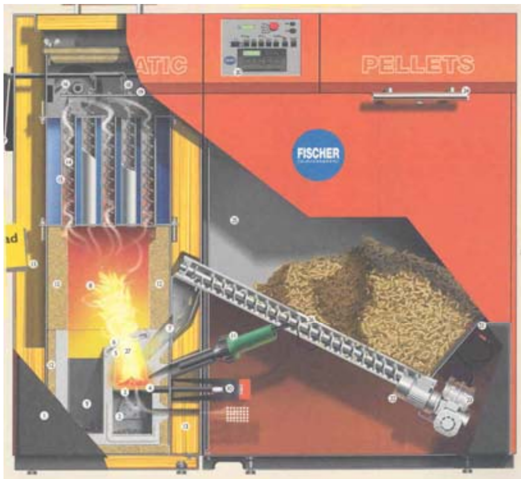

Figure 3.19: *Type of boiler for backside mounting(source: Joanneum Research)*

Backside mounting comes into consideration when the side part of the boiler is used for flue gas channels. However we have to consider the maintenance space and maybe redesign the flue gas channels so the Stirling engine could be more accessible.

3.5 Wood pellets as a fuel

3.5.1 Technical characteristics

Wood pellets are a compressed biomass fuel made exclusively out of wood. Considering the high labor intensiveness the raw material is mostly of the local nature. Raw material featured for pellet production is:

- Hard or soft wood
- It is free of bark
- It can be sawdust, shaving and chips
- Its ash content is lower than 0,8 %.

Because of their standardized shape they show a great ease of use for various heating applications, have lower storage costs and their manipulation in the burning process is automatic, which adds to a higher comfort of the consumer.

Due to the low water content higher temperatures can be achieved in pellet fired boilers, raising the theoretical efficiency of the heat engine and consequently the overall output

3.5.2 Economic aspects

From the economic point of view pellet also have some attractive characteristics. Since they are standardized it is very easy to determine the exact cost per thermal unit. Which is not the case with other biomass e.g. wood chips. By wood chips there are multiple factors that influence their energetic value and most of them (moisture content, % of bark; particle size etc) can vary a lot and are not always easy and straightforward to determine.

Wood pellets are on many EU markets already for many years and they are commonly available. This is not the case yet in the countries of the Balkans. However since new pellet producer are emerging also in these countries, we can expect that a pellet market will develop soon and that pellet will be commonly available also in these countries,

We can expect that also their price will be quite stable since it cannot deviate much from the price in the EU.

Prices for the pellets in EU range from 150 – 220 € / t. This corresponds to 0,02 – 0,05 € per kWh of primal energy.

However with the emerging pellet market in the Balkans it has shown that also lower prices can be achieved. Also as low as 90 € per ton of pellets.

3.5.3 Environmental aspect

As we saw in Figure 3.8, the overall efficiency of the biomass fired micro CHP is 86,5%. Due to increased overall output energy needs decrease and result in lower environmental impact.

Since the pellet fuel is CO_2 neutral, releasing only the CO_2 accumulated in the wood during the growth, the overall environmental aspect is very positive.

3.6 Economic evaluation of a project

While economically evaluating a project, several factors must be taken into consideration. Every investment should be in the first line economically viable. The viability of the micro CHP depends mostly on house size and insulation (thermal load), fuel cost, electricity cost..

In our studying case a larger family house with a thermal demand of 37.000 kWh/year and a maximum demand of 14 kW was taken into account. Considering these facts a boiler between 15 kW and 20 kW should be installed.

Input data for the case study:

- Larger family house: area 310 m^2
- Specific heat consumption: 120 kWh/m^2a
- Total yearly energy consumption: 37.000 kWh heat
- Peak heat demand: 15 kW
- 1 kW of electric power installed as a Stirling engine

3.6.1 Full cost analysis

First of all we have to take into consideration all the costs connected with the CHP. Here we have to be prudent and take into account only the incremental costs of the installed Stirling engine and generator.

The incremental costs of electricity production with a Stirling engine mounted on a boiler are:

- investment costs,
- additional fuel consumption,
- maintenance costs.

The investment costs are actually capital costs and they depend on three factors:

1. size of investment
2. cost of capital
3. pay back period

The investment into a Stirling engine, generator and mounting amounts to 2.000 €. This is and estimated price since there is not yet a commercially supplied Stirling engine on the market, that would be suitable of such a use.

For the cost of capital (i.e. discount rate) in our case we have taken the rate of 5%. This is a rate at which a private entity can get a loan.

The pay back period - the length of the period in which the investment has to be paid out – it can also be paralleled with the pay back of the loan – has been estimated to 15 years. Absolutely speaking it is quite a long period, however the life time of the bolier and stirling engine can be even longer.

Table 3.5: Cost breakdown

	per year	per generated kWh el.
cost of capital (5% pa, 15 years)	193 €	0,09 €
maintenance costs	100 €	0,05 €
fuel costs	73 €	0,03 €
Total	366 €	0,17 €

The estimated cost of electricity produced by a micro pellet fired CHP is 17 € cents per kWh. We can see that he main cost represents the cost of capital cost. The variable costs, those connected with the fuel, represent only about 20 % of all costs. However the figure would change if the utilisation of the CHP would be higher.

3.6.2 Revenues

The revenues depend on the amount of electricity produced and on the selling price. If the electricity is not sold into a grid then an internal price should be calculated. Usually the substitution costs are taken into account as the maximum chargeable price.

3.6.2.1 Amount of electricity produced

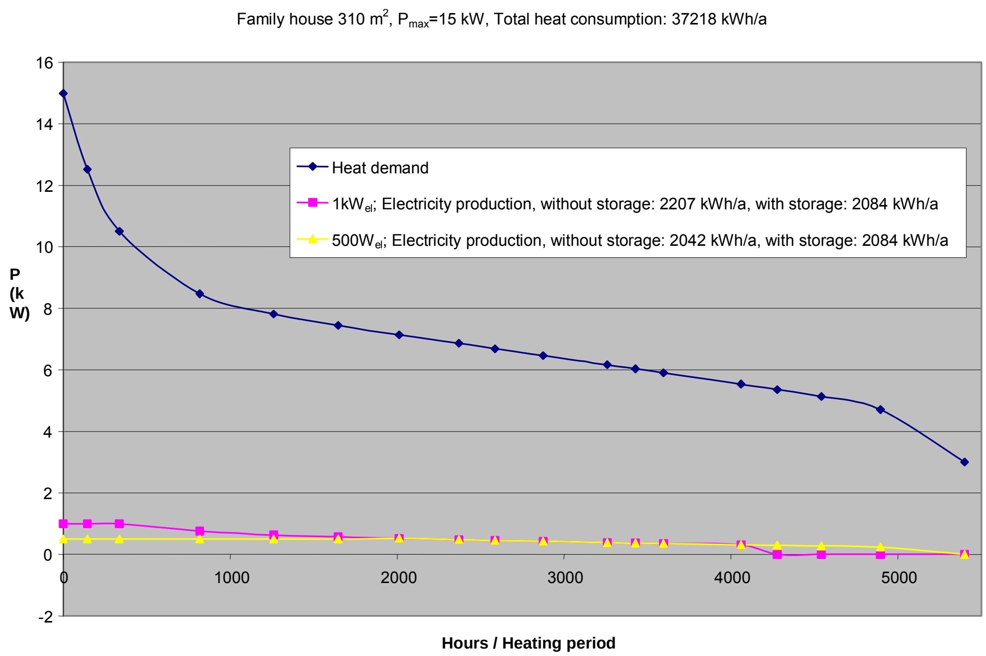

Figure 3.20: Heat demand and electricity production of a larger family house*(source: Joanneum Research)*

Considering the upper table and the minimum thermal output from we can evaluate the maximum total running time of the boiler.

Table 3.6: Maximum boiler running time estimation using minimum output criteria

	KWB USP 15	KWB USP 20
Minimum output(kW)	4,3	6,1
Estimated maximum total running time(hours)	4900	3200

3.6.2.2 Price

In many countries green electricity feed in tariffs are implemented. In the following table there are a few examples of the feed in tariffs in some countries. Since this is regulated by law the tariffs depend much on national policy as well as on the economic status of the country.

Table 3.7: Electricity feed in tariffs

		per kWh
Breakeven price of el.		0,17 €
Feed in tariffs	Bosnia and Herzegovina	0,04 €
	Slovenia	0,07 €

	Austria	0,17 €

However the electricity price can be even higher in isolated regions and can go well beyond the calculated electricity cost from our case.

3.6.3 Economic feasibility

As we have shown there are two critical factors for the economic feasibility of pellet fired micro CHP implementation:

- number of operational hours,
- price of electricity.

When the price of electricity is equal or higher to 17 € cents per kWh then a micro CHP is an economically viable solution. However the cost of production can be further lowered by increasing the number of operating hours. This can be done by lowering the average power output of the bolier (e.g. by installing a heat storing capacity - on the other hand this makes the investment costs highe) or by increasing the consumption (domestic water heating or similar).

Price of electricity is in isolated areas very site dependent. If there is no grid connection than electricity production can be very costly and a micro CHP can be an economic solution. With grid connection electricity prices usually do not tend to get extremely high, however a micro CHP provides additional supply independency and can thus justify the higher price form such a plant.

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4 Technical design of wood chip fired Steam turbine CHP plant

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4.1 Introduction:

Countries of Southeastern Europe are faced with diverse problems in agriculture and rural areas. Beside many economic problems, the problem of migration from isolated and rural areas to the cities has significant social, demographic and environmental impacts. At the doorstep of the EU, some further reduction of use of fossil fuels and usage of renewable energy sources are expected.

The whole region of Southeastern Europe is depending on imported fossil fuels. This is a heavy burden for national budget and economy. Any increase of use of domestic energy sources will have a positive economic impact. In the strategic documents and discussed Energy Law a rise of use of renewable energies until 2010, from today's 1,5% to 5% of total energy consumption is foreseen. The strategy is also in accordance with trends in the World and in Europe related to Kyoto declaration and other environmental and economic-oriented policies.

Significant economic, social and demographic problem in the country is migration of population from rural to urban areas. The reason for migration is goal for better life conditions. In addition, better employment possibilities and the quality of living in the cities is potentially better. From the point of view of regional development, urban organization and environmental sustainability this trend is unfavorable, not only in Serbia and Montenegro, but throughout the Europe. So some strategic decisions regarding this are expected, electricity network, reliable infrastructure – roads and telecommunication, should be also improved. Know-how in the field of free enterprise is needed to accelerate general development of these areas. One of the problems is a lack of comfortable household heating, where the investment and fuel costs are of great importance.

The total annual biomass energy potential of about 2.7 million toe represents 40% of the total coal energy production in Serbia. Towns located in agricultural regions and in regions rich in forest can satisfy their energy demand for centralized heating systems with biomass residues from the territory of their own municipality. Economic advantage of wood biomass energy is that wood is usually significantly less expensive than competing fossil fuels, and therefore a biomass power plant design has been proposed in this paper.

More electricity and heat are generated for a lesser amount of fuel by a combined unit than by a separate heat and power unit. The main points of investing into CHP lay in fact that for the past decade in Serbia the price of electricity has been several times cheaper than average in EU, and it was a social category. In this period majority of population switched to using clean, electrical energy for household heating, amounting in even greater need for electricity and not appropriate energy efficiency. Therefore a CHP systems would bring benefit not only in providing sufficient DH and reducing a great load of electricity consumption previously used for this purpose, but also increase electricity production on a local level.

4.2 Forestry biomass potential

Forest fund in Serbia amounts around 235 million m3, while registered cropping of forest wood amounts about 2.9 million m3. Besides registered cropping, there is also a case of unregistered wood cropping. It is estimated that total cropping amounts 3.3 million m3. This value represents about 55% of annual crop of forestry biomass of 6.1 million m3. In developed EU countries, where forest exploitation is well organized, rate between forest cropping and annual production of wood biomass is up to 75%. With better organization, increased forest control and conditions of forest roads there is a possibility of increased but preservable of existing forest fund. Also, there is a plan to increase surfaces under forest from present 27.3% to 31.5% until year 2010, and to 41.4% until 2050. These two measures will contribute in increasing the energy potential of forest biomass.

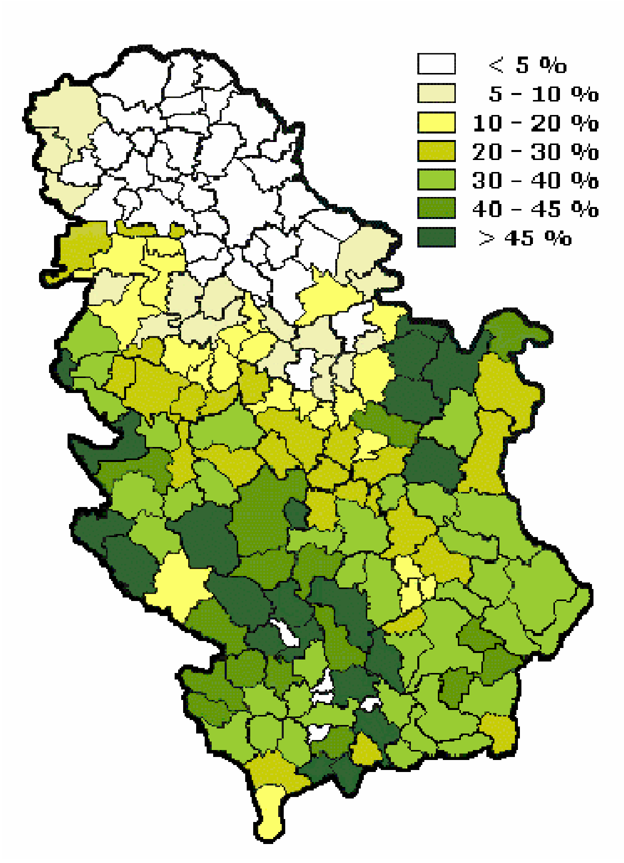
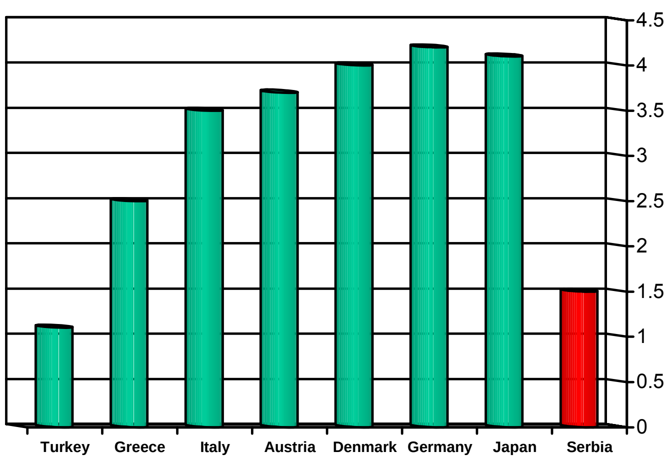


Fig.4.1 – Energy potential of forestry biomass in Serbia

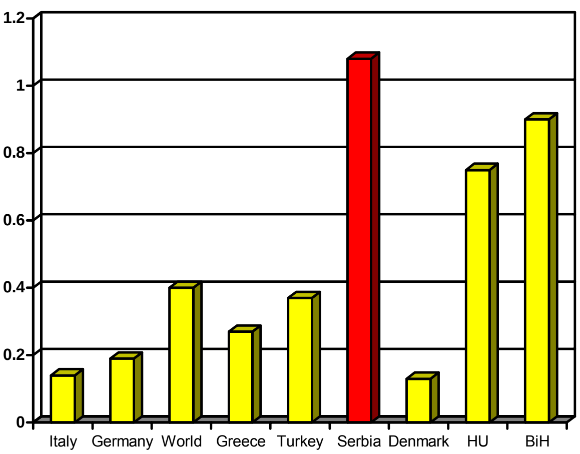
4.3 Energy Balance in Serbia

The estimated values of annual energy potential are: about 1.7 million toe (ton of oil equivalent) in biomass residues in agriculture, comprising crop farming, fruit growing, viniculture and stock breeding, and about 1 million toe of biomass from forestry, including different biomass residues and fuel wood – Figure 4.1. The total annual biomass energy potential of about 2.7 million toe represents 40% of the total coal energy production in Serbia.In Serbia 43 towns and different industry sectors have got own heating systems with total installed capacity of 6 600 MW. The main heat energy sources are heating plants (47%), industrial cogeneration plants (16%) and industrial heating plants (10%).

However, the statistics show that the consumption of primary energy is small in average



a)



b)

Fig.4.2 – a) comparison of primary energy consumption of Serbia in ten/capita, b) comparison displayed in ten/1000$USD

comparison with other countries, and yet irrational - Fig.4.2 a) and b). In addition to the pictures above, some indicators of energy efficiency and consumption in Serbia are: Gross domestic product (GDP) has decreased since 1989 for 2.5 times, energy consumption per capita of 3400 kWh/capita annually is in level of medium developed European countries. While energy consumption per 1000$ GDP – 1700 kWh/000$ annually is the highest in Europe, the total energy consumption of 1500 ten/capita is the lowest in Europe.

4.4 Biomass combustion

The principle economic advantage of wood biomass energy is that wood is usually significantly less expensive than competing fossil fuels. Public institutions, such as schools, hospitals, prisons, and municipality-owned district heating projects, are prime targets for using wood biomass energy. Instead of paying disposal costs, wood combustion for electricity and heat is one way in which forest products companies can utilize their wood residues. Typically, wood in a variety of forms, particularly green chips (45% to 65% moisture content on a wet basis), is shipped and maintained at a holding site by the energy plant. Augers or belt conveyors transport the wood chips to the combustor, where they are burned, and the heat of combustion is transferred to a steam or hot water boiler. Steam is converted to electrical power by steam turbines. Hot water boilers can provide heat to a building through a piping distribution network.

4.5 Moisture content

Energy value of wood depends of amount of moisture in it, and therefore depends on sort of preparation and storage. If the moisture level is higher than 25%, there is a probability of mould, which causes rotting of wood chips. The following table – Table 1, represents average energy values of wood depending on moisture content.

Tab.4.1 – Energy values of wood depending on moisture content

Moisture content on wet basis (%)	Moisture content on dry basis (%)	**Energy value (kJ/kg)**
61.5	**160**	**5880**
54.6	**120**	**7350**
50.0	**100**	**8400**
43.5	**80**	**9660**
37.6	**60**	**10920**
33.3	**50**	**11970**
23.0	**30**	**14070**
17.0	**20**	**15540**
9.8	**10**	**16800**

The water content of biomass can be a major problem if it isn't recognized, and a wet log looks exactly like a dry one, so one can't judge "by eye".

Biomass is a complex fuel, composed of the volatile components (typically 70-90%), charcoal that results on heating (10-30%), some mineral/ash content (1-20%) and varying amounts of moisture. For this reason most analyses are given on a "dry ash free" (DAF) basis.

However, wood and other biomass are almost never bone dry, and go up and down with the seasons. Sometimes moisture content is reported on a wet basis (MCWB) and sometimes on a dry basis. When a tree is cut down in summer it can contain 50% moisture (wet basis) or 100% moisture dry basis. These two standards can cause a lot of confusion unless understood.

The moisture content wet basis (MCWB) is given by:

MCWB = 100 X (Initial Wt - Dry weight)/(Initial Weight)

However, since we are interested in the dry use of biomass and don't want to pay for the water, biomass moisture content is sometimes reported on a "dry" basis (MCDB) where

MCDB = 100 X (Initial Wt - Dry weight)/(Dry Weight)

MCWB would be the basis usually assumed, but if one is interested in the fuel or lumber properties, one is most interested in the MCDB.

4.6 Technology, transport and storage of wood biomass

Wood chips are produced is different sizes. For automatic burning are preferred smaller (up to 3 cm) and medium sized (up to 5 cm). Larger chips can often produce problems in this case.

In order to decrease use of energy for preparation of biomass it should be attempted to use if possible larger chips (up to 20 cm). Burning of this kind of biomass is rather simple, cost effective and absent of major problems.

Mobile and universal chopper provides adjustments to different purposes. Rationalized procedure is limited to cutting, pulling to cropping machine, manufacturing wood chips and transport. In machinery for wood chip production are included all from tractor trailers to large machines with remote drive. Machines depending on individual power can produce different amounts of chips, largest of them being able to produce annually 25 000 m3.

For transport of wood chips are used separate vehicles with about 70 m3 of cargo area. The entire system of preparation and transport needs to be economical in comparison with total process of the system. Transport of dry or prepared wood biomass to larger distances is done by railroads, although it is a general fact that small or medium scale CHP cannot reach economy if the transport distances are larger than 100 km.

Wood should be stored not only to ensure supply of power plants on regular basis, but also for drying and possibility of collection of larger amounts of biomass at better cost. Wood chips are easily stored on covered concrete surface, or closed silos. Stored amount for power plants usually satisfies the capacity on shorter time basis 1-9 days, with maximal power and therefore drying of wood chips is not necessary as construction of boilers provide efficient drying and burning of biomass with even higher moisture amounts.

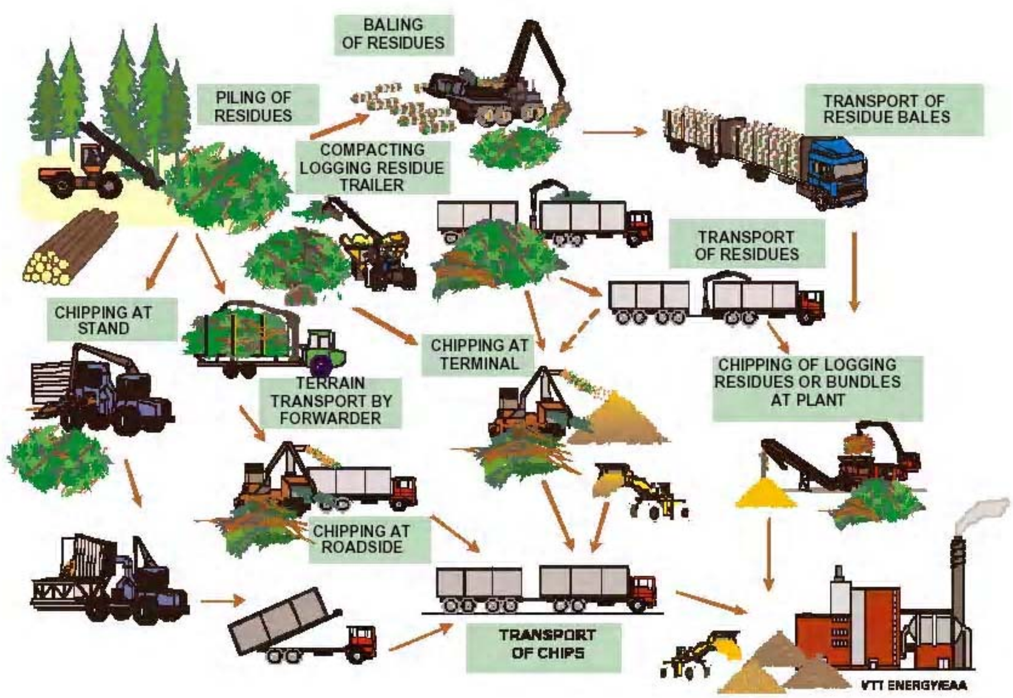


Figure 4.3 – Process of preparation, transport and storage of wood chip biomass.

4.7 Cogeneration

Cogeneration is the simultaneous production of heat and electricity, commonly called combined heat and power (CHP), from a single fuel. Traditionally, a steam engine (for electricity power less that 1 MW) and steam turbine (>1 MW) is used to produce electricity, with new technologies such as ORC and Stirling process emerging in the market. Several factors affect the economic feasibility of a CHP unit including wood waste disposal problems, high electricity costs, and year-round steam use.

Two common mistakes when installing a CHP system are buying a steam boiler that is designed for less than 100 lbf/in² (689 kPa = 6,89 bar) or over sizing the system. Buying a steam boiler that is designed for less than mentioned pressure, results in a quality of steam that is not adequate for turbine operation. Oversizing the system results in additional capital costs, not better quality steam.

More electricity and heat are generated for a lesser amount of fuel by a CHP unit than by a separate heat and power (SHP) unit. Common challenges for all wood-fired systems are ensuring adequate fuel acquiring and solving the complex fuel handling and storage issues.

Providing cost estimates for wood energy systems requires flexibility and a technical understanding that, depending on the site requirements and present site capabilities, costs fluctuate widely. The cost estimates shown in Table 4.2 are meant as a guideline to assist in determining the possibility of installing a wood energy system at a facility.

Tab.4.2 – Comparison of electric, thermal and CHP power facilities, source: USDA, Forest Products Laboratory, State & Private Forestry Technology Marketing Unit, Madison, WI, 2004

	Size (MW)	**Fuel use (green ton/year)**	**Capital cost (million $)**	**O&M** (million $)**	**Efficiency (%)**
Electrical					
Utility plant	10-75	100,000-800,000	20-150	2-15	18-24
Industrial plant	2-25	10,000-150,000	4-50	0.5-5	20-25
School campus	N/A ***	N/A	N/A	N/A	N/A
Commercial/ins.	N/A	N/A	N/A	N/A	N/A
Thermal					
Utility plant	14.6-29.3	20,000-40,000	10-20	2-4	50-70
Industrial plant	1.5-22.0	5,000-60,000	1.5-10	1-3	50-70
School campus	1.5-17.6	2,000-20,000	1.5-8	0.15-3	55-75
Commercial/ins.	0.3-5.9	200-20,000	0.25-4	0.02-2	55-75
Combined heat & power (CHP)	*				
Utility plant	25 (73)	275,000	50	5-10	60-80
Industrial plant	0.2-7 (2.9-4.4)	10,000-100,000	5-25	0.5-3	60-80
School campus	0.5-1 (2.9-4.4)	5,000-10,000	5-7.5	0.5-2	65-75
Commercial/ins.	0.5-1 (2.9-7.3)	5,000	5	0.5-2	65-75

* Sizes for the CHP facilities are a combination of electrical and thermal; the first figure is electrical and the figure in parenthesis is thermal

** O&M - Operation and Maintenance

*** N/A – Not Applicable

4.8 Criteria

Many different types of CHP plants are used worldwide. When choosing the type the following elements have crucial influence:

1. The size of the heat market e.g. small heat markets requires standard equipment like piston engines or gas turbines while big plants often are designed special.
2. The fuel to be used, e.g. clean fuels like natural gas and light oil can be used in all types of CHP while more difficult fuels like biomass and coal mainly are applicable in boiler-steam-turbine types of CHP.
3. The cost ratio between fuel and electricity, e.g. cheap fuel and high price of electricity makes it feasible to invest in types with high electric-efficiency as Combined Cycle plants.
4. The needed temperature of heat, e.g. if industrial steam with high temperature is needed, gas turbines are most suitable due to a rather high temperature of the exhaust gas.

4.9 Basic principle

- Conversion of mechanical energy (turbine) into electrical energy with the help of a generator.
- Utilization of the heat energy of the steam discharging from the turbine to provide heat.

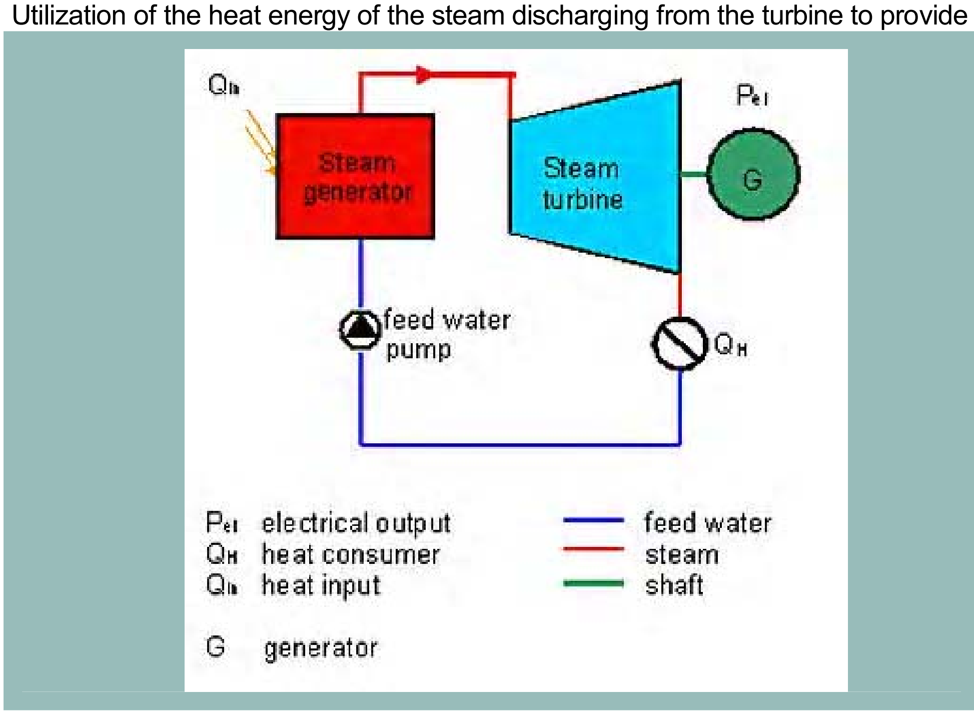


Fig.4.4 - Principle of CHP with steam turbine cycle

The basis for this type of CHP is the steam turbine cycle, which is explained in more detail in the following.

4.10 Steam turbine

The main elements of a steam turbine cycle are: the boiler with super-heater, the turbine, the condenser and the feed water pump. Rotor of such steam turbine has been presented in Figure 5.

The water is vaporized in the boiler and later brought to the desired temperature in the super-heater. This live steam then is flowing through the turbine, which drives the generator to generate power. In the condenser the steam discharging from the turbine condenses and is brought to process pressure with the help of the feed water pump. Afterwards the steam is fed into a boiler whereby the cycle is closed.

As a cooling medium in the condenser usually river water or surrounding air will be used, and the released condensation heat remains unused.

To use this waste heat there are a series of different configurations allowing the usage of any incidental heat. It is crucial though that for using waste heat a higher pressure and temperature level is required.

The following figure (Fig.6) shows a section through a steam turbine for high output, which consists of a high pressure-, a medium pressure-, and a low-pressure section. In this kind of machines about 70 % of live steam from the low pressure sections is passed on to the condenser, the remaining 30 % are used for preheating feed water and afterwards are fed to the steam cycle.

Fig.4.5 - Rotor of a steam turbine with 8 MWel (Source: Peter Brotherhood Ltd)

In Figure 4.6 a plant with a condensation steam turbine is depicted.

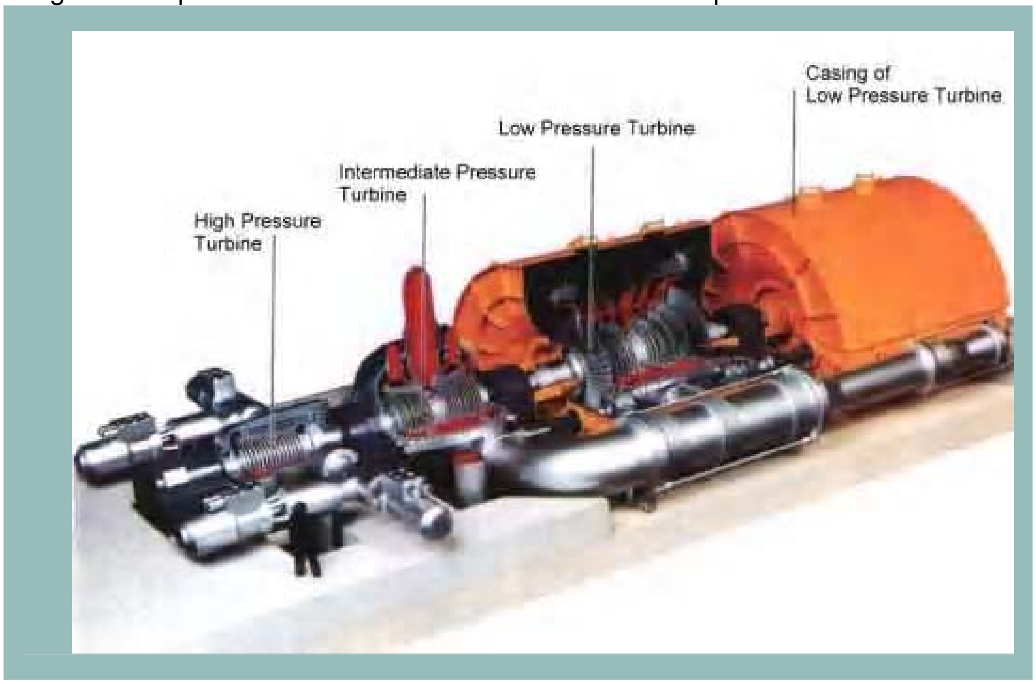


Fig.4.6 - Section through a steam turbine

There are two main types of CHP plants based on steam cycle:

- Steam cycle with a back pressure turbine
- Steam cycle with an extraction condensing turbine

For lower heat output steam is extracted by tapping the steam turbine and therefore the technical design is simpler compared to an extraction-condensing turbine. Yet pressure and temperature during the tapping process can only be kept when run in full load.

4.11 CHP with steam cycle and back pressure turbine

4.11.1 Functionality

In a turbine (back pressure turbine) the hot steam produced in the boiler is expanded down to backpressure, which results from the desired temperature of the process heat. Thus it is performing mechanical work for the generator. The generator transforms mechanical energy into electrical energy. Heat exchangers outside the turbine can be used to pass the remaining heat quantity of the steam to another medium (e.g. water) with the help of condensation. This heat quantity can now be utilized in different ways. Later the condensed steam is fed to the steam generator again with the help of water preparation through a feed water pump. Thus the cycle starts again. Valves on the turbine are used for control.

This design is mostly used when a more or less constant amount of heat is required.

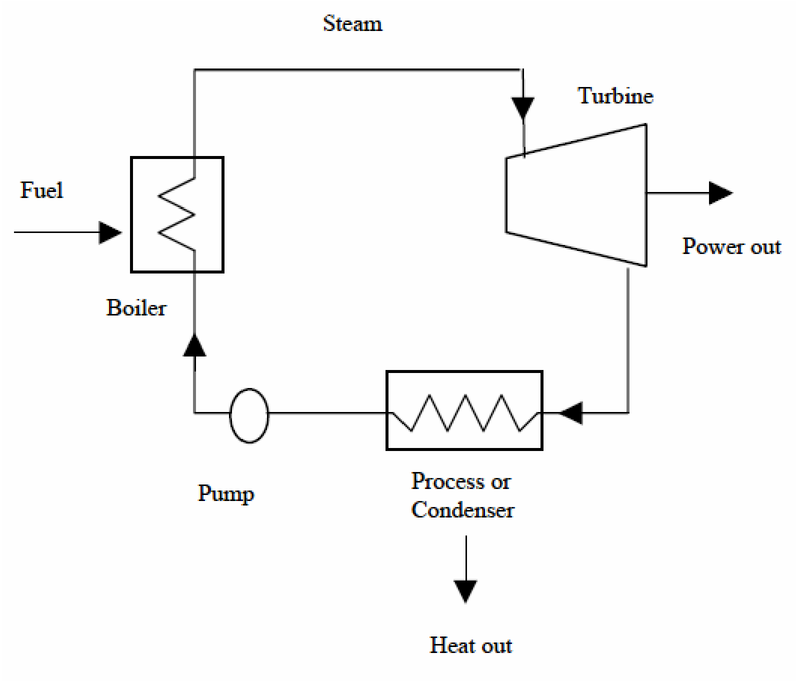


Fig.4.7 – Basic principle of back pressure turbine process

The characteristics of this type are very similar to those of the Extraction type, but there are two main differences: 1. The ration between electricity and heat production is fixed. 2. The design of the steam turbine is simpler and therefore cheaper. The back Pressure type is normally only used for small CHP plants operated according to the heat demand.

4.11.2 Heat transmission

If cheap heat sources are available, it can be feasible to transport the heat over longer distances in transmission pipes. Transmission pipes are often separated from the distribution network with heat exchangers, because high pressure is used in the transmission system to reduce the necessary number of booster pump stations. A typical big DH system, including a transmission network is illustrated in Figure 4.8.

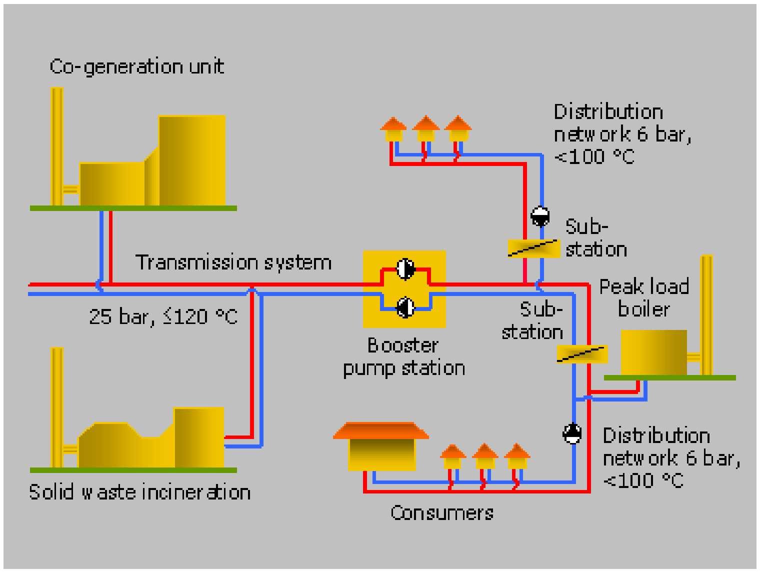


Fig.4.8 -Typical configuration of large DH system.

4.11.3 Space heat installations

The normal heat installation in DH heated building is radiators. In old houses and in new houses, where the installations are designed for DH, two pipe installations are the most common, resulting in a good cooling of the circulated water. In newer buildings where the heat installations originally were designed for individual boilers in each house, one-pipe systems (with by-pass) is rather common, because the cooling of the water has no influence on the boiler efficiency. In this type of installation, it is important with a good control of the system to optimize the operation and in that way to secure an acceptable cooling of the circulated water.

In many of the medium and larger DH system it is common to connect the consumers installations for space heat directly to the DH network without heat exchangers. This solution reduces the investment costs and no temperature is lost in the heat exchanger. In other systems, all consumers are connected to a heat exchanger and with use of modern plate heat exchangers, the additional investment costs are limited and only few degrees are lost. The biggest disadvantages, special in small installations, are the need of an internal circulation pump.

4.11.4 Description of the site: municipality in northern region Vojvodina

Municipality Bečej is located in northern part of the country, region Vojvodina. Vojvodina is agricultural area with dominant rural area and majority of households and farms, with exception of several larger cities. The city of Bečej with surrounding area has around 42.000 inhabitants. Heating requirement for the entire municipality is estimated at 660 TJ annually, and some of it covered by heating from city power plant (1/3 of inhabitants). Biomass as less cost fuel should be used in households in rural surrounding areas. As far as energy economics, price of gas in November 2004 was 13 din/Nm3 (1 euro = 76 din). However gas does not have costs of storage and transport. While on the other side, estimated price of wood chips 2.5 -3 din/kg. This gives an advantage of using biomass as a fuel. The proposed design of power plant is estimated to cover heating requirements of surrounding rural area and contribute with electricity production by connecting to medium voltage distribution network.

4.11.5 Technical design:

The plant uses primarily wood chips as fuel. The moisture content of the fuel is usually between 50-65%. The wet fuel is burned in underfeed rotating grate fired boiler (the example used is provided by Sermet Oy, Finland).

Steam values after the boiler are 350 deg. C and 24 bar and producing 0.9 MW electric power. After the engine the steam is led to a heat exchanger to produce district heat. Condensed water is then pumped back to the boiler. Electricity is produced by using steam turbine. Process diagram of wood chip CHP plant with steam turbine is given in Figure 9.

Tab.4.3 - Summary:

Electricity:	0.9 MWe
District heat:	6 MWth
Electrical efficiency:	0.11
Power-to-heat ratio:	0.15
Overall efficiency:	85%
Fuel input:	8.1 MWfuel
Fuels:	Wood chips (primary), sawdust, bark
Boiler:	Underfeed rotating grate
Moisture content of fuel:	50-65 w%
Steam values:	2.8 kg/s, 350 deg. C, 25 bar

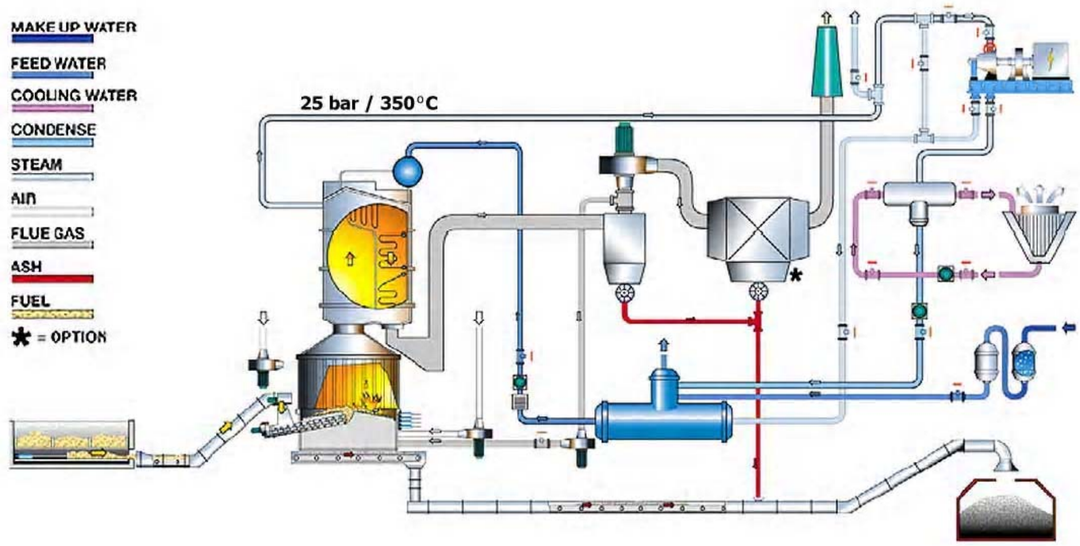


Fig.4.9 – Process diagram of wood chip CHP plant with steam turbine

Boiler:

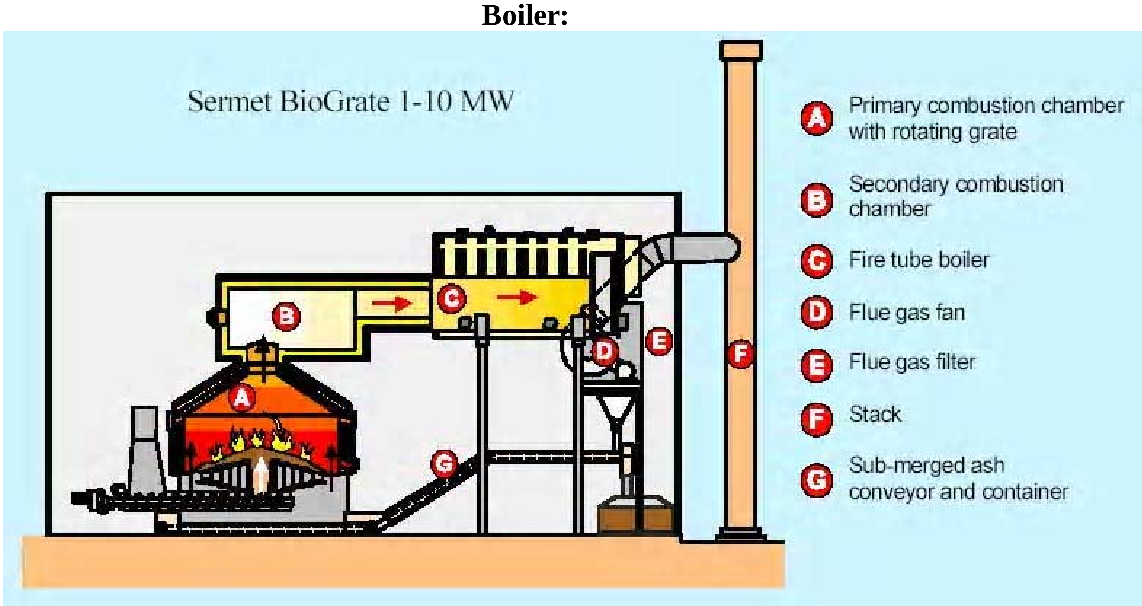


Fig.10 – Sermet Biograte boiler with underfeed rotating grate

The proposed combustion technique as in BioGrate, is capable of burning biomass fuels with water content 30-65%. The boiler is equipped with underfeed rotating grate which moves the fuel bed cyclically by hydraulics elements. The movement of the grate is adjusted in such a way that the fuel is distributed as an even bed over the whole grate. The fuel dries and ignites on the bed.

The main advantages of the rotating grate are:

- There are no spots in the primary combustion chamber
- The burning surface is even
- Movement of the grate zones are smooth

- The secondary combustion chamber ensures complete combustion

4.11.6 Benefits of CHP

The energy efficiency of CHP is typically 40% higher than the one with separate production of electric power at a condensing power plant and heat at a heat-only-boiler, all of them using the same fuel. In other words, the CHP uses 30% less fuel than the separate production. In the (separate) condensing power plants, usually gas or coal fired, or nuclear plants, even 40—70% of the fuel consumption is lost to the environment through condensing and stack losses. Thus, the high fuel efficiency of CHP is a considerable benefit in the energy business with substantial positive impact on energy economy and environment protection.

Fuel	Heat Value		CO2 emission	SO2 emission
	MJ/kg	MJ/ m3	g/MJ	g/MJ
Natural gas		36	56	0
Hard coal	26		91	0,4
Oil	41		76	
Peat	22		106	0
Wood waste	20		0	0

Tab.4.4 – Comparison of heat value and emissions for different types of fuel

Therefore, in the other cases:

- Based on solid fuels, the total efficiency is also typically 40% higher than the one with separate production of electric power at a condensing power plant and heat at a heat-only-boiler, all of them using the same fuel, but the power to heat ratio is lower than with gas; and,
- Based on the CHP technology in small scale, the power to heat ratio is usually lower than with CHP in large scale, but similar benefits in fuel economy and environmental protection can be achieved as with the large plants.
- In addition to energy efficiency, the electricity transmission losses are normally lower with CHP, because electricity is generated close to the municipality.

4.11.7 Economic Boundaries of CHP

The CHP technology is capital concentrated. In order to pay back the high investments,

- The annual operation time should be as long as possible, typically more than 4 000 hours; which is possible if the heat is also used in summer in thermal driven air conditioning (absorption cooling or desiccative-evaporative cooling systems).
- The produced heat energy usually covers the major part, 50-80%, of the industrial and/or the municipal heat demand;
- The price of fuel and waste heat should be relatively low, and,
- The price of the electricity sold to the grid should be sufficiently high to gain sales revenues.

4.11.8 Costs of CHP

Since the price of electricity in Serbia still has not reached the level matching European prices and is several times lower, also since the feed-in tariffs have not yet been introduced (2004/05), construction of DH instead of CHP systems is currently favorized among investors. However, with new Energy law and government policies in near future constructing new and adopting old CHP systems should bring changes in approach and rapid growth.

The financial viability depends very much on the operation costs and sales revenues being a function of

- Power to heat ratio varying from 0,2 up to 1,0 depending on the type and the actual loading of the CHP plant;
- The peak load duration time varying from 4 000 to 8 000 hours a year;
- Variations of heat load on daily and weekly basis during the winter, summer and intermediate seasons;
- Relations of fuel prices between natural gas, oil, coal, peat and biomass;
- Price of electricity for sale to either the low, medium or high voltage grid and depending on the time of sales;
- Price of heat for sale to heat customers;
- Connections to fuel supply, water and heat networks and the electric grid; and,
- Financial parameters including taxes.

4.12 Conclusion

Energy potential of biomass has significant value in comparison with energy consumption in Serbia. Contents of ashes in biomass are much lower compared to coal. Biomass practically does not produce sulphor and use of biomass does not bring to increase of CO2 in atmosphere. Besides environmental protection, use of biomass as energy source contributes to security of energy supply because it is locally oriented, and reduces dependence on imported fuels. It is contributing as a strong socio-economic factor of increasing life standard in rural areas and preventing major migration of population from rural to urban areas. Since most of the biomass as energy source is available in rural and less developed forest regions, employment of local inhabitants in biomass related jobs, as well as intensifying biomass production will bring development of such areas.

The economic advantage of wood biomass energy is that wood is usually significantly less expensive than competing fossil fuels, while with cogeneration technology more electricity and heat are generated for a lesser amount of fuel by a CHP unit than by a separate heat and power unit. This paper proposes technical design of CHP plant with steam turbine, powered by biomass – wood chips. This plant is aimed to satisfy the requirements of district heating of rural area, of municipality of Becej and therefore significantly improve energy efficiency by changing of consumer behavior who were using rare and clean energy source – electricity for additional heating, while also producing electricity in the distribution network.

Recent Energy Law predicts certain conveniences for use of renewable energy sources. But only with future legislation, proposals, regulations and standards would with more precision determine conditions and benefits for energy use of renewable sources. In which amount will energy potential of biomass be efficiently used does not depend only on energy policy, but also of capability and willingness of all involved in this business, investors, producers, research institutions, forestry and agricultural sectors, financial institutions, to each individually and in an organized way give their contribution to greater use of biomass as energy source.

4.13 Literature:

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/5/ A. Nuorkivi, “Institutional Handbook for Combined Heat and Power Production with District Heating”, 2002, Baltic Sea Region Energy Co-operation

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5 Wood chip fired ORC-plant for CHP-production for rural village

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5.1 Abstract

The Organic Rankine Cycle (ORC) process has attained a high level of development and demonstration units are already in operation. This technology is applicable for small-scale biomass fired Combined Heat and Power (CHP) plants with nominal electric capacities between 400 and 1,500 kW. It is often preferable to produce electricity from biomass by means of relatively small generation units, in order to get cheap biomass from a single source or from a number of sources located in a limited area, without a complex biomass gathering organisation and without the additional commercial, transport and storage costs. Such of requirements fit well for power generation in woody and agriculture rural areas. Some basic features of the ORC plant technology and its applicability for combined heat and power generation in isolated regions are discussed in this report.

5.2 Basic information on ORC plant technology

A Rankine cycle is usually known as a closed circuit steam (water vapour) cycle. An "organic" Rankine cycle uses a heated chemical instead of steam as found in the original Rankine Cycle. Chemicals used in the Organic Rankine Cycle include freon, butane, propane, ammonia and the new environmentally-friendly "refrigerants" and as well as diffetent oils. The selected working fluid for biomass fired ORC plants is silicone oil. This approach allows exploiting efficiently low temperature heat sources to produce electricity in a wide range of power outputs (from few kW up to 3 MW electric power per unit) [3].

The biomass fired ORC-power generation is based on the following main steps:

- Biomass is burned in a combustion chamber made according to the well-established techniques in use also for hot water boilers. These facilities with their set of accessories (filters, controls, automatic ash disposal and biomass feed mechanism etc.) are nowadays safe, reliable, clean and efficient.
- Hot thermal oil is used as primary heat transfer medium, giving a number of advantages, including low pressure in boiler, large inertia and insensibility to load changes, simple and safe control and operation. Moreover, the adopted temperature (about 300 ^{0}C) for the hot side ensures a very long life of the oil. The utilization of a thermal oil boiler also

allows operation without licensed operator required for water vapor systems in many European countries;

- An Organic Rankine Cycle turbo-generator is used to convert the available heat to electricity. Thanks to use of properly formulated working fluid (silicone oil) and to the optimization of machine design both high efficiency and high reliability are obtained. The residual heat of the cycle (heat of condensation) is used to produce hot water at typically 80-90 ^{0}C level, a temperature range suitable for district heating and other low temperature needs (like wood drying and process cooling through absorption chillers etc.)

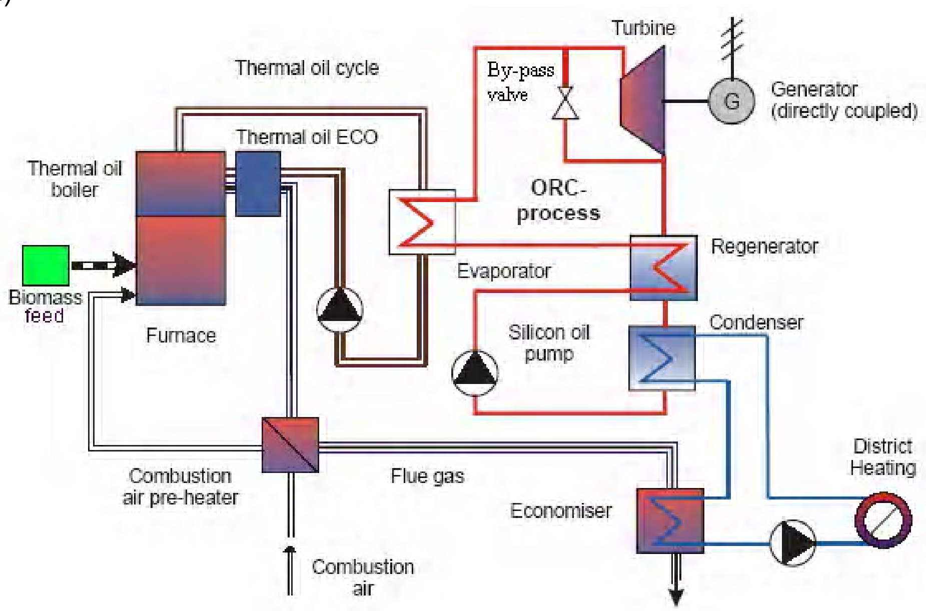

Figure 5.1 Layout of biomass fired ORC plant for combined heat and power generation in Lienz, Austria [1]

As it shown on the Fig. 5.1 a biomass fuelled ORC power plant is composed of the following items:

- An automatic biomass feeding system, suitable to automatically operate the boiler adapting to the available biomass;
- A biomass boiler consisting of a combustion chamber with fixed or sliding grates, air or water-cooled according to the biomass to be burned. On the top of the combustion chamber, a hot gas/thermal oil primary heat exchanger is installed. Normally, this heat exchanger is composed of a single pass coil in which a relatively high thermal oil speed is assured, in order to avoid oil stagnation. In fact, it is essential to avoid hot spots in thermal oil tubes, as this would lead to its overheating and as a result a reduction of its lifetime.
- Due to relatively high thermal oil inlet/outlet temperatures (250 ^{0}C / 300^{0}C) the exhaust gas temperature is high enough to allow installation of hot gas/thermal oil economizer, combustion air pre-heater and flue gas/district heating water economizer. Using these approach in Lienz demonstration project, the thermal efficiency of the biomass fired thermal oil boiler reaches 82% (= thermal power output/fuel power input), which is about

10% higher than corresponding values from conventional biomass-thermal oil boilers. This increased thermal efficiency, subsequently changed the over all electric efficiency of the CHP plant (= net electric power produced/fuel power input into the biomass-fired boiler) to about 15%, Fig. 5.2.

- A thermal oil circulation system driven by a pump provides heat exchange between the boiler and ORC turbine. Normally two pumps are installed (one in standby), in order to assure in any case circulation of thermal oil through the boiler. In case of malfunction of the first pump, the second one is automatically started. If a grid failure occurs, then an UPS supplies electric power to the pumps.
- An evaporator using heat from the thermal oil to vaporize and slightly to pre-heat the organic fluid
- A direct cooling by-pass, suitable to transfer heat from the thermal oil circuit to the cooling water circuit. This by-pass valve is useful tool during turbo-generator start-up or shutdown procedures.
- An Organic Rankine Cycle unit. The key component of the whole biomass fired ORC-power generation plant is an axial turbine that drives directly coupled generator. It allows heat to electricity conversion with good efficiency and reliability from thermal oil at relatively low temperature of 300^0C.

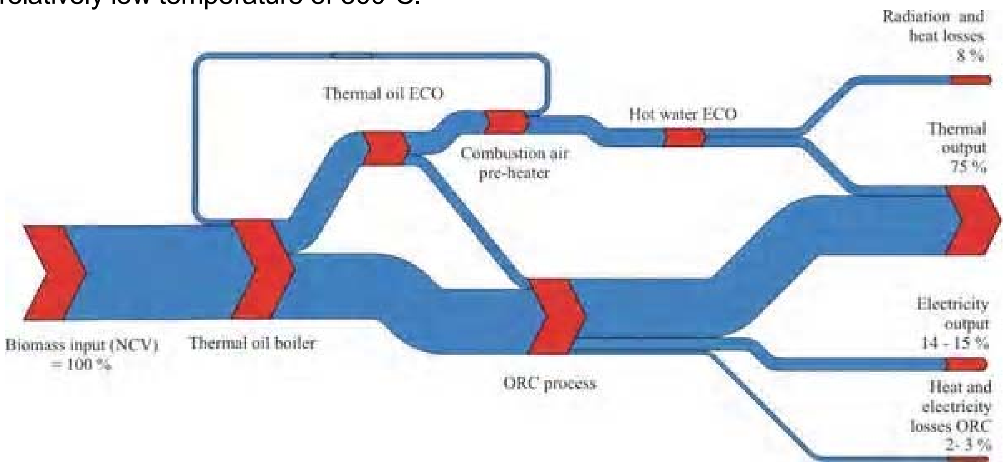

Figure 5.2 Energy balance of the biomass CHP plant in Lienz, Austria [1,4]

5.3 Technical Description of the ORC plant in the Benedictine Abbey

The Benedictine Abbey of Admont is located at woody region in Styria, Austria. The biomass-fired plant developed at this site is discussed later on as appropriate example of ORC application in rural area. The plant is owned and operated by STIA Holzindustrie GmbH. This company is typical mid-size wood-processing manufacturer. Before the realization of the new biomass-fired CHP plant STIA-Holzindustrie GmbH covered its process and space heat demand for the production sheds and warehouses with one biomass-fired and two oil-fired (light heating oil) furnaces. At the same time the wood-processing factory has generated plenty of residues in the form of sawdust and chips. The heat supply of the Benedictine monastery of Admont was provided by three oil-fired (heavy heating oil) furnaces. As all these old combustion units did not meet the technical and environmental standards required any more, STIA-Holzindustrie GmbH decided to substitute them by a new and completely biomass-based CHP system /2/.

The overall plant consists of two combustion units, one with a thermal oil boiler (nominal capacity 3.2 MW) and the other with a hot-water boiler (nominal capacity 4.0 MW). A dust precipitator combined with a common flue gas condensation unit follows each furnace. After the successful start-up of the new CHP plant the two oil-fired combustion units at STIA were shut down and are now only used as stand-by units. Furthermore the three oil-fired furnaces at the Benedictine monastery of Admont were shut down, too.

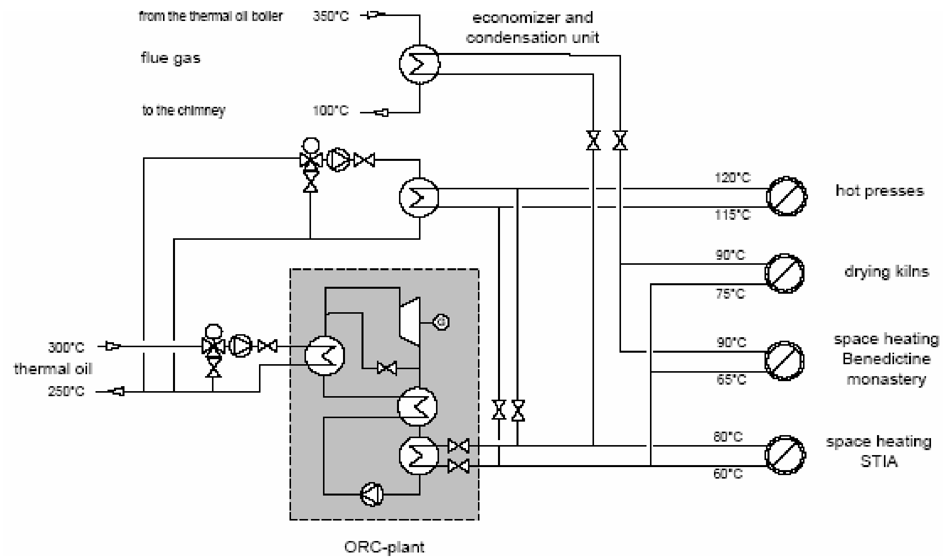

Figure 5.3 Diagram of ORC based combined heat and power plant in STIA Admont [2]

The main innovative component of the process is the biomass-fired combined heat and power unit based on an ORC process. It has got nominal electric capacity of 400 kW, nominal thermal capacity of 2.25 MW. Figure 5.3 outlines the working principle of the ORC sub-plant. The ORC process is connected with the biomass-fueled furnace via a thermal oil cycle and the thermal oil boiler (nominal capacity 3.2 MW, 0.95 MW of the thermal oil power are directly utilized via hot presses located in the wood processing plant). The ORC unit itself operates as a completely closed process utilizing silicon oil as organic working medium. This pressurized organic working medium is vaporized by the thermal oil in the evaporator and then expanded in a two-stage axial turbine, which is directly connected to an asynchronous generator. Subsequently, the expanded silicon oil vapors pass through a regenerator (where cycle-internal heat recuperation takes place) before it enters the condenser. There condensation of the working medium takes place at a temperature level, which allows the heat recovered to be utilized (hot water feed temperature about 80 to 90°C). The liquid working medium then passes the feed pumps to achieve the appropriate pressure level of the hot end of the cycle again. The flue gas of the biomass boilers enters a common flue gas condensation facility, which has been designed in order to achieve an efficient energy recovery of the flue gas and to optimize thermal efficiency.

To achieve maximum electric efficiency, it is necessary to minimize the temperature level of the process heat, which is produced by the condenser of the ORC process. The project case study shown (Admont, Austria) allows for such optimization steps, because the high temperature level of the process heat required for the hot presses (115°C) is provided by a thermal oil side circuit (downstream of the ORC) and not by the ORC process. All other heat consumers (drying kilns, space heating STIA, space heating Benedictine monastery) require lower temperature levels (maximum 90°C). The temperature level on the cold side of the ORC process is fixed at 80°C. The temperature level of 90°C can be reached by further heating the feed from the cold side of the ORC process in an economizer (first stage of the flue gas condensation unit). In this way the electric efficiency of the ORC unit is optimized due to the big temperature difference between hot and cold side and energy from the flue gas can be recovered at the same time.

5.4 Performance of the ORC plant in STIA-Admont, Austria

The combustion system and the flue gas condensation unit started operation in autumn 1998, the ORC plant in August 1999. The operating experience gained in STIA-Admont plant has confirmed that ORC system can run automatically without permanent supervision and with high availability. The nominal net electric power output of the ORC can even be achieved with thermal oil inlet temperatures below 300°C (300°C was the nominal value specified). The electric efficiency of the ORC (= net electric power output/power input with the thermal oil) at nominal load is about 17.7 %, what is a quite high value for small-scale CHP plants, Fig. 5.4.

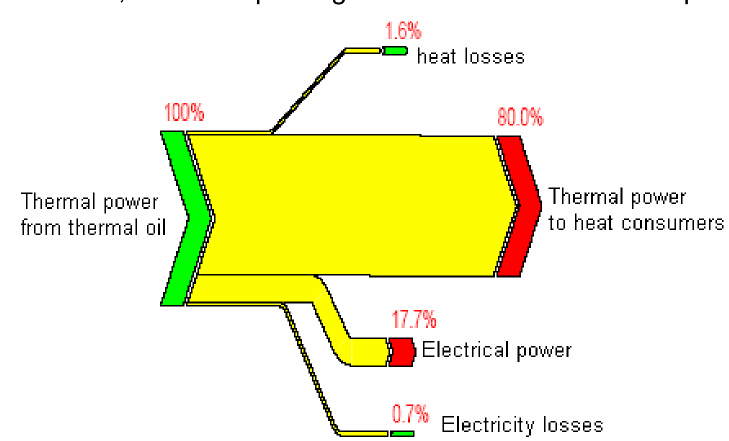

Figure 5.4 Energy balance of the biomass CHP plant in Lienz, Austria [2]

The unit installed at Admont has reached in August 2002 more than 22000 hours of successful operation. Most of the stops have been due to the normal boiler cleaning operations and the availability of the ORC unit has been higher that 98%.

The main ORC unit operational parameters observed during its operation in 2001 is presented at **Table 5.1**

Technical data of the ORC process (case study Admont, Austria)

Nominal thermal capacity (energy input on hot side)	2,250 kW
Heating medium	thermal oil
Inlet temperature	300°C
Outlet temperature	250°C
Working medium	silicon oil
Nominal thermal output	about 1,800 kW
Cooling medium	water from the process heat network
Water inlet temperature	60°C
Water outlet temperature	80°C
Nominal net electric capacity	400 kW
Electric efficiency at nominal load	0,18
Electric efficiency at partial load (50%)	0,14

The ORC unit has demonstrated excellent partial load behaviors, Fig.5.5. As a result high nominal load net electric efficiency can also be kept at partial load operation (between 50 and 100 % load almost no deviations regarding electric efficiency occur), which is very important for CHP plants in heat-controlled operation and power generation in isolated regions. The thermal efficiency of the ORC unit (= thermal power output/power input with the thermal oil) is about 80% and is slightly increasing at partial load operation. Following, the overall efficiency of the ORC plant is about 98% (thermal and electric losses amount to about 2.3%).

The ORC plant is fully automatically controlled by a PLC (Programmable Logic Controller), which permits automatic start-up and shutdown of the plant as well as an automatic phasing with the electric grid. The ORC plant can be coupled to the electric grid within 5 minutes (after having passed all security checks). In fact, the unit is operated controlling only by the thermal oil temperature and flow and cooling water flow.

The ORC unit adapts easily to the variable feeding conditions, producing the electricity that can be generated depending on the feeding conditions. The result is a system that, thanks to the high inertia of the thermal oil and to good partial performance of the ORC unit, adapts easily to inevitable changes typical for the combustion of biomass with variable composition and power generation in isolated regions.

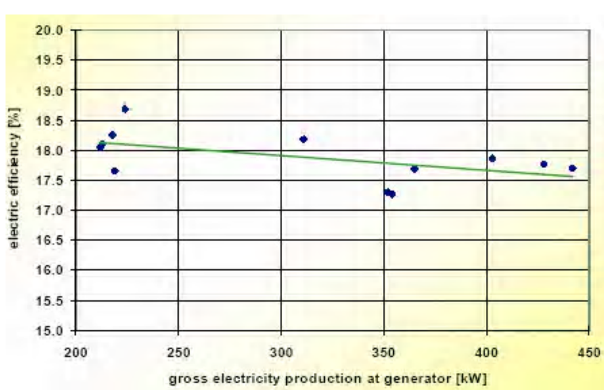

Figure 5.5 Electric efficiency depending on the ORC unit load [3]

Because the cycle of the ORC process is closed and very tight, the losses of the working medium are negligible and consequently the operating costs of the ORC plant are low. Furthermore staff costs and maintenance expenses are low. Owing to the fully automatic control of the plant no additional need for staff arises for the operation of tile ORC process (an expenditure of three hours per week for one person will be required only). Moreover, an on-line process control will be realized that enables the plant operator as well as the manufacturer of the ORC unit to check the most important operating parameters continuously.

Due to the excellent results obtained during the initial operation of several demonstration ORC plants, recent years have seen fast growing numbers of the newly constructed plants. Most of the newest ORC units are located in wood rural areas in Austria and Germany, Table. 5.2. Usually these are CHP biomass plant burning virgin wood. The discharged thermal power is mainly used for wood drying chambers and in wood presses.

Table 5.2 ORC plants located in woody areas

Country	ORC units in operation	ORC units under construction	Total number of ORC units
Austria	4	1	5
Germany	2	3	5
Total number of ORC units	6	4	10
Total ORC plants capacity	5170 KW_{el}	5100 KW_{el}	10270 KW_{el}

5.5 Technical design data of TURBODEN's ORC plants

The ORC process has already attained a high level or development. At present, the ORC technology represents state of the art and is available on the market. Compact ORCmodules are available in container size with nominal capacity between 500 and 1500 KW_{el}. (Table 5.3)

Table 5.3 Data sheet of TURBODEN's ORC units (source web site: http://www.turboden.it)

	T500-CHP	T600-CHP	T800-CHP	T1100-CHP	T1500-CHP
Heat source	Thermal oil in a closed circuit				
Thermal oil nominal temperature (In/Out)	300/250 ^{0}C				
Thermal power input from the thermal oil	2900 KW	3500 KW	4500 KW	6200 kW	9000 KW
Thermal oil flow (about)	23.6 kg/s	28.3 kg/s	36.3 kg/s	51 kg/s	74 kg/s
Cooling water temperature (In/Out)	60 / 80 ^{0}C	60/80 ^{0}C	60 / 80 ^{0}C	60 / 80 ^{0}C	60 / 90 ^{0}C

Cooling water flow	28.1 kg/s	33.9 kg/s	43.3 kg/s	59.6 kg/s	58.4 kg/s
Thermal power to the cooling water loop	2320 KW	2800 KW	3580 kW	4930 kW	7350 KW
Net active electric power output	500 KW	600 KW	800 kW	1100 KW	1500 KW
Electric generator	asynchronous 3 phase, L.V., 650 kW	asynchronous 3 phase, L.V., 750 kW	asynchronous 3 phase, L.V., 930 kW	Asynchronous 3 phase, L.V., 1250 kW	asynchronou 3 phase, L.V., 1650 kW
Over all dimensions (LxWxH)	13x3x3	13x3x3	13x3x3	12.5x6x5.8	13x7x4.5

5.6 Conclusion

Power plants based on Organic Rankine Cycle (ORC) are very promising solution for biomass co-generation in woody and agriculture remote areas. The advantages of this technology in terms of high availability, low maintenance costs, completely automatic and unmanned operation and high electric efficiency have been confirmed in practice. Typical applications are co-generative district heating systems and co-generation in wood manufacturing industries, where this technology is experiencing the fast growing number of installations.

5.7 References

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6 Absorption cooling system powered by wood residues

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6.1 Introduction to wood and wood residues as a Biofuel

Biomass is an organic material which has stored sunlight in the form of chemical energy. Biomass fuels include:

- wood,
- straw,
- manure,
- sugar cane, and
- many other byproducts from a variety of agricultural processes.

In the past, wood was the primary fuel for heating and cooking in homes and businesses, and was used for steam in industries, trains, and boats. 1900 ethanol as a product of biomass fermentation was competing with gasoline to be the fuel for cars. 1984 the Burlington Electric in Vermont, USA, built a 50-MW wood-fired plant with electricity production as the primary purpose. In USA, due to 1990, the electricity generating capacity from biomass (not including municipal solid waste) reached 6 GW.

Because of the basic energy situation in Europe and owing to climatic change, the European countries lunched a new energy strategy in which the RES has the important place. The European Commission target is 12% of total energy consumpted in 2010 to be satisfied from RES. About 16 GW is proposed in EU of biomass energy based facilities to be on in energy network by the 2050.

Biomass can be converted into energy by simple combustion, by co-firing with other fuels or through some intermediate process such as gasification (anaerobic digestion to produce methane or fermentation to produce ethanol is suited only for non lignocellulosic materials). The energy produced can be electricity, heat or both (combined heat and power, or CHP).

The advantage of utilising heat as well as or instead of electricity is the marked improvement of conversion efficiency – electrical generation has a typical efficiency of around 30%, but if heat is used efficiencies can rise to more than 85%. The main driving factor, which influences the wood-based biomass using, is the kWh price of electricity and MJ of distributed heat in the market.

In Table 6.1 are presented the costs of electricity production for some of the energy sources.

Table 6.1: The costs of electricity production for some of the energy sources in Eurocents/kWh

(Source: WEC)

Source	Cost of production	Extern cost (political-economical costs)
Coal	2,9-3	0,9-12,5
Gas	2,25-3	0,9-3,7
Nuclear	3-5,75	0,18-0,55
Good wind	5,5	0,045-0,24
Optimum wind	3,75	0,045-0,24
Woody residues	3	0,08

The Table 6.2 shows the comparative capital costs of biomass and fossil fuel technology for electricity and heat production. It is evident that biomass heating is cheaper per kW installed than any of the power options, but the return from heat sales is correspondingly low. Compared to fossil fuel heating technologies, biomass plant is more capital intensive by a factor 2 to 3. The savings by the use of biomass come through cheaper fuel.

Table 6.2: Comparison of capital costs of biomass and fossil fuel technology for electricity and heat production (source DOE of UK)

Technology	Size	Euro/kW installed
Biomass heat production	> 1 MWth	105
Biomass heat production	> 300 kWth	150
Biomass heat production	< 300 kWth	300
Gas fired combined cycle of gas and steam turbine	150 MWe	600
Gas fired combined heat and power - CHP	750 kW – 1 MW	900 - 1050
Pulverized coal power	600 MWe	1500
Steam turbine biomass power production	5 MWe – 40 MWe	2100 - 2700
Pyrolysis biomass power	10 MW	6600

The simplest way to use biomass as an energy source is heat generation. Typically up to 90% of the Net Caloric Value of the fuel can be used as heat. Most of the non-combustible part of the fuel as primarily minerals, leaves the combustion chamber as bottom ash. Finer particles are conveyed out of the combustor and removed in the gas cleaning stage as fly ash. Heat-only applications for biomass are constrained to locations where biomass fuel is available and a market for the heat exists, such as we proposed here in this report.

One of the most appropriate solution to apply the biomass as energy source is combining of heat and power (electricity). For generation of electricity and heat, the plant requires a generator driven either by the combustion gases or by some other working fluid. In any case, the CHP facility requires consistent free-flowing fuel for automatic operation (sawdust pellets, willow chips, forestry residue).

In many countries we can see coal-fired power stations that, with slight modification, can use a proportion of processed biomass (usually as sawdust) blended into the fuel. A number of these plants currently co-fire a variety of biomass materials, including that from energy crops, to produce electricity and consequently qualify for renewable obligation certificates that exist in some countries.

However, the important aspect of biomass materials as the energy sources is environmental implication. The emission of most concern pollutants is much lower with respect to plant fuelled with coal, gas or oil.

Biomass as fuel can be gathered or grown. Energy crops are grown using agricultural methods. The energy crops encompasses the willow (Salix spp.), grass miscanthus, poplar (populus spp.), and other grasses. In Bosnia and Herzegovina there are limited conditions like environmental and landscape to make energy crops. If we want to make detailed picture regarding potential of the biomass-derived fuel in B&H, we should determine the financial conditions under the some of projects could be successful. In addition, each case must be separately considered with respect to biomass heating and biomass CHP economic evaluation, respectively. We have to be awareness that exists about 2 eurocents/kWh gap between the price chargeable for electricity output of CHP facilities and the income necessary for economic viability. Becasue of that, the state's policy must help in reducing of the high up-front costs of such systems through the grants, taxes, etc. In these analysis one should take into consideration the reducing of emission pollutants like CO_2, SO_x and NO_x through the biomass facility operation.

Although there are no reliable statistical data for Bosnia and Herzegovina (BiH), it is possible to mention certain estimates, which do not guarantee the reliability of the data offered. For instance, based on the data of the international institutions, there are approximately 2.273,000 hectares of forest region in BiH, with app 110m³/ha. The data is presented in the FAO (Food and Agriculture Organization of the United Nations) report, Forestry Department from July 2003.

Today, total timber mass of the Tuzla Canton (one region in Bosnia and Herzegovina) is approximately 18.6 million m³. In 1998 the total of 67.000m³ of timber mass was processed. Seventy-two percent of the entire wood production accounts for industrial wood and the entire mass of the industrial wood is used for the production of wood for mechanical processing. These numbers show clear that tremendous quantities of wood residues especially from the industrial and commercial wood processing sector are available.

This short review of wood production and its residues (wood waste), then its conversion into heat and electricity have to be integrated so as the investment, efficiency and public acceptance are to be achieved. The introduction of biomass as a renewable energy in the BiH will not be easy without considerable planning and certain amount of investment by government and other financial funds.

6.2 Cooling systems and machines

6.2.1 General

Biomass wood chips or pellets combustors can be used as an equipment to provide requested input energy for thermal driven cooling process. Generally there are two different cooling processes:

- thermal driven cooling processes, like several absorption and adsorption technologies and
- mechanical driven cooling processes, like compression cooling systems.

6.2.2 Compression cooling systems

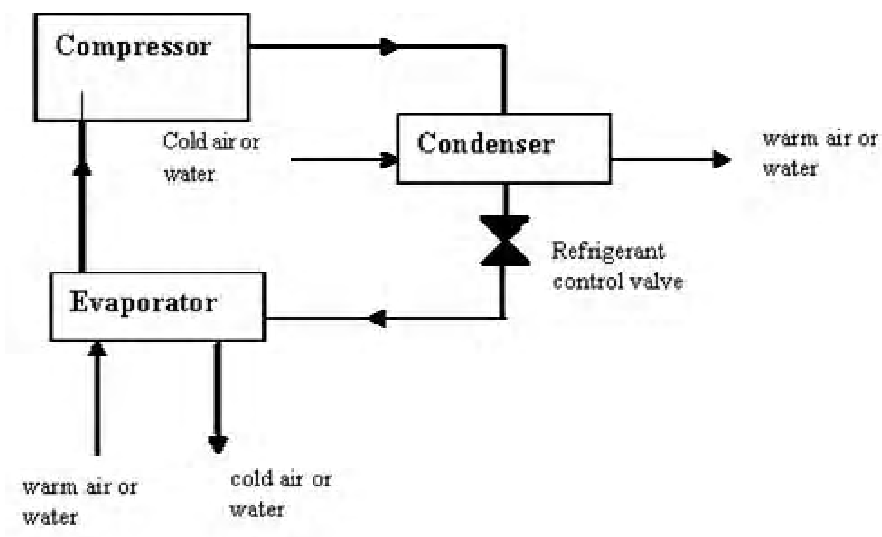

Figure 6.1: Principle of a compression cooling system

The compression cooling system (CCS needs mechanical energy to drive the process. The electric driven compressor pressurizes the gaseous refrigerant. The refrigerant leaves the compressor as a vapor and is condensed at the water or aircooled condenser at about 30 °C. The liquid refrigerant enters the pressure reduction valve (refrigerant control valve) by which the pressure and later on also the temperature of the refrigerant is decreased. The refrigerant evaporates in the evaporator at low temperature depending on the low pressure, caused by the sucking stroke of the compressor and the thermodynamic characteristics of the refrigerant. The cold evaporated refrigerant vapor leaves the evaporator and is sucked in by the compressor. The compressor increases the pressuer of the refrigerant vapor which is condensed again as explained above. The process described was invented by a group of scientist and engneers, especially by Linde (1870 to 1875) and is presented by its structural scheme in Figure 6.1.

The compression cooling system needs the mechanical driven compressor, which consumes electric energy. If we want to exchange the compressor by a thermal driven one, then an absorption-cooling system (ACS) have to be constructed.

6.2.3 Absorption Cooling systems

Many different types of absorption refrigeration systems have been designed and constructed in the past. Every time the engineers would like to avoid the need of any mechanical energy for the absorption refrigeration cycle. Two engineers from Sweden, Platen and Munters, invented at the beginning of the 20 th century an interesting absorption refrigeration unit which do not need any mechanical energy. They used an auxiliary gas like hydrogen to reduce the partial pressure of the refrigerant gas in the absorber and in the evaporator.

6.2.3.1 Absorption refrigeration system with an auxiliary gas (hydrogen)

The system of the continuously working absorption refrigeration process with an auxiliary gas is described as follows and is presented in Figure 6.2.

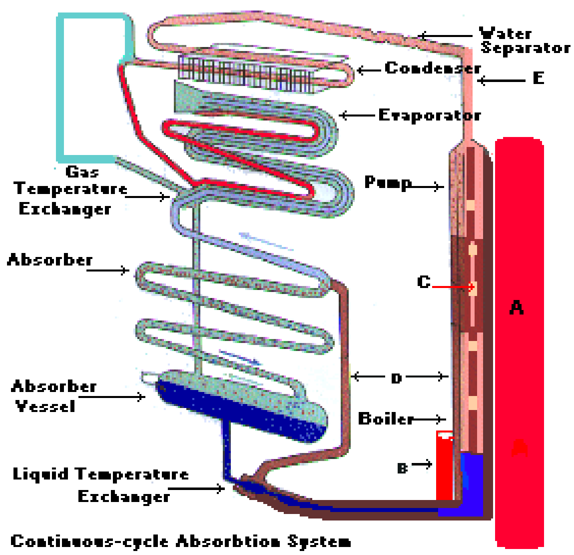

Figure 6.2: Continuous working absorption system with auxiliary gas (hydrogen)

The unit consists of four main parts, the boiler (generator or expeller), condenser, evaporator and the absorber. When the unit operates on kerosene, biomass, or natural gas, a burner supplies the heat. This element is fitted underneath the central tube (A). When operating on electricity, the heat is supplied by an element inserted in the pocket (B).

The unit charge consists of a quantity of ammonia, water, and hydrogen. These are at a sufficient pressure to condense ammonia at room temperature. When heat with suitable temperature is supplied to the boiler, bubbles of ammonia gas are produced. They rise and carry with them quantities of waek ammonia/water solution through the bubble pump (C). This weak solution passes into tube (D), while the ammonia vapor passes into the vapor pipe (E) and on to the water separator (rectification). Here any water vapor is condensed and runs back into the boiler, leaving the dry ammonia vapor to pass to the condenser. Air circulates over the fins on the outside of the condenser and removes heat from the ammonia vapor. It condenses into liquid ammonia and then it flows into the evaporator.

The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia. It lowers the ammonia vapor pressure deep enough (partial vapor pressure) to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the evaporator. This, in turn, extracts heat from the food storage space, lowering the temperature inside the refrigerator.

The mixture of ammonia and hydrogen vapor passes from the evaporator to the absorber. A continuous trickle of weak ammonia solution enters the upper portion of the absorber. It is fed by gravity from the tube (D). This weak solution flows down through the absorber. It meets the mixed ammonia and hydrogen gases. This readily absorbs the ammonia from the mixture. The hydrogen is free

to rise through the absorber coil and to return to the evaporator. The hydrogen circulates continuously between the absorber and the evaporator.

The strong ammonia solution produced in the absorber flows down to the absorber vessel. It passes on to the boiler, thus completing the full cycle of operation. This cycle operates continuously as long as the boiler is heated. A thermostat, which controls the heat source, regulates the temperature of the refrigerated space.

Since the refrigerant is ammonia, it can produce quite low temperatures. Except for the thermostatic controls and in some cases fans, there are no moving parts. Service is usually quite simple.

The burner and stack must be kept clean. The refrigerator should be carefully levelled before being placed in operation. The hydrogen gas creates the low partial pressure on the surface of the liquid ammonia in the evaporator which allows the refrigerant to boil at low temperature and to evaporate. At the same low partial pressure the ammonia vapor is absobed in the absorber which have to be cooled continuously by the ambient air. At the same time the strong solution boils in the boiler (expeller) at high pressure and ammonia vapor is produced

6.2.3.2 Continuously working absorption refrigeration machine with working fluid pump

These kinds of absorption refrigeration machines are usually used for larger capacities in the evaporation temperature range from +5 to – 30 °C.

6.2.3.2.1 Priciple description of the process

Figure 6.3 shows the principle of a continuous absorption cooling process which can operate also with woody residues as an heat source.

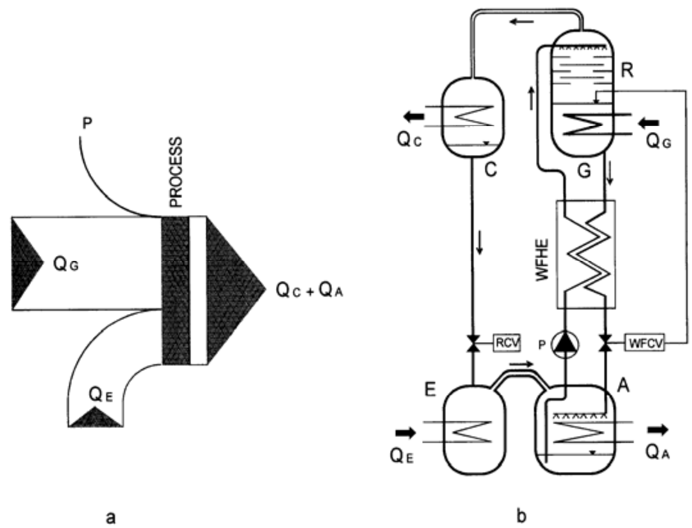

Figure 6.3: Principle of a continuous working, single lift absorption cooling system (b) with energy flow diagram (a) [4]

Q_G ... heat input at generator (expeller) at about 80 °C, Q_A ... heat output at absorber at 25 °C, Q_C ... heat output at condenser at 25 °C, Q_E ... heat input at evaporator at about 0 °C

The mechanical compressor is replaced by a thermal compressor. The thermal compressor consists of the generator (G), the absorber (A) the working fluid heat exchanger (WFHE) the working fluid control valve (WFCV) and the working fluid pump (P). The energy flow diagram (a) indicates that about 60 % cold is produced by 100% heat from biomass residues. A minor share of electrical energy is for driving the working fluid pump. More details on the process are given in the report on the 1th Workshop of the Work Package 1 of the curret VBPC project.

6.2.3.2.2 Technical design of the absorption refrigeration process

With the aid of the enthalpie vs. concentration-diagram which is shown in principle in Figure 6.4, the basic data for the circulation of 1 kg ammonia in a model absorption cooling machine can be designed.

The definitions of the model process are used to design the absorption cooling machine, which is operated by heat from biomass residues. Figure 6.4 show the closed process of the thermal compressor in the field of liquid ammonia/water in the lower part of the diagram and the enthalpy and concentration of the ammonia vapor in the upper part of the diagram. Detailled explanations are given in /1/, /4/ and /5/.

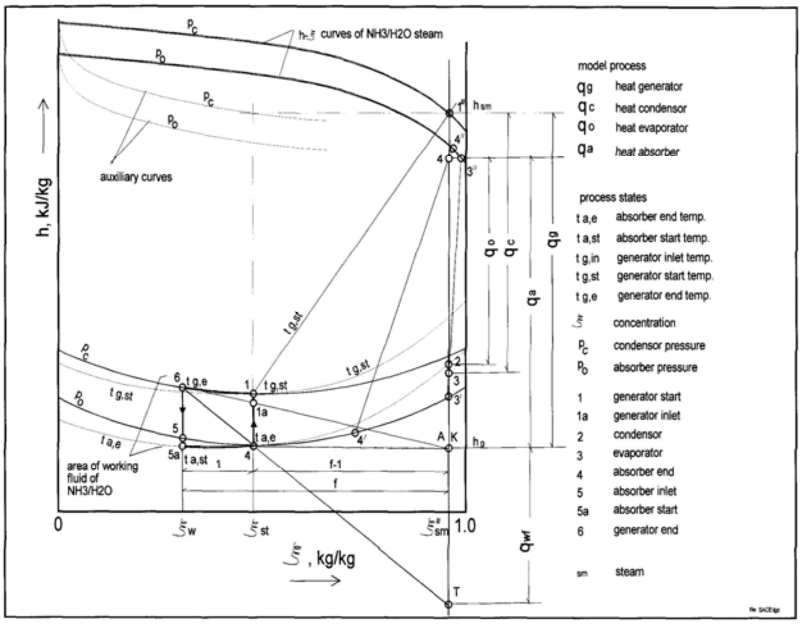

Figure 6.4: Design diagram of Merkel-Bosnjakovic for the absorption cooling model process (enthalpy vs. concentration with temperatures and pressures as parameters)

6.2.3.2.3 Technical design of the absorption cooling model machine

The results of the thechnical design of the absorption refrigeration process with the aid of the diagram in Figure 6.4 are shown in Figure 6.5. The principle sketch of a single stage absorption cooling model machine shows all the heat quantities which have to be transferred, if 1 kg of refrigerant (NH3) circulates in the system. By the results of the design it can be learned, that in the model machine have a refrigeration capacity of 312 W caused by the heat input at the evaporator. In order to produce 312 W of cooling capacity by the model machine, 1 kg ammonia has to be circulate and 6,6 kg of strong working fluid has to be pumped from the low pressure section (absorber) to the high pressure part (generator) of the absorption machine. Only 5,5 kg of the weak solution returns via the working fluid control valve back to the absorber, due to the vaporizing of 1 kg ammonia in the generator. If 312 W of cooling capacity can be produced by the model absorption machine on the evaporator, the necessary heat energy input at the generator has to be 494 W. 362 W has to be rejected continuously at the condenser and at the absorber 443 W.

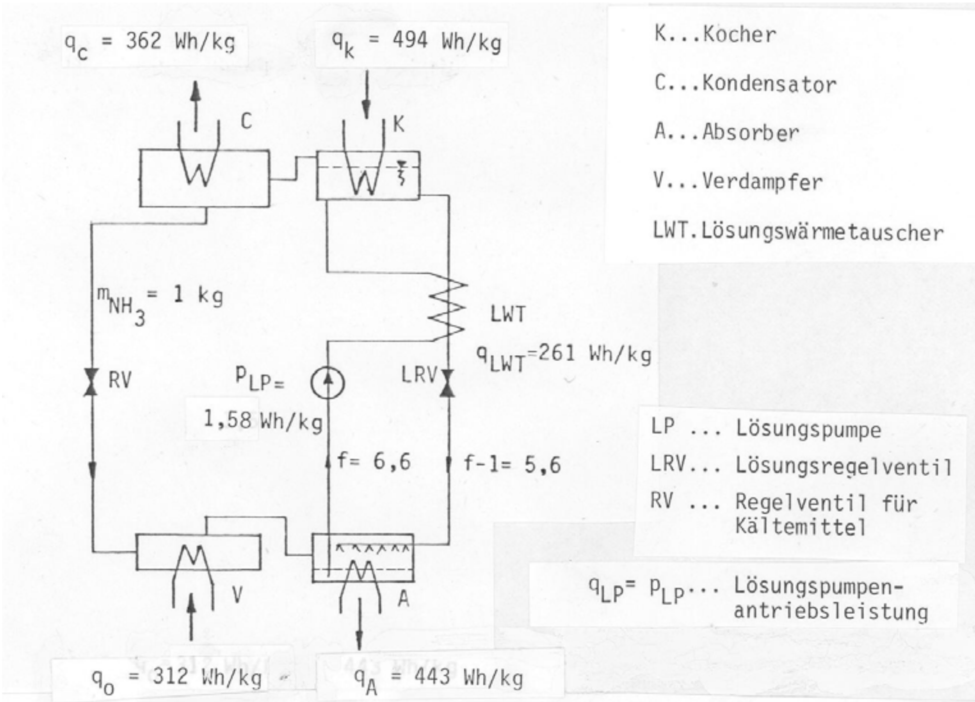

Figure 6.5: Continuously working absorption refrigeration unit, model process /4/
K ... Generator (expeller), C ... condenser, A ... absorber, V ... evaporator, LWT ... working fluid HEX, LP ... working fluid pump, LRV ... working fluid control valve, p_{LP} ... power of the working fluid pump.

6.2.3.2.4 Technical design of an absorption refrigeration machine with 12 kW

After the design process of the absorption model machine it is very easy to make the technical design of the real absorption cooling machine for any cooling capacity. For this technical design a cooling capacity of 12 kW was determined.

Table 6.3: Technical data of a 12 kW absorption cooling machine (evaporation at 3 °C)

Subject	abbreviation		unit
Generator	Q_K	19,46	kW
Evaporator	Q_E	12	kW
Absorber	Q_A	17,14	kW
Working fluid heat exchanger	Q_{LWT}	10,6	kW
Condensor	Q_C	14,37	kW
Working fluid pump	P	0,058	kW
Specific working fluid circulation	f	6,6	kg/kg
Hourly working fluid circulation	M_{WF}	255	kg/h
Hourly working fluid volume	V_{WF}	326	litre
Electric power for the working fluid pump	P_{el}	0,116	kW

Subject	abbreviation		unit
Hourly mass flow of refrigerant	M_{ref}	38,7	kg
Generator pressure	P_G	12	bar
Absorber pressure	P_A	5	bar
Concentration difference of the working fluid	$\Delta\xi$	8	%
Concentration of the weak working fluid	ξ_w	46	%
Concentration of the stronf working fluid	ξ_{st}	54	%
Heat ratio (coefficient of performance)	COP	0,61	--

For this step of the technical design all the data of the model machine have to be linearely enlarged. The factor is 38,5 (12.000 devided by 312). The most important technical data of the real absorption machine can be now defined.

6.2.3.2.5 Technical design of the condenser of the absorption cooling machine

The condenser should be designed in detail to be ready for construction as an example of the technical design of the main components of the absorption cooling machine. The temperature vs. heat-diagram in figure 6 shows that the input temperature of the cooling water of the condenser is 27 °C and it leaves the condensor with 30 °C. The ammonia vapor enters the condensor with 65 °C, is cooled down to about 32 °C to the condensing point and condenses at constant temperature. After condensing the condensate is cooled down by the cooling water to 29 °C.

With the aid of the technical data in the Table 6.3 and with the technical features which are defined in Table 6.4, the technical design of the condenser can be finished and the drawing for the condenser construction can be executed. The figure 6.7 displays a possible design of a laying tube heat exchanger which can be used as a condenser in the absorption refrigeration machine.

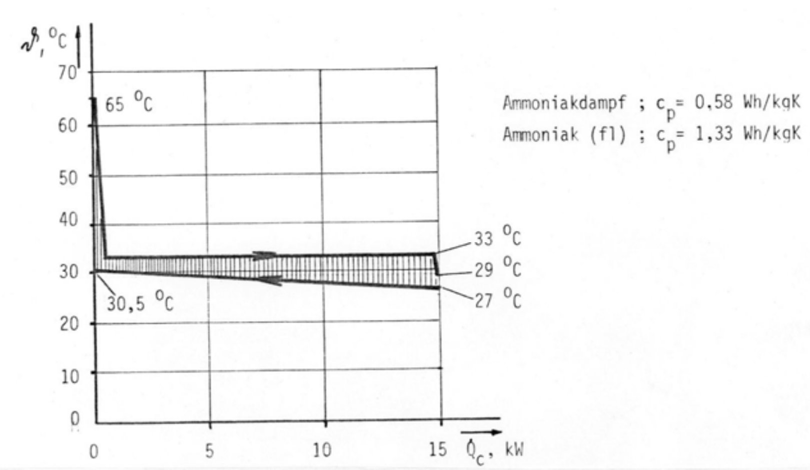

Figure 6.6: Temperature-heat diagram of the condensor /4/

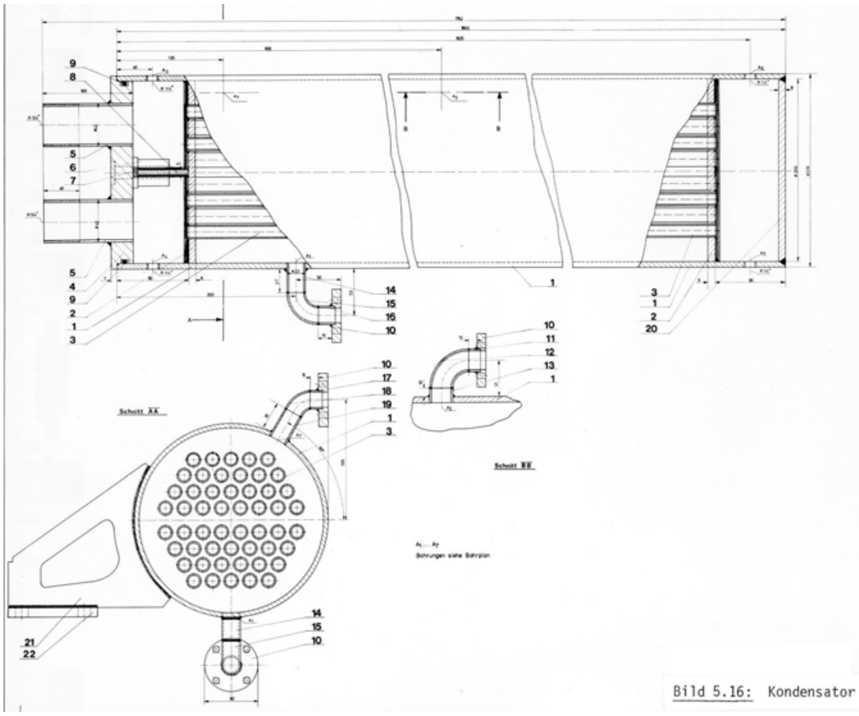

Figure 6.7: Drawing of the condenser with the aid of the technical design data in Table 6.3 /4/

The technical characteristics of the condensor are displayed in Table 6.4.

Table 6.4: Technical data for heat transfer in the condensor

Heat exchanger capacity 15 kW at the design point			
1. Primary side of the process, medium: ammonia			
Ammonia mass flow per hour	Mc	38,7	kg/h
Input temperature	ϑ 11	65	°C
Output temperature	ϑ 12	29	°C
pressure	P1	12	bar
Heat transmission coefficient	α1	10.798	W/m$_2$ K
2. Secondary side, medium water			
ass flow per hour	MKW	3700	Kg/h
Input temperature	ϑ21	27	°C
Output temperature	ϑ22	30,5	°C
Pressure difference	Δp	0,1	bar
Pressure	p	0,7	bar
Heat transmission coefficient	α2	2.751	W/m$_2$ K
3. Implementation of the condenser			
Jacket tube (outside)	D x s	∅ 219x4,2	mm

Heat exchanger tube	D x s	∅ 16x2	mm
Heat transition coefficient	k	1.517	W/m2 K
Middle temperature difference	$\Delta\vartheta$	3,99	°C
Heat transfer area (theoretical)	Ath	2,48	m2
Number of tubes	Z	76	--
Tube length	L	1.500	mm
Heat transfer area (practical)	Aeff	3,9	m2
Security	ν	1,5	--
Mass	M	120	kg

6.2.3.2.6 Absorption cooling plant powered by woody residues

The absorption cooling machine (ACM) uses ammonia-water mixture as the working fluid (WF). The thermodynamic properties for the ammonia-water mixture are well explained, for example as in [1]. The good attribute of the working fluid based on the ammonia-water mixture is possibility of the multi-purpose application ranging from air conditioning to deep freezing. Depending on the temperature of the heated water produced in biomass boiler, one can apply ACM for air conditioning, cooling at -10^{0}C (temperature from biomass boiler should be amounted to 90^{0}C) and deep-freezing at -34^{0}C (temperature from biomass boiler should be amounted to 120^{0}C).

Many industrial and commercial sectors have a need for cooling . The common vapor compression technique uses the remarkable amount of electricity from power plants and contributes to pollution. Because of that, the biomass boiler driven ACM could be a good opportunity and a new mechanism for cooling needs taking into account all advantages of renewable energy sources.

Despite of the fact that the ACM - technology is well known, their influence on the market is not developed. Some of the reasons are high costs and large weight of components, and low level of knowledge of end-users. Technologies for biomass-fired heating plants are well established. Applications depend on matching biomass supply to heat demand. Biomass for fuel can be gathered from forestry and municipal tree management as wood chips, straw as agriculture residues and miscanthus as a special plantation. Also energy crops are used at present partly.

6.3 Industrial application of an absorption-cooling system driven by woody residues

6.3.1 Possible application

In the northeast part of Bosnia and Herzegovina, there is a factory for fruit and vegetable processing plant. For own needs this factory uses a cooler of 300 kW. In the neighboring of this factory there are several sawmills which can provide about 1.000 tons of wood-derived fuel per year. That includes, forestry materials, sawmill co-product, and straw. This is equivalent to about 450 kW of heat (assuming 85% total efficiency). This is a sufficient resource to initiate a biomass usage for the own needs. It is very important that sufficient fuel can be sourced within a 30-km radius of this factory, which will keep transport distances to a minimum.

6.3.2 Rough economical assessments

The factory's cooler consumes electric power for about 100.000 Euro/a for its operation. The investment cost of ACM accounted to 615.000 euros for refrigeration capacity of 300 kW. The investment cost of a biomass boiler with a capacity of 300 kW(th) for annual heat production about 2.500.000 kWh is amounted to 50.000 Euro. The total capital cost of ACS based on wood- residues as biomass is therefore estimated to reach 665.000 Euro. This investment capital is provided by a credit from the bank. We can calculate the annual repayment of credit by means of the time value of money method, taking into account the 6% of interest rate over 20 years. This results into an annual repayment of 55.000 Euro. The price of wood-derived fuel is amounted to 25 Euro/ton (including transport). The biomass fuel cost is amounted to 25.000 Euro/ a.

Therefore, the total operating cost per year for considered ACS is amounted to 80.000 Euro. This is lesser than the total annual running cost only for the current conventional cooling system based on vapor compression technique. Before a realisation of this project idea a detailled economic calculation has to be done. Investment costs and operational costs of the two different plants have to be compared.

The principal scheme of ACS driven by heat from woody residues is presented in Figure 8.

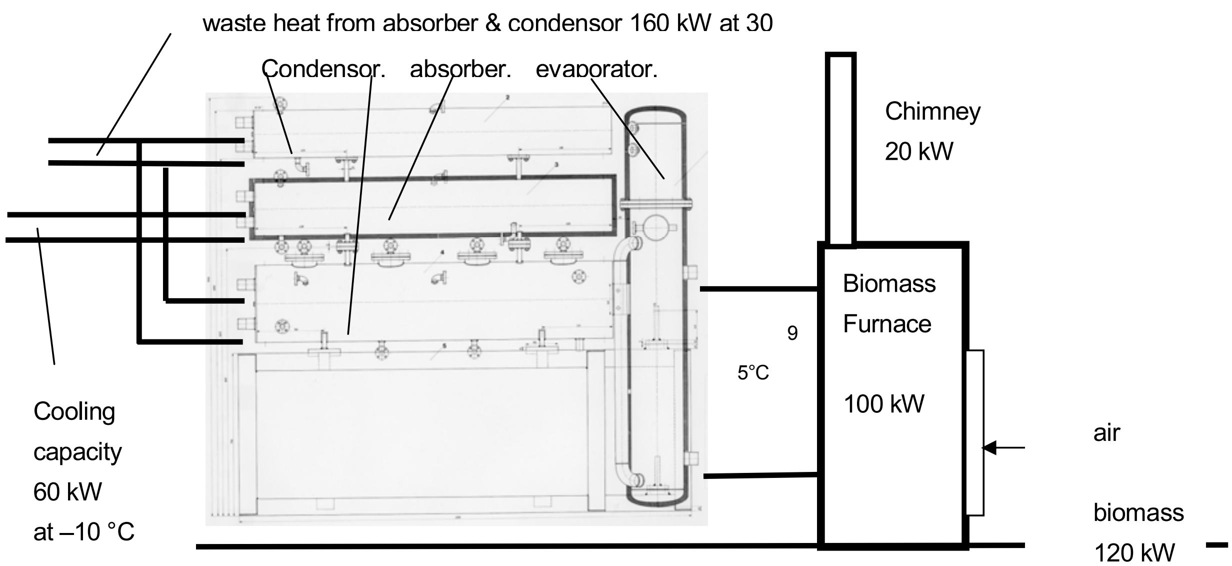

Figure 8: Absorption cooling machine driven by heat from woody residues (priciple sketch)

6.4 Conclusion

At present time, in creation of refrigeration systems due to danger of climate fluctuation there begin to dominate the following tendencies:

- Preferable using of refrigerants with low global warming potential. To them there are related hydrocarbons, ammonia, nitrogen, carbon dioxide and water
- Advancing of technological procedures of servicing of the refrigeration systems,
- Reduction of refrigerant emission out of the refrigeration systems,
- Decreasing of the amount of the refrigerant charged into the system,
- Increasing of requirements to the quality of assembling of refrigeration machines and facilities,
- Improvement of the operating refrigeration machines with the aim of increasing of their energy effectiveness and development of new refrigeration machines.
- Replacement of electrical driven cooling systems by RES driven absorption cooling techniques with refrigerants like ammonia or water.

There is very limited knowledge of absorption technique in the refrigeration community anymore. Engineers have to be cognizant of the state-of-the-art of absorption technology, and there are only a few people in the world who are able to practice that knowledge.

In Bosnia and Herzegovina there are enough recources of wood residues, therefore it makes sense to develop and apply the presented techniques. However, due to fluctuations of oil and gas prices, environmental challenges, social reasons, keeping of the present fosil fuel based resources, the presented approach to solve cooling (and heating) needs is very acceptable.

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7 Low enthalpy geothermal ORC power generation the case of Milos island, Greece

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7.1 Abstract

Low enthalpy geothermal power generation is important to short term sustainable development by direct exploitation of the heat of subsurface water bearing formations, as well as to long term large scale geothermal energy use by exploiting the heat of hot dry rock systems. The corresponding technology includes exclusively engines operating with an organic substance (ORC) or ammonia, in contrast with the ones of high enthalpy which mainly include plants operating with a water vapour cycle (H_2O). Power generation technology with organic or ammonia cycle has been established in the geothermal industry as the most cost effective for geothermal fluids 100-150 ºC. Today, several such units are installed in geothermal fields in Europe and the globe, operating with geothermal fluids of temperature from ~90 ºC and higher. As a proven technology, further technology development and new applications are foreseen. In Europe, geothermal resources of 90-150ºC available at permeable formations within major sedimentary basins at depths 1-3 km can sustain 5.900 MW_e of Rankine geothermal power plants. This article presents the case of an ORC power generation system utilizing low enthalpy geothermal energy on Milos island, Greece.

7.2 Background

Milos island is located in the Aegean Volcanic Arc (Figure 7.1) and is characterized by abundant geothermal resources of high temperature (Figure 7.2). Early geothermal exploration undertaken by the Institute of Geological and Mining Research of Greece, summarized in Fytikas 1977, includes temperature measurements in shallow wells drilled for this purpose and Schlumberger resistivity measurements of subsurface rocks. The results, which are shown on Figure 7.2 , indicate that the eastern part of the island and especially the plain of Zefyria is the region with the highest temperature gradients and lowest apparent resistivities, hence the parts of the island most promising for high enthalpy geothermal potential. Later drilling exploration undertaken by the Public Power Co (PPC) of Greece, summarized in Mendrinos (1988), identified geothermal fluids of temperature 300-323 ºC at depths 800-1400 m below sea level in Zefyria plain By examining Figure 7.2, we conclude that the region of the island most promising for exploitation of shallow, low enthalpy (<100 ºC) geothermal resources, is the one where deep fluids are present in shallow aquifers, namely the east half of the island.

Mendrinos (1988) performed evaluation of exploration data, well test analysis, resource assessment and computer simulation of the Milos geothermal system and indicated that the deep geothermal fluids correspond to boiled seawater of 80.000 ppm salinity. Mendrinos (1988) also calculated that by cooling the upper 2 km of the hot rocks below Zefyria,

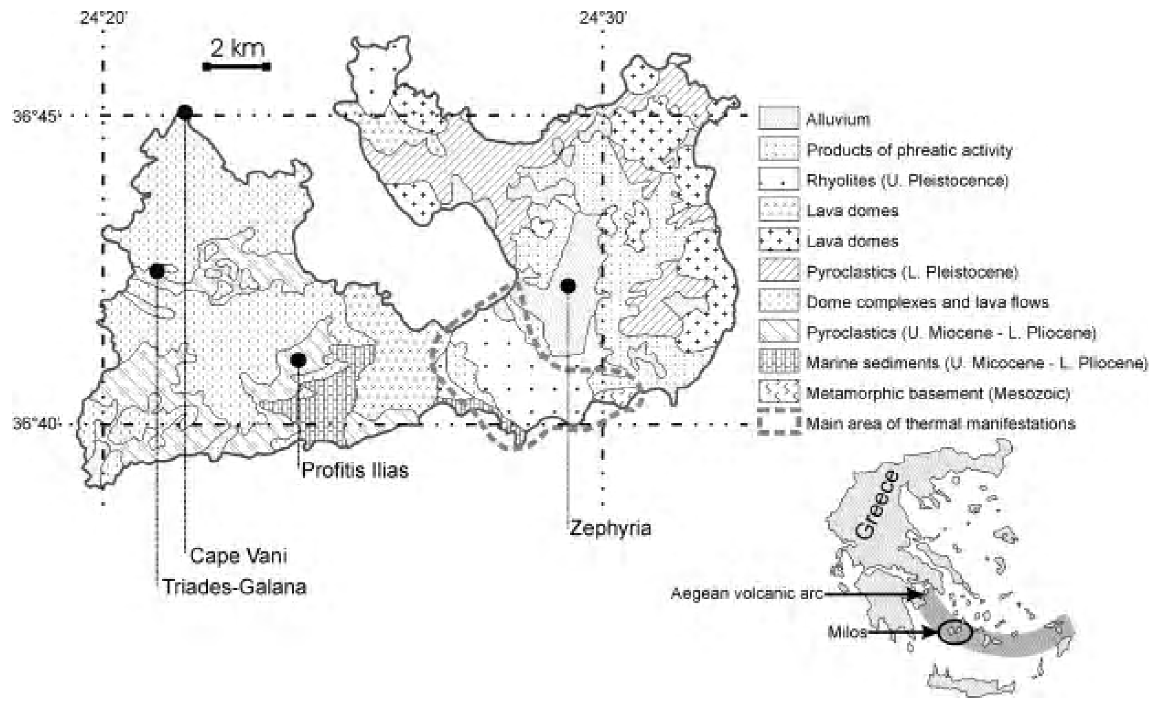

Figure 7.1: Milos geological map and location of Milos Isl. on Aegean Volcanic Arc

Vounalia and Adamas by 90 ºC would release $5*10^{18}$ J of heat (or 141 million TOE), which justifies the commissioning of 260 MWe geothermal power plant. In parallel, showed that the minimum heat flow from deeper rocks cannot be less than 87,8 MWth. This value is slightly higher than the natural conductive heat flow towards the surface of the island, which has been estimated as 77 MWth (Mendrinos 1991) due to the convective heat flow component.

The figure of 87,8 MWth was based on small amount of natural convection through the geothermal system, due to the low permeability measured in the deep geothermal wells. Recent drilling in Vounalia however showed very high permeability and seawater infiltration to shallow rocks. This indicates that heat flow from deeper layers should be considerably higher.

7.3 The Low Enthalpy Geothermal Energy utilization project for electricity generation

The main objective of our ongoing project is to construct and operate a low enthalpy geothermal energy driven ORC power generator unit of installed capacity of 470 kWe on Milos island. The only source of energy is geothermal heat and the unit is anticipated to be entirely self sufficient in thermal energy. Local community will benefit from the production of electricity from the utilization of a sustainable and environmentally friendly energy source, which is low enthalpy geothermal energy. The project will use geothermal water from the Vounalia concession of the Municipality Development Company (D.E.A.M.) (Figures 7.1, 7.2 and 7.3) based on the flow chart shown on Figures 7.4 and 7.5.

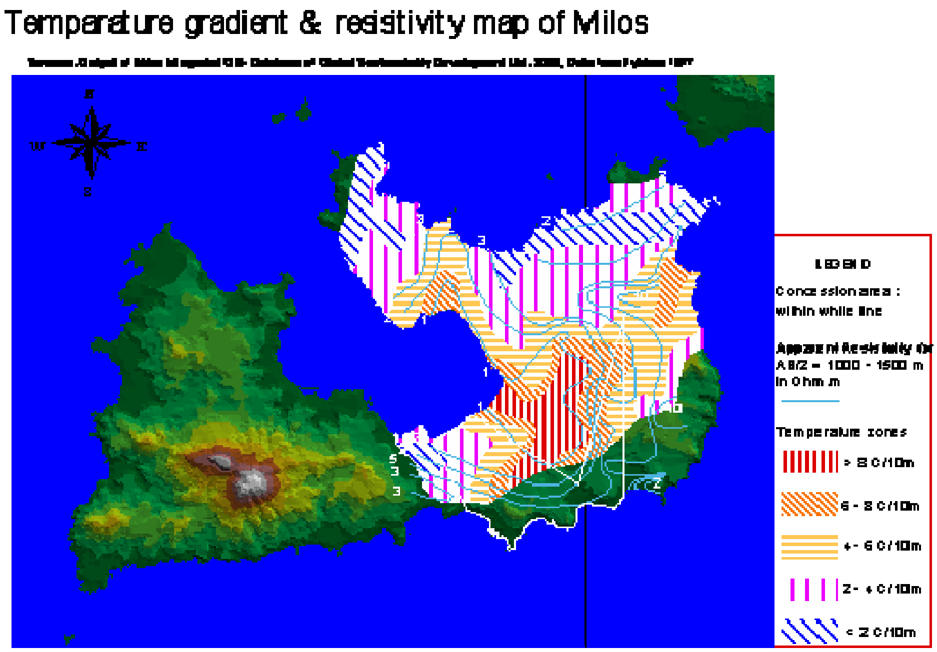

Figure 7.2: Temperature gradient and resistivity map of Milos.

7.4 Technology presentation

When the geothermal fluid has temperature less than 150ºC, the technology used, exclusively corresponds to Rankine cycle units (binary). In these units, the geothermal fluid transmits its thermal energy to a closed loop of circulating fluid through a heat exchanger. The circulating fluid, or working fluid, may either be an organic substance, usually a hydrocarbon (isobutane or isopentane) or fluoro-hydrocarbon and the process is termed as Organic Rankine Cycle (ORC), or ammonia with the corresponding process termed as KALINA Cycle. As the boiling point of the circulating fluid corresponds to low temperature, it evaporates within the above mentioned heat exchanger. Then, its vapour is conveyed in a turbine for power generation. Next, the circulating fluid condenses within a second heat exchanger, which can either be water cooled (cooled by surface water or by water from a cooling tower), or air cooled.

Thereon, the liquefied circulating fluid is pumped to the geothermal heat exchanger and the cycle goes on. The whole process of a geothermal power plant with Rankine cycle is presented on Figure 7.4.

The function steps of the generator, as shown on Figure 7.4, are:

- The turbo-generator uses the geothermal water to pre-heat (2→3) and evaporate (3→4) the working fluid
- After separation the organic fluid vapor powers the turbine (4→5). The separated liquid fraction is re-circulated
- The vapour is condensed (5→6→1)
- The working fluid is finally pumped back completing the closed-loop circuit (1→2)

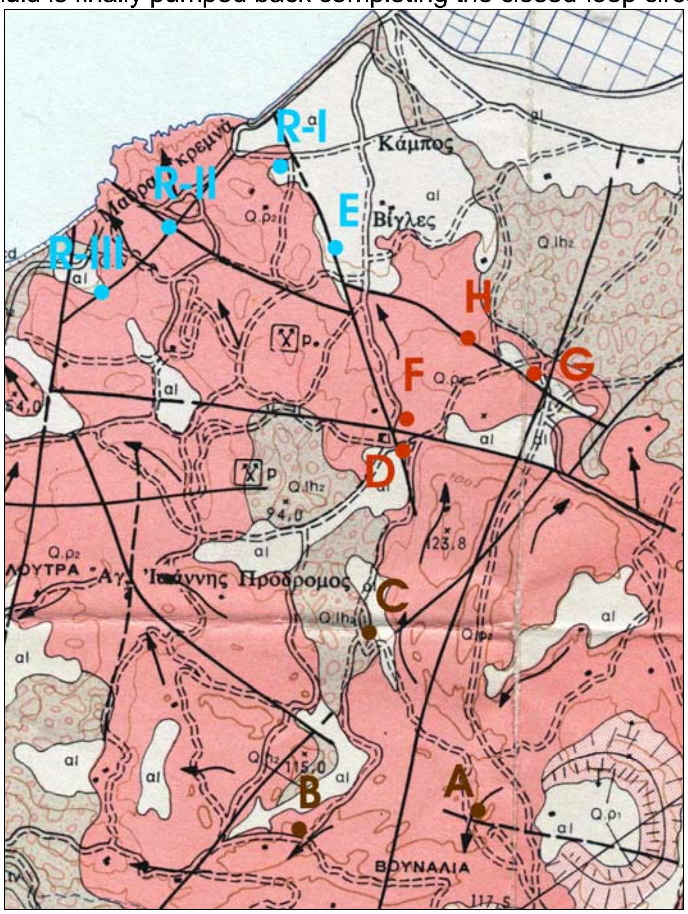

Figure 7.3: Geology and location of geothermal wells in Vounalia, Milos isl.; a proposed reinjection well R-III is also included. Wells A, B and C are in high elevation, have low permeability and high temperature: their utilisation is rather expensive. Wells D, F, G and H are in medium elevation, have high permeability and flow rate: they are best suited for production. Wells E, R-I, R-II and R-III are in low elevation

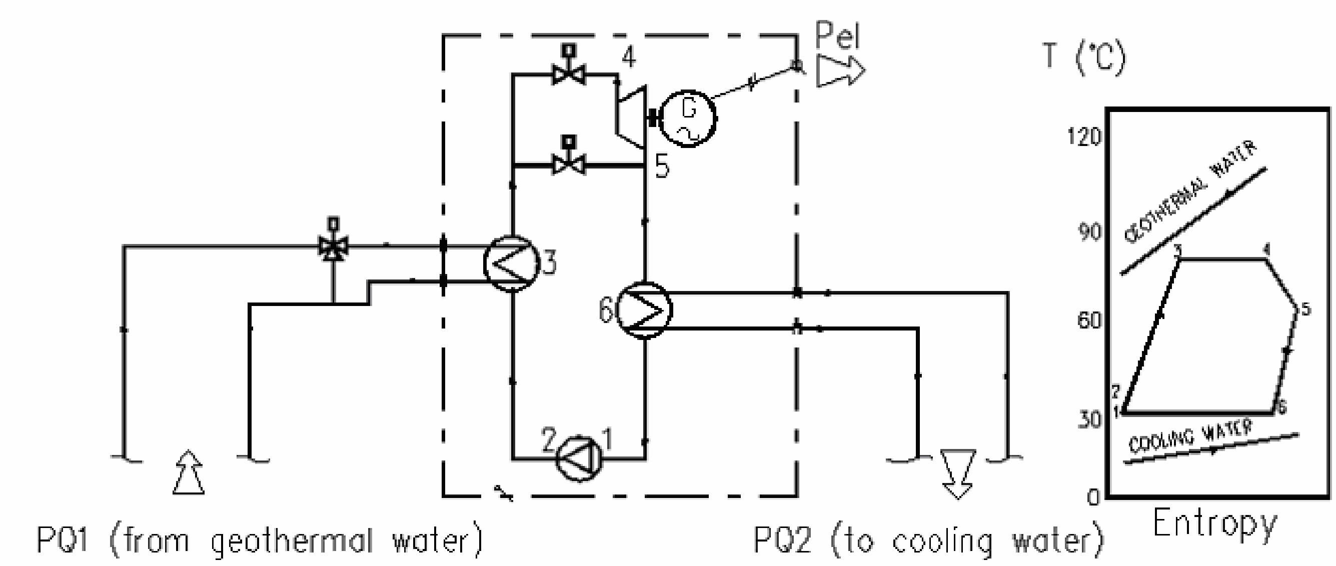

Figure 7.4: Connections of the ORC-unit to the geothermal water and cooling water source circuits and thermodynamic cycle

By selecting the right circulating fluid, geothermal binary plants are designed for cost effective operation with entering geothermal fluid temperature of 90°C and higher. Due to the relatively low geothermal temperature, binary plants tend to have higher capital cost per unit of installed power, compared with traditional condensing geothermal power plants; in many cases however, they are the best, if not the only, option for the exploitation of a geothermal resource.

Rankine cycle geothermal power generation plants usually use as a heat source fluids between 90 and 180ºC. They have a high degree of computer automation, including automated start-up. They can operate 100% of the time without any supervision, with tele-monitoring and control through telephone or satellite, or they can be operated by part time semi-skilled personnel. They can cover both base or peek load, as well as fluctuating load, including load between 0 and 25% of installed power. Conversion efficiency from thermal energy to electricity of binary plants depends on the geothermal fluids temperature and on the load. Conversion efficiency varies from 6,5% for geothermal fluids of 90ºC, to 12% for 120ºC geothermal fluid and to 15% for 150ºC.

In the next years, we expect technology development, in terms of conversion efficiency improvement, as well as in terms of minimum entering temperature of the geothermal fluid. It must also be mentioned that, future exploitation of hot dry rock heat for power generation will use exclusively Rankine units, as the temperature of the fluids produced by such systems will be 120-150 ºC for 3-5 km depths and normal geothermal gradient.

7.4.1 Energy costs

Overall geothermal power generation costs by Rankine units amount at 3,7 to 7,7 Eurocents per kWh_e (2004) on average, with an average value of around 5,3 Eurocents per kWh_e. These costs include the present value of capital costs discounted during the life time of the unit

(20 years period and 5% discount rate). The corresponding capital costs amount at 900-1500 Euro/kW_e installed for large binary plants (1-5 MW_e) and up to 1800 Euro/kW_e installed for smaller units (400-500 kW_e installed)..

7.5 The Geothermal ORC-power generation plant of Milos island

The geothermal power plant of the project will comprise the following components (based on CRES's engineering study please also refer to the plant flow chart on Figures 7.5 and 7.6):

- Geothermal production wells: Production will be derived from the wells located closer to the sea, due to their high energy yield and the corresponding hot water transmission costs.
- Wells F, D, G and H will produce 300 m^3/h of geothermal water 55-99ºC. Wells A and C will not be used due to their low energy output, their distance from the sea and their

elevation, factors that raise considerably the capital costs and electricity needed for the production and transport of the geothermal water (see also Table 7.1).

- Geothermal submersible pumps and inverters installed at the production wells.
- Piping network conveying the geothermal water to the main Plant. Buried steel or fiberglass
- piping will be used. Closed, pressurized at 10 bars maximum.
- Power and data transmission lines from the main Plant to the wells.
- ORC unit, transforming approximately 7% of geothermal energy to electricity designed to generate approximately 470 kWe.
- Main heat exchanger, transferring the energy from the hot geothermal water exiting the ORC unit.
- Reinjection wells (RE I and II) located at the margin of the geothermal field, close to the coast, downstream and at lower elevation of the main Plant, in order to minimize water transmission costs and avoid disturbing the hot part of the geothermal aquifer, well E will also operate as a reinjection well, due to its low well-head temperature (only 55 ^oC).
- Geothermal water transmission lines from the main heat exchanger to the reinjection wells: buried steel or fiberglass piping, closed pressurized system at 10 bars maximum, no extra pumping.
- Seawater transmission lines conveying 200-575 m^3/h cooling water for the ORC unit: Buried polyethylene piping, seawater intake and disposal from a trench close to the sea line, pumping station close to the intake point.
- Power substation for power provision or delivery to the local power net: 500 kWe.
- Main computer monitoring and control system for real time data logging and automation control.

Until now drilling of production and re-injection wells has been completed. Construction works for the ORC power plant (plus sea-water networks) are expected to commence shortly.

Table 7.1: Summary of geothermal well data in Vounalia, Milos.

Well	Well bottom m	Casing shoe m	Water Level, m	maximum Flow Rate m^3/h	water production Temperature ^oC	Thermal Power MWth (T_{base}=25^oC)
A	150	149	74	20	98	1,70
B	71	67	–	0	–	0,00
C	184	183	86	25	84	1,71
D	158	152	65	100	85	6,97
E	125	122	19	125	55	4,35
F	89	82	54	100	97	8,36

G*	85	82,5	57	100	99	8,59
H*	106	86	35	75	85	5,25
R-I*	102	98	18	85	60	3,45
R-II*	63	61	24	125	50	3,63
R-III*, **	100**	98*	20**	125**		

Performance characteristics of the Milos ORC-plant are presented on the following Table 2.

Table 7.2: Performance characteristics of the Milos ORC-plant

Thermal power input from geothermal water	6.5 MWth
Geothermal water inlet temperature	93 °C
Geothermal water outlet temperature	72 °C
Geothermal water flow rate	270 m3/h
Fouling heat transfer coefficient (geothermal water side)	5700 W/(m2K)
Pressure loss in the evaporator + pre-heater (geothermal water side)	< 1.2 bar
Cooling water inlet temperature	25 °C
Cooling water outlet temperature	35 °C
Cooling water flow rate (about)	150 kg/s
Fouling heat transfer coefficient (cooling water side)	5700 W/(m^2K)
Pressure loss in the condenser (cooling water side)	< 0.8 bar
Net electric power output *	470 kW_{el}

7.6 Conclusions

Organic Rankine Cycle (ORC) geothermal power generation cycle, is a proven technology, internationally accepted as the only cost effective and reliable power conversion technology from geothermal fluids of temperature less than 150ºC, and at the same time it can compete successfully with other geothermal power generation technologies (condensing plants) at higher temperatures. These have become evident from the many Rankine cycle geothermal power plants installed in different parts of the globe.

In this project we have examined aspects of installation of an autonomous ORC power production unit, on Milos island. The unit presents an installed capacity of 470 kW_{el} and it can partially cover the electricity needs of the island. The total electricity production of the above mentioned unit is estimated at 3.911,4 MWh annually. The electricity production cost for the low enthalpy geothermal energy driven ORC plant is estimated at 4.5 cents of EURO per kWhe, with an initial investment cost in the order of 1.600.000 EUROs.

After the ORC electricity production stage the geothermal fluid, exiting at 72^{o}C, can provide further thermal energy for other applications such as Multiple Effect Distillation (M.E.D.), district heating and/or cooling, greenhouse heating, fish-farming etc. The possible total exploitable installed capacity of the entire cascade geothermal utilization scheme is estimated to be 40 MWth (when a geothermal re-injection temperature of 25°C is considered) and with a load factor of 40%, leading a total energy substitution of 15.000 Tonnes Oil Equivalent annually.

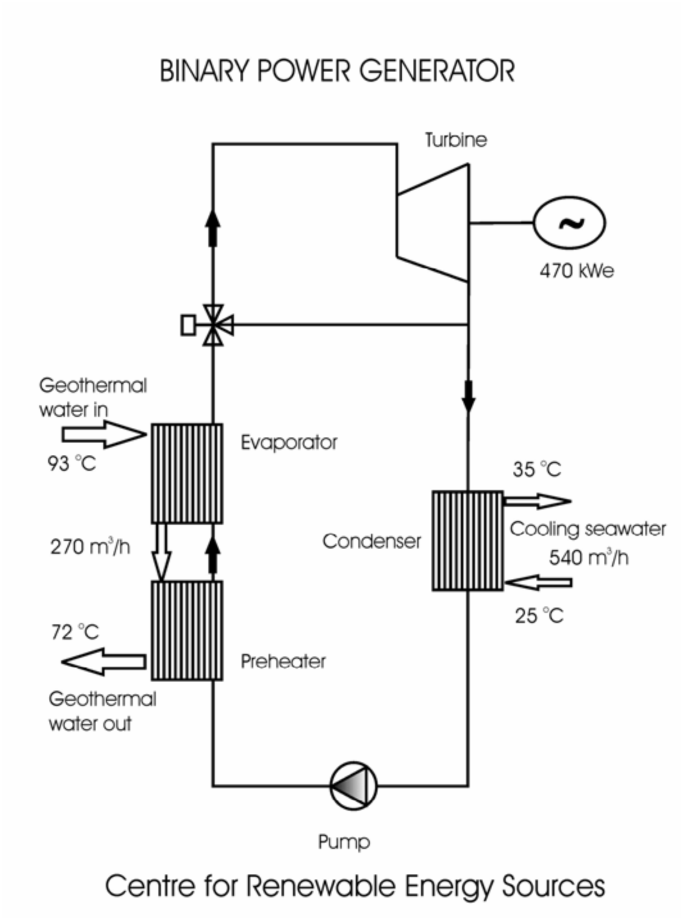

Figure 7.5: Schematic presentation of the Milos geothermal ORC-power generation plant

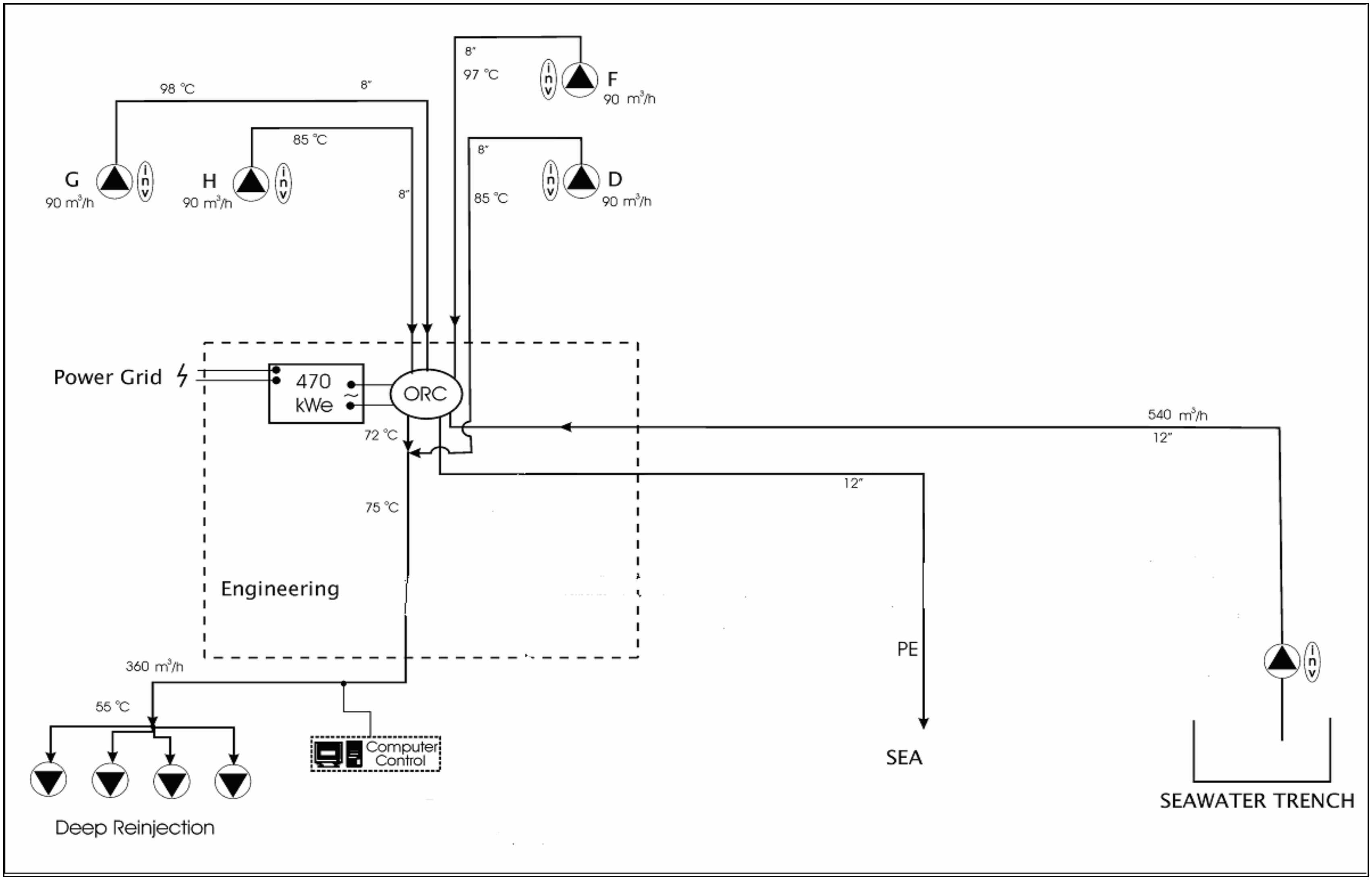

Figure 7.6: Flow Chart of the MILOS geothermal ORC plant

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