ENERGY AND ENVIRONMENTAL PERFORMANCE OF A POLYGENERATION PLANT FROM VINEYARD PRUNING RESIDUES

F. Cotana, G. Cavalaglio, S. Rinaldi
Biomass Research Centre – University of Perugia
Via G. Duranti, 06125 Perugia, Italy
Tel: +39.075.505.3806 Fax: +39.075.515.3321
Email: cotana@crbnet.it; cavalaglio@crbnet.it; rinaldi@crbnet.it

ABSTRACT: The pilot plant for the energy production from vineyard pruning residues (ERAASPV project), started in September 2008, consists of an harvesting and chipping machine, a chips stocking site, a chip transportation system and an energy conversion and distribution system, formed of a diathermic oil boiler, a section for exhausted gases treatment, an hydraulic distribution system, an heat exchanger, and an absorption chiller. The following paper analyses and monitors in particular the energy conversion process and the environmental efficiency of the bioenergy chain. We have monitored first working year of the biomass boiler and absorption chillers, evaluating performances and solving management problems, which have reduced working hours of the system. Moreover we have estimated the energy and environmental performances of the plant, through a parameter indicating the renewable level of the chain. Finally we have started to design an integration of the biomass plant, for electricity production by Organic Rankine Cycle system.
Keywords: agricultural residues, conversion systems, energy balance, environmental impact, pilot plant.

1 INTRODUCTION

Biomass complies with 15% of primary energy needs in the world, approximately 55 millions TJ per year (1.230 mtoe/year). In the European Union 4% of energy needs is provided by biomass, equivalent to 69 mtoe in 2003, which 59 mtoe from agroforestal resources, 3 mtoe from zootechnical wastes and 2 mtoe from energy crops. The European Commission has established the objective of increasing biomass contributes, 188 mtoe by 2010 and 227 mtoe by 2020. [1-2]

In Italy biomass whole consumption, shown in table I, is 5,6 mtoe in 2005 (2,8% of the primary energy needs); moreover 1,8 mtoe are used in wood heating houses. Focusing on electricity sector, bioenergy represents 2,2% of total needs, according to the typologies in table II; main production plants use agroforestal biomass or biogas in anaerobic digestion plants.

Table III shows power plants fed by wood biomass and gross electricity production (biomass consumption in 2004 has been 3 million of tons, equivalent to 1 mtoe).

Table I: Biomass consumption in Italy (mtoe) [3]

Biomass Sources	2001	2002	2003	2004	2005
Wastes	721	818	1.038	1.305	1.501
Wood	2.475	2.482	2.929	3.478	3.558
Biofuels	146	189	255	280	172
Biogas	196	270	296	335	343
Total	**3.538**	**3.759**	**4.518**	**5.398**	**5.574**

Table II: Gross biomass energy production in Italy (GWh) [4]

Biomass Sources	2004	2005	2006	2007
MSW*	2.277	2.620	2.917	3.025
Crops/residues	2.190	2.337	2.492	2.481
Biogas dump	1.038	1.052	1.177	1.247
Biogas sludge	1	3	3	9
Biogas dung	18	26	48	53
Biogas crops	112	117	111	138
Total	**5.636**	**6.155**	**6.748**	**6.953**

Table III: Agroforestal biomass power plants [5]

Characteristics	2004	2005
Number of plants	41	43
Gross power (MWe)	413	389
Gross production (GWhe)	2.190	2.337
Working hours	5.300	6.000

Table IV: Biogas power plants [5]

Characteristics	2004	2005
Number of plants	21	23
Gross power (MWe)	35	42
Gross production (GWhe)	131	143
Working hours	3.700	3.400

Table V: Thermal plants picture in Italy

Plant size	Small	Medium	Large
Number of plants	6.000.000	1.500	100
Power (MW)	30.000	3.000	378,5
Primary energy (mtoe/y)	3,30	1,1	0,04
Efficiency (%)	35	70	75
Useful energy (mtoe/y)	1,16	0,75	0,03

Table IV describes biogas power plants in Italy. In 2005 the installed power was 42 MW, with 143 GWh/year electricity production. [5]

Biomass use for heat production is summarized in table V. Primary energy is 4,4 mtoe, equivalent to 60% of National biomass consumption.

Biofuels sector is completely covered with biodiesel, 200.000 tons produced in 2005.

Agroenergy chain project ERAASPV (renewable energy for farms deriving from vineyards pruning residues) has been financed by Italian Ministry of Agriculture and Forestry in order to develop bioenergy chains for farms starting from biomasse residues.

The project, started in 2005 and concluded in 2008, was developed by the Biomass Research Center (CRB) and realized near “Cantine Giorgio Lungarotti”, a wine company in Umbria (Italy) which owns about 250 hectares of vineyards. The bioenergy chain designed and realized consists of pruning harvesting (round-baling), bales transport, storage and drying, bales chipping, chips storage and biomass energy conversion in the boiler. The different chain stages were discussed during previous articles. [6-9]

This paper focuses on biomass plant first working year, describing the system, main results (energy production, working hours, ashes, savings), analyzing problems and solutions and evaluating the energy and environmental efficiency.

2 BIOMASS POWER PLANT DESCRIPTION

Biomass thermal plant consists of the following sections:

- chips storage system with 60 m^3 capacity;
- chips transport system from silos to boiler which consists of moving rack at the bottom of the silos, conveyer belts and screws until the boiler;
- moving grate heater;
- 400 kW useful thermal power heater; the boiler produces diathermic oil at a maximum temperature of 300°C;
- absorption chiller (Robur model GA ACF 60-00 LB Power Fluid – 19 kW) for production of cool water until -10°C;
- heat exchangers oil-water and oil-steam for farm requirements;
- exhaust gas cleaning and ejection which consists of a cyclone dust collector, gas extractor fan and a chimney 9 meters tall;
- diathermic oil pipeline system for fluid distribution to the thermal and refrigerating users.

Biomass energy conversion allows energy production in four different shapes, using diathermic oil:

- heat, by a heat exchanger oil-water, for rooms heating and for hot water;
- cool water up to -10°C, by an absorption chiller fed with diathermic oil, for the vinification process;
- cool water up to 7°C, by an absorption chiller fed by diathermic oil, for summer conditioning of company rooms;
- steam production, by an heat exchanger oil-steam, for bottles sterilization process.

Biomass plant has been completed in summer 2008 and has started to work in September 2008. [7,9]

2.1 Diathermic oil absorption chiller

The largest energy needs in the wine company are required for silos conditioning in the vinification process; moreover the working temperature is up to -10°C. In order to satisfy this necessity, common in all wine farms, we have installed an absorption chiller machine (Robur ACF60 Power Fluid), actually a prototype, which uses diathermic oil (280°C) as warm fluid instead of an oil burner. The machine consists of:

- refrigerating circuit;
- heat exchanger oil-water ammonia;
- fan condenser;
- control and security system: water flowmeter, safety valve, by-pass valve between low and high pressure circuits, thermostat, antifreeze control system. [10]

Figure 1 shows the machine installed near the company; figure 2 shows cool power in function of diathermic oil and external air temperature; table VI describes technical characteristics of the chiller.

Figure 1: Diathermic oil absorption machine

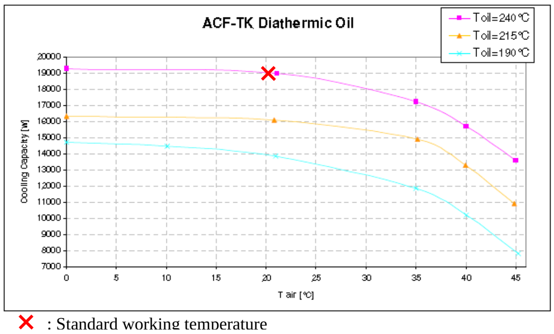

Figure 2: Cool power trend

Table VI: Chiller technical characteristics [10]

Characteristics	Quantity
Cool capacity (20°C)	19 kW
Input oil temperature	240°C
Oil capacity	3.500 l/h
Water ammonia input temperature	0°C
Water ammonia output temperature	-10°C
Water ammonia capacity	2.600 l/h
Electric power	840 W
Maximum pressure	3 bar
Size (H x L x l)	1290 x 1230 x 890 mm

3 FIRST WORKING PERIOD OF THE BIOMASS PLANT

During the first period the biomass plant has worked only for a limited number of hours, due to several problems occurred to some part of the system. However data regarding consumptions, savings and energy flows have been collected.

3.1 Operation problems

Main problems met during operation plant are the following:

1. obstruction in the side of the silo;
2. frequent cochlea clogging and one breaking;
3. clogging in the final part of chips feeding system;
4. diathermic oil pump cavitation.

The position of these failures is indicated in figure 3.

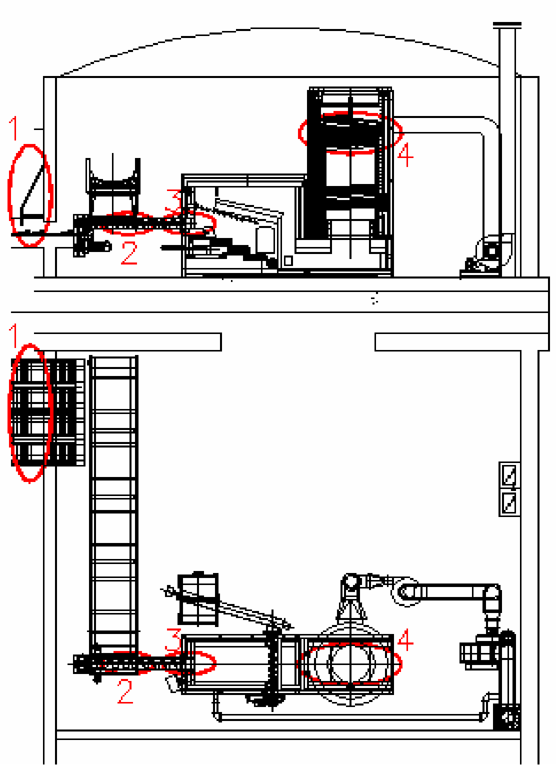

Figure 3: Problems occurred in the biomass plant

3.2 Solutions

The first problem occurred inside the silos: when the biomass moisture content is high (>30%), the last part of the silos, before biomass charging in the conveyer belt, create a "bridge" that block biomass charging in the boiler. The solution found is the enlargement of the charging hole to avoid the creation of the bridge. The second problem met was the frequent cochlea blocking, due to biomass size, that sometimes is more than 7-8 cm. This problem has been overcome adopting two different solutions:

- improving chips quality, using harder knives for biomass chipping in the mixer wagon;
- installing an automatic system that, in case of clogging, reverses the cochlea movement in order to unblock the system; if, after three reverses, the system is still unblocked, the boiler will stop.

These two solutions (in particular the second one) has reduced 99% machine stops.

The third problem depended on the biomass boiler characteristics that, during the starting stage, formed a plug at the combustion chamber entry, increasing the starting phase duration. The solution found is the cochlea enlargement that moves chips in a more internal zone of the chamber, avoiding the plug effect.

The last problem has been solved after several months of working. When diathermic oil reached a temperature of 170-180°C the pump had a cavitation and was impossible to increase the oil temperature. The cause was the presence of air in the oil pipes, which has been removed emptying and filling another time the oil circuit.

3.3 Results

The biofuel is obtained through bales chipping; a bale consists of pressed vineyard prunings and has an average weight of 120 Kg (10-20% moisture).

During the period September 2008-April 2009 the boiler has worked for 250 hours and has burned approximately 85 round bales equivalent to 10 biomass tons. Starting from net calorific value, 4,8 kWh/Kg measured in previous studies [6-7], we have evaluated primary energy produced, net energy obtained and fossil fuels savings; moreover, we have estimated ash production and its percentage. These results are shown in table VII.

Table VII: Biomass plant working results

Characteristics	Quantity
Working hours	250
Bales burned	85
Biomass consumption (tons)	10
Primary energy produced (MWh)	48
Useful energy produced (MWh)	25
Diesel saving (litres)	2.500
Ash (Kg)	200
Ash (%)	2%

These results are in proportion very close to previous estimations [8-9]; next year, without the working problems of the first period, we could reach savings estimated (28.000 l/y diesel and 5.000 l/y liquefied petroleum gas saved).

4 ENERGY-ENVIRONMENTAL ANALYSIS OF THE CHAIN

The aim of the energy-environmental analysis of the chain, from biomass harvesting to heat and cool utilization, is to evaluate two kinds of efficiency:

- energy chain efficiency: equivalent to the difference between energy available in the input biomass boiler and the energy consumption in the chain steps;
- environmental chain efficiency: equivalent to the renewable energy percentage of the process.

The first parameter could be improved only optimizing the logistic of the energy chain. The second one could be improved using biofuels or producing electricity with biomass plant.

In the calculation it's necessary to consider both primary energy obtained from one biomass ton (4.800 kWh), and the consumptions (in terms of fossil fuels and electricity used) per tons of biomass in the energy chain, showed in table VIII.

Table VIII: Energy chain consumptions

Typology of consumption	Fossil fuel use	Energy use
Diesel (harvesting stage)	5,74 l/t	57,4 kWh/t
Diesel (transport stage)	22,00 l/t	220,0 kWh/t
Diesel (chipping stage)	3,11 l/t	31,1 kWh/t
Electricity (conveyer belts)	5,77 kWe/t	14,42 kWh
Electricity (moving racks)	15 kWe/t	37,4 kWh
Electricity (cochlea)	2,5 kWe/t	6,25 kWh
Electricity (oil pump)	25 kWe/t	62,5 kWh
Total Consumption	**479,17 kWh**	

In order to compare electric and thermal consumptions, the electric one has been transformed in thermal, dividing the value with a corrective factor of 0.4, which is the average efficiency of Italian thermoelectric plants. Regarding electricity consumption, we have estimated a working period of:

- 2 hours for the moving racks (10 kW power);
- 1,5 hours for the conveyer belts (10 kW power);
- 2,5 hours for the cochlea (1 kW power);
- 6,25 hours for diathermic oil pump (4 kW power).

Total energy consumption (479,17 kWh/t) during the chain is approximately 10% of the energy obtained from the combustion of the biomass (4.800 kWh/t); the effective renewable energy is equivalent to 4.320 kWh/t.

The environmental efficiency is 90%, while the energy efficiency is 0.9.

The result is shown in the graphic of figure 4, which represents the energy part really renewable and the energy part obtained from fossil fuels.

If the diesel was substituted by biodiesel the environmental efficiency would increase to more than 96%.

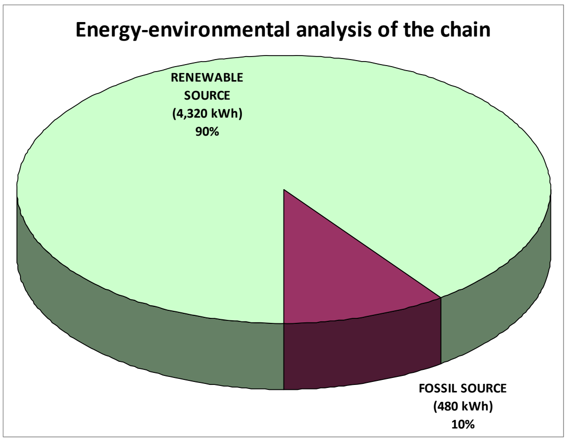

Figure 4: Energy-environmental analysis of the chain

5 INTEGRATION WITH ORC POWER SYSTEM

The actual biomass plant produces heat and cool energy for farm uses, but company energy requirement is only for maximum 2.000 hours per year. The plant could be used, for the other 5.000-6.000 hours, for the electricity production using diathermic oil in an Organic Rankine Cycle (ORC). This cycle uses the oil (250-300°C) to obtain the evaporation of another organic fluid which expands in a turbine linked to an alternator that produces electricity.

Biomass Research Centre is working at the designing and integration of this new plant with existing system. The difficulty is to find an ORC system with a size less then 100 kWe, with a primary energy request similar to that available (400 kW).

Technical systemcharacteristics of the chosen system are described in table IX; the 100 kWe size is slightly higher then necessary, but comparable with available primary energy.

Figure 5 shows a modeling of the ORC power plant, while figure 6 a plan of the system designed. [11].

The plant consists of the following sections:

- ORC machine made up of a turbine with gross power 125 kW and an alternator, complete with power board for electric net connection and switch board;
- Exchanger evaporator, with 450 kW thermal power;
- Condenser evaporator, 700 kW size, which decrease organic fluid temperature down to 29°C;
- Diathermic oil pipe system complete with pump and other equipments, connected with the existing plant;
- Control and supervision system.

Table IX: ORC system technical data [11]

Characteristics	Quantity
Primary energy (input)	732 kW
Electricity produced	125 kW
Net electricity produced	100 kW
Operative net electricity produced	50 kW
Gross efficiency	17%
Min diathermic oil temperature	121°C
Max diathermic oil temperature	250°C
Voltage	400 V
Frequency	50 Hz

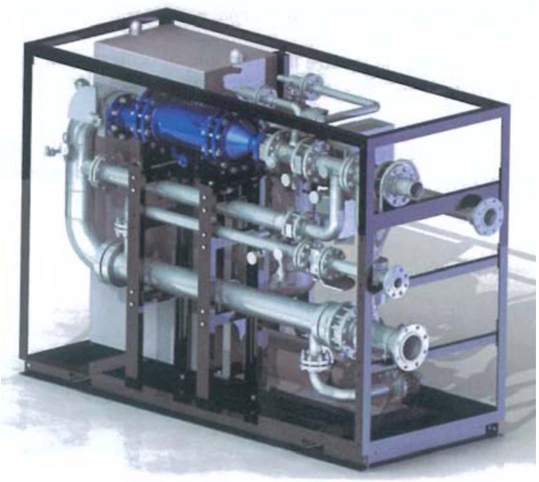

Figure 5: ORC system modeling

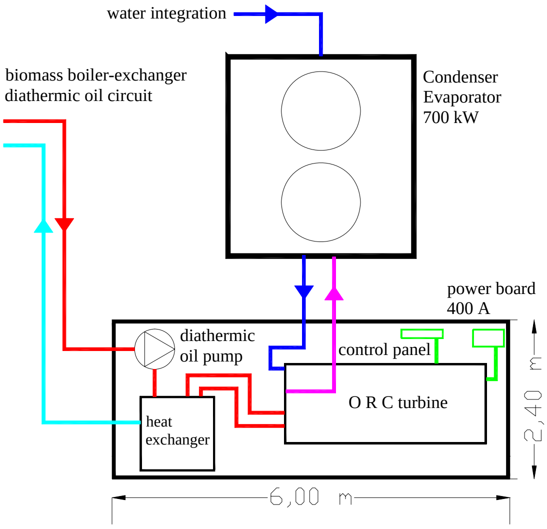

Figure 6: ORC system plan

Graphic in figure 7 shows performance curve in function of thermal power available. Under the characteristics of the biomass plant, 400 kW thermal power, the system will produce a gross power of 65 kWe, corresponding to a net operative power of 50 kWe. [11]

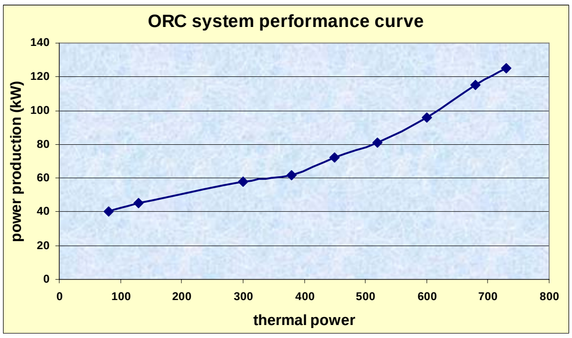

Figure 7: ORC system performance curve

6 CONCLUSIONS

The biomass energy production pilot plant from vineyard prunings has been completed and started up. During the first working phase the plant has encountered several problems, so the working period was only 250 hours. Problems have been solved and next period biomass boiler will work continuously.

The energy environmental analysis of the plant shows an efficiency of 90%; that means that 10% of the biomass energy is consumed during the energy chain, using fossil fuels; the remaining part is the effective renewable energy obtained from prunings. The environmental efficiency grows to 96% if we use biodiesel instead of diesel, and could reach 100% if we produce electricity by biomass plant.

The expansion of the plant regards electricity production. CRB is designing an Organic Rankine Cycle turbine that produces electricity from diathermic oil that will be built in the next months.

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