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Assessment of micro-combined heat and power system based on an organic Rankine Cycle coupled to a boiler for residual biomass valorization

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Abstract

Energy from biomass obtained in rural areas provides a sustainable alternative for heat and power production. In particular, the combustion of biomass in boilers represents the most widely used valorization route for the production of thermal energy. Furthermore, cogeneration has proven to be an efficient and clean way of simultaneous production of electricity and useful heat in the place of consumption, with the consequent saving of primary energy and emissions.

The specific aim of this experimental work is to study the feasibility of employing forestry wastes as feedstock for microcogeneration (electrical power <15 kW) processes for small scale (residential and commercial level) applications in order to avoid problems associated to their accumulation, mainly risk of fire.

Three forestry biomasses (Pinus pinaster, Eucalyptus globulus, and Acacia melanoxylon) abundant in Galicia, north of Spain, were selected as fuels to be used in the above-mentioned processes. An organic rankine cycle (ORC) coupled to a biomass boiler (60 kWt) were used to carry out the experiments. Cogeneration yields (thermal + electrical), as a function of temperature difference between cold and hot focus, were studied.

1. Introduction

Among all the countries of the European Union, Spain and Portugal are two of the most vulnerable against the climate change. In fact, in the last 30 years, both countries have suffered numerous wildfires which destroyed a large fraction of the local vegetation. In this context, the FIREPOCTEP project aims to: 1) Identify strategic management areas to minimize the risk and impact of large fires throughout an integral management of the landscape in relation to global climate change; 2) Promote public and private investment through pilot experiences in the framework of Green Circular Economy and investigation of new market opportunities; 3) Educate the permanent and occasional rural population about the risk of large forest fires, preventive practices and self-protection.

One of the main causes of these fires is the accumulation of forestry biomass derived from tree-pruning operations, due to the large quantities of dry material that can is left in-situ. Therefore, research on alternative uses of forestry wastes is mandatory to prevent beforementioned risks.

One alternative is represented by the biomass cogeneration, which allows the simultaneous production of electricity and useful heat in the place of consumption, with consequent saving of primary energy (up to 40%) and emissions into the atmosphere. In fact, cogeneration is considered as the main option for the replacement of traditional energy systems (D'Accadia, 2003). Taking this into account, microcogeneration (referred to small power equipment, less than 50 kW) is emerging as a suitable alternative in the aforementioned small-scale applications (Fenercom, 2012). One of the most promising techniques for electrical energy obtention through biomass is the so-called organic rankine cycle (ORC) (Qiu, 2012). The ORC follows the same principles as the traditional steam Rankine cycle used in most thermal power plants to produce electricity but uses an organic fluid instead of water. This fluid (generally a fluorocarbon) has a high molecular weight and a boiling point below 100°C, which allows to considerably simplify the traditional process in terms of complexity and cost.

In this work, carried out in the framework of the FIREPOCTEP project, the potential of three forestry biomasses (*Pinus pinaster, Eucalyptus globulus* and *Acacia melanoxylon*) as fuels for energy recovery through

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microgeneration was investigated. This was done employing those biomasses in a pilot ORC module coupled to a boiler in order to determine microcogeneration feasibility in terms of global efficiency.

2. Materials and methods

To demonstrate the feasibility of the use of microcogeneration as a system for energy recovery of the biomass previously presented, a pilot plant was used with the main following elements:

- A 60-kW multi-fuel boiler (hot source) equipped with a caterpillar burner, fed by a hopper and responsible for generating the thermal energy needed to produce electricity in the ORC (provided by hot water up to 90°C).
- An ORC module thermal machine based on an organic Rankine cycle with a maximum power of 4 electric kW and designed for the use of heat at low temperature (up to 100°C in water) by its conversion into electricity. This system employs an organic refrigerant fluid (R245fa).

Despite being a plant for cogeneration, the experimental system has an aerorefrigerator (cold source) to evacuate the heat from the condenser through a water circuit. This equipment is an air/water heat exchanger that drives air by forced convection to cool the incoming water. The system also has a heatsink in the form of resistors to prevent the injection of electricity generated by the grid. Finally, the plant has a data control and visualization system where all parameters relevant to the operation of the plant are displayed and recorded.

Figure 1 shows the scheme of the ORC module employed.

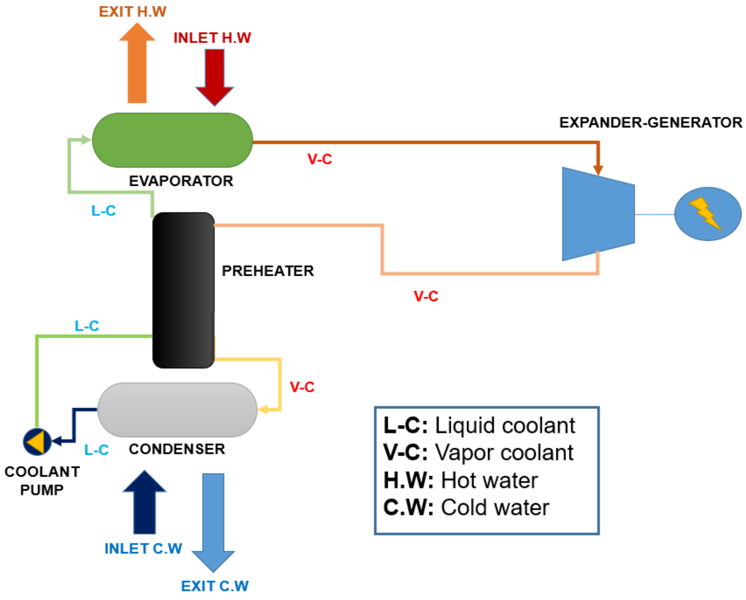

Figure 1- ORC.

As it can be observed in Figure 1, once preheated, the liquid refrigerant is conducted to the evaporator where it changes its state to the vapor phase. It is then led to an expander on whose axis mechanical work is generated. That expander is coupled by a mechanical transmission to an asynchronous generator, producing electrical energy. Once the fluid leaves the expander, already with a reduced pressure, it gives part of the heat in the regenerator or preheater and then goes to a condenser where the vapor – liquid phase change occurs and the cycle can start again in the coolant pump.

Microcogeneration performance is assessed based on the global efficiency obtained (electrical plus thermal). Equations (1) and (2) show the electrical and thermal efficiency calculation.

η_{el}= electrical power on terminals generator (kWe)/thermal power apported by the evaporator (kWt) (1)

η_{t} = heat provided by the condensator (kWt)/heat captured by the evaporator (kWt) (2)

3. Results

As confirmed by other authors (Peris, 2015), the greater the temperature difference between the hot and the cold source, the greater the electrical power generated by the module studied. This behaviour was also observed for the generated power.

In the tests conducted, values around 4 kW were obtained in all evaluated cases. Using the ORC module used in the present investigation, cogeneration efficiencies close to 97% can be achieved, demonstrating its suitability for energy recovery with the forestry biomasses studied.

4. Conclusions

The results obtained during the preliminary microcogeneration tests show that it is feasible to valorize the selected biomasses (*Pinus pinaster, Eucalyptus globulus* and *Acacia melanoxylon*). The tests carried out make it possible to determine that the temperature differences between the hot and the cold source had a significant influence on the results obtained. In the conditions used in this work, cogeneration yields close to 97% can be obtained (around 9% net electric yield and around 88% thermal yield). Those results are highly promising as micro-cogeneration allows simultaneous heat and electricity production, which opens the door to an interesting way to use forestry wastes for energy production instead of its accumulation and the risk of fire associated.

5. References

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