A NOVEL MICRO-COGENERATION UNIT FOR MARKET APPLICATIONS BASED ON A BIOMASS-FIRED ORC SYSTEM

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ABSTRACT

In the transition towards smart grid systems, a problem of increasing importance is the distributed generation of thermal and electric power at low cost and low environmental impact. This work proposes a novel cogeneration system based on a biomass boiler and a micro-Organic Rankine Cycle (ORC) unit. The biomass boiler heats up an unpressurised thermal oil circuit, which, in turn, supplies heat to an ORC unit that produces electricity and hot water for the users. The ORC system is based on a single-pressure regenerative cycle that works in the subcritical region. The goal of this study is twofold: i) the analysis of the design choices that were made to achieve a good compromise between efficiency and cheapness of the micro-CHP system, and ii) the performance evaluation of the system for variations of key parameters, such as temperature and flow rate of the thermal oil, mass flow rate of the cooling water and operational assets of the ORC unit. An in-depth experimental campaign has been carried out, where the rotational speeds of the pump and expander of the ORC unit have been varied to choose first the best operating asset, and then investigate the influence of the other key parameters. The best combination of the speeds has been identified as 2250 rpm for the pump and 2300 rpm the expander. In these conditions, maximum values of electrical efficiency (7.4%) and total energy utilization factor (62%) are found. With an oil temperature of about 150°C, the achieved power production is 2530 W, the ORC utilization factor 93% and the expander global efficiency 57%. Simplicity and low specific cost contribute to increase the efficiency-to-cost ratio, making this novel system appealing for the customer.

1. INTRODUCTION

In the fight against climate changes, the European Union has concluded the agreement of reducing carbon emissions by 80-95% within 2050, taking as reference point the emissions of 1990 (Union, 2014). Biomass energy may have an important role in replacing fossil fuels within this energy scenario. Currently, about 90% of the world heating demand from renewables is covered by biomass sources (Union, 2014). The right strategy to use biomass is at local level because of the high-energy consumption associated with transportation. Biomass combustion typically reaches high temperatures (around 900-1000°C), which would justify the installation of plants for high temperature heat recovery such as steam Rankine or supercritical CO_2 cycles. However, these systems are economically viable only for large-scale sizes because of the high volumes of steam and of the complications deriving from a direct heat exchange between combustion gases and working fluid. Thus, in biomass micro-cogeneration applications, it may be more convenient to use a heat transfer loop between boiler and power conversion device. The presence of this intermediate circuit implies, on the one hand, a temperature decrease of the exploitable heat source, but, on the other hand, allows the use of compact and cheap technologies for power production. Organic Rankine Cycle (ORC) systems have demonstrated to be one of the most promising technologies for heat recovery from low-to-medium temperature heat sources. In spite of being a mature technology for power sizes above 100 kW, ORC systems for small power applications are still at the prototypal stage, because the downscaling of these systems penalizes both the efficiency and specific cost (Quoilin *et al.*, 2013). A great push in moving fast towards the first commercial stages has been giving with many experimental works on micro-scale ORC units. Galloni *et al.* (2015) investigated the potential of a small-scale ORC system (1-3 kW) to exploit thermal energy in the temperature range 75-95°C. During the tests, the cold sink temperature varied in the range between 20°C and 33°C and the vapour maximum pressure of the working fluid ranged from 6 up to 10 bar. The best efficiency achieved within these operating ranges was around 9% with an output power slightly higher than 1 kW. Bracco *et al.* (2013) carried out the first tests on the laboratory prototype of a domestic-scale ORC cogenerator. The system has revealed promising performance, showing a cycle efficiency of about 8% and a delivered power of 1.5 kW with a temperature at the outlet of the evaporator of 130°C and an expansion ratio of 5.5. In spite of the increasing interest in testing micro-ORC applications (Park *et al.*, 2018), there is still a big lack of knowledge for what concerns the experimental testing of biomass-fired micro-ORC systems, as can be seen from Table 1. The few available experimental results reported in Table 1 show very low electrical efficiency values in the range 1.34 – 2.5%, which indicate a consistent gap between the efficiency values predicted by simulations and those observed during the tests. Algieri and Morrone (2014) simulated the behaviour of a biomass-ORC system for an estimated power production of 5 kWe and they indicated the range 9-16% as reference values for the electrical efficiency of the CHP system, defined as the ratio between the power output of the ORC unit and the thermal power input of the biomass boiler. Liu *et al.* (2011) investigated a similar domestic system with a power output of 2 kW. From the simulations they obtained values of the electrical efficiency of the CHP system of about 7-13%, which are sensitively higher than those found in the experimental tests of another work by the same authors (1.34%, Liu *et al.*, 2010).

Table 1. Overview of previous micro-CHP biomass fired-ORC experimental studies.

Size [W]	T_{max} of source [°C]	Expander type	Working fluid	$\eta_{el,CHP}$ [%]	Q_{cond} [kW_{th}]	Authors
284	120	modified air motor	HFE7000-7100	1.34	18.4	Liu et al., 2010
846	128.9	vane expander	HFE7000	1.41	47.26	Qiu et al.,2012
500	140	scroll	HFE7100	/	10.28	Jradi et al.,2014
1840	654	rotary vane expander	Hexamethyldisiloxane	2.5	57.7	Mascuch et al 2018

This work addresses the challenge of making micro-cogeneration units competitive, searching for a good compromise between efficiency and economic feasibility. It contributes to fulfil the gap in the design and experimentation on micro-scale ORC systems, analyzing the operation of a biomass-fired ORC unit. The goal is twofold:

- Presenting the design choices of the micro-cogeneration unit, which were mainly driven by three aspects:
  - simplicity and market availability of the components,
  - high efficiency-to-cost ratio,
  - short time of installation and putting into operation.
- Assessing the performance of the micro-cogeneration unit, relying on a large amount of data from a properly-planned experimental campaign.

The combined analysis of design features and operating performance aims at showing the potential of the system to become appealing for the customer.

2. THE MICRO-COGENERATION UNIT

The micro-cogeneration system consists of four main parts: a biomass boiler, a micro-scale ORC system, the heat transfer loop that links the boiler with the ORC unit and the cooling circuit. The layout of the plant is shown in Fig. 1, where also the working conditions at maximum power operation are reported in some points of the circuits. The biomass boiler heats up the thermal oil of the heat transfer circuit, which in turn supplies heat to the ORC unit that produces electricity and hot water for the users. The heat transfer loop (shown with red lines in Fig.1) is an unpressurized circuit with an open expansion tank. A gear pump driven by an asynchronous motor assures circulation of the oil and its rotational speed can be adjusted by a frequency driver. The cooling circuit is fed by tap water that is heated up in the condenser. For safety reasons, a plate heat exchanger is also installed between the circuit of hot oil and the water circuit. This heat exchanger is isolated during normal operation and its supply line is suddenly opened if an emergency dissipation of heat is needed. In case, for example, of a sudden shut-down of the ORC unit, the thermal power that the boiler still produces due to its inertia must be urgently dissipated to prevent the oil from reaching too high temperatures.

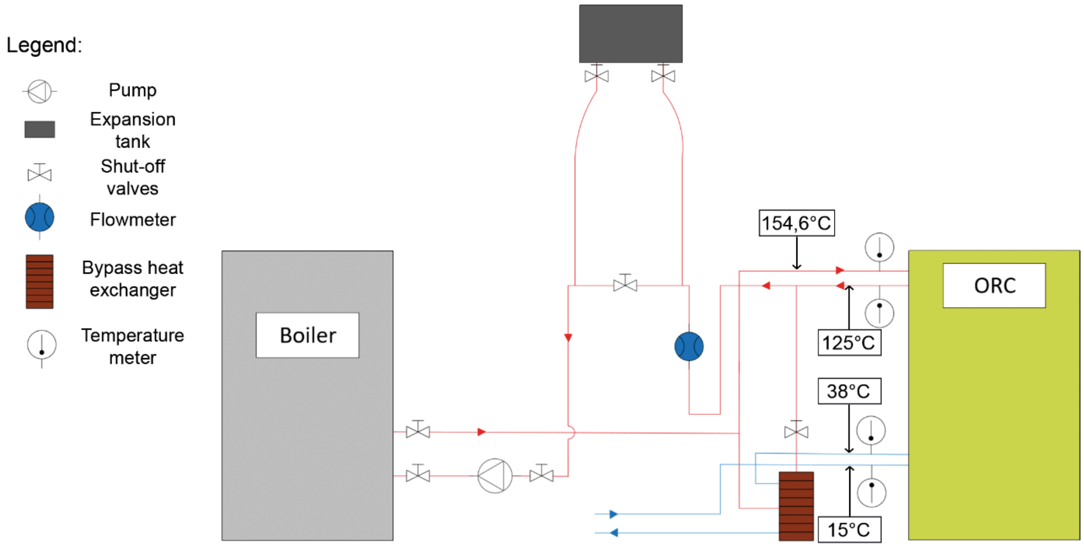

Figure 1: Layout of the micro-cogeneration unit

2.1 Biomass boiler

The biomass boiler of the plant was chosen among the few ones that are commercially available at domestic scale. A further selection was necessary to identify those boilers that could easily convert their operation from the use of water as heat transfer fluid (normally used in domestic applications with maximum temperature of 90°C) to the use of thermal oil, which allows reaching higher temperature (up to 160°C) for feeding the ORC unit. In this application, the biomass boiler has a nominal thermal power of 37 kW_{th} and is fed by pellets. An auger collects the fuel from the boiler tank and send it into a direct-flame combustion chamber. The exhaust fan channels the exhaust gases into 6 tubes of the heat exchanger that cross the tank of the oil to be heated up. Inside each tube, a turbulator transforms laminar flow into turbulent flow to improve the heat exchange.

The control system adjusts the thermal power output to reach the oil temperature set by the user. It acts on the auger speed (i.e. on the feeding rate of pellet) according to three steps of thermal power output (40%, 70% and 100% of the nominal power).

2.2 Micro ORC system

A schematic representation of the ORC system is shown in Figure 2 (location of pressure and temperature sensors along the circuit is also highlighted). It is based on a single-pressure regenerative cycle that works in the subcritical region. It consists of evaporator, volumetric expander (scroll type), recuperator, water-cooled condenser, liquid tank and volumetric pump. All heat exchangers are brazed plate heat exchangers and the working fluid is R245fa. The system is designed as an independent package to be connected with a heating and cooling circuit. Evaporator and condenser were conceived to accomplish the heat transfer with liquid heat source and heat sink, respectively. Thus, hot thermal oil or pressurized water normally feed the system at the evaporator and heat is released to water in the condenser. Crucial points such as compactness and simplicity have been deeply considered in the design of this micro-scale prototype to achieve a high efficiency-to-cost ratio, and increase the possibility of market spread. Only standard components deriving from applications in which thousands of pieces are sold (automotive, industrial boilers etc.) were selected to have high reliability and low cost. For such sizes, volumetric machinery is normally preferred to turbomachinery in ORC systems (Rahbar *et al.*, 2017). In this ORC unit, a scroll expander is used and an alternator is directly connected to it to save space and decrease friction thermal losses that instead would be higher in case of a belt-pulley power

transmission system. The pump is driven by a brushless electric motor that guarantees a good compromise between dimensions, cost and efficiency. An asynchronous motor, instead, would certainly be cheaper but would have bigger size and lower efficiency. This choice considers that, in small-scale ORC systems, the low efficiency and the power consumption of the pump-motor assembly can heavily affect both power output and overall efficiency of the cycle (Carraro *et al.*, 2017)) The motor of the pump is controlled by a frequency driver that keeps the rotational speed at the set value by the user. Two in-house electronic circuit boards manage the ORC operation: the SVS (Supply Voltage Supervisor) board collects signals from the measurement devices and supervises start-up and shut-down procedures; the inverter board keeps the expander rotational speed fixed at the set value. The power entering the inverter can be either dissipated into an electric resistance (e.g. during transients) or injected into the grid.
Nominal characteristics of the ORC system are listed in Table 2. A net power output of 3100W and an electric efficiency of 8% are obtained when thermal oil at 170°C and water at 20°C are considered.

Table 2. Nominal values of the main parameters of the ORC system

Parameter	Nominal value	Parameter	Nominal value
Cooling water flow rate [m^3/h]	0.9	Thermal oil temperature [°C]	170
Water temperature [°C]	20	Expander speed [rpm]	2500
Thermal oil flow rate [m^3/h]	1.2	Pump speed [rpm]	2800

Table 3. Features of the installed measurement devices

Meter type	Physical principle of measurement	Measuring range	Accuracy
Energy meter	Power meter	0 to 5000 W	1%
Flow meter	Variable area flow meter	100 to 1800 l/h	1.5 %
Temperature meter	Pt 1000	-50…+200°C	0.9 °C
Pressure meter	Sealed Gauge	0 to 30 bar (abs)	0.5 %

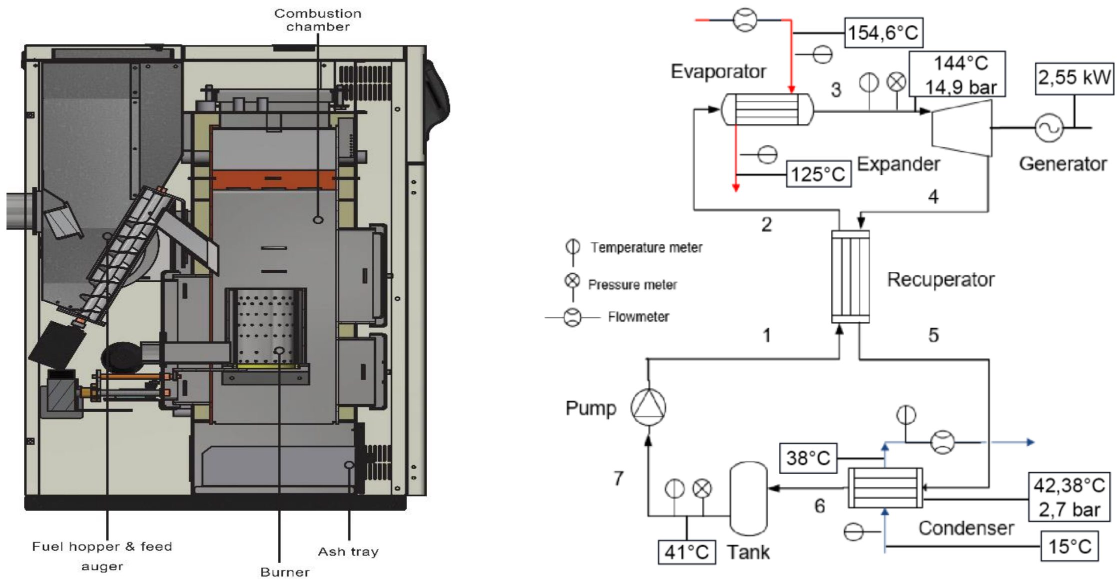

Figure 2: Cross section of the biomass boiler and layout of the micro-ORC system

3. THE EXPERIMENTAL STRATEGY

The novel micro-cogeneration plant has been tested in the Thermal Machines Laboratory of the University of Padova. The goal of the experimental campaign is the assessment of the productivity and efficiency of the system, analysing either the whole system or the single units and components.

3.1 Plan of the tests

The first series of tests focuses on investigating the operating match between boiler and ORC system. This preliminary analysis allowed identifying feasible ranges of the following parameters:

- volume flow rate of the thermal oil: 1 – 1.5 m^3/h,
- volume flow rate of the cooling water: 0.66 – 1.2 m^3/h,
- ORC pump speed: 2000 – 2500 rpm,
- ORC expander speed: 2000 – 2500 rpm.

The experiments have been organized according to the "tree structure" shown in Figure 3. The most important parameter at the top of the tree is the pump speed, which primarily influences the balance between thermal power production by the boiler and thermal power exploited by the ORC unit. Indeed, higher pump speed results in higher flow rate of the working fluid within the ORC circuit, and in turn in higher heat transfer in the ORC evaporator, which increases the heat load to be satisfied by the boiler. It is important to note that the operating range of the pump speed is lower than the nominal speed (2800 rpm – see Section 2.2) because of the limitation given by the maximum thermal power output of the boiler (37 kW). Tests pointed out that the operation of the pump at nominal speed would imply two-phase conditions at the expander inlet and difficulties in increasing the oil temperature to achieve acceptable values of efficiency.

Different combinations of pump and expander speeds correspond to different operating assets of the ORC unit, each of which has been tested and compared under variable temperature and mass flow rate of the thermal oil and variable cooling water flow rate. Each level in each branch of the tree from the top to the bottom (expander speed, oil flow rate, oil temperature and water flow rate) stands for a type of experiment, where the parameter of the level has been varied while the parameters of higher levels were kept constant. In particular, after having chosen the operating asset and the oil mass flow rate, the boiler has been set to reach specific oil temperatures in the range between 120°C and 155°C. As a last step, the flow rate of the cooling water in the condenser has been varied while keeping a constant oil temperature at the inlet of the evaporator.

The pump speed is varied by means of an inverter, which controls the electric motor that drives the pump. On the other hand, the SVS electronic board that manages the operation of the alternator adjusts the expander speed. The mass flow rate of the thermal oil is changed by varying the rotational speed of the circulation pump of the oil circuit. Finally, the throttle valve opening and closing in the water circuit control the water flow rate.

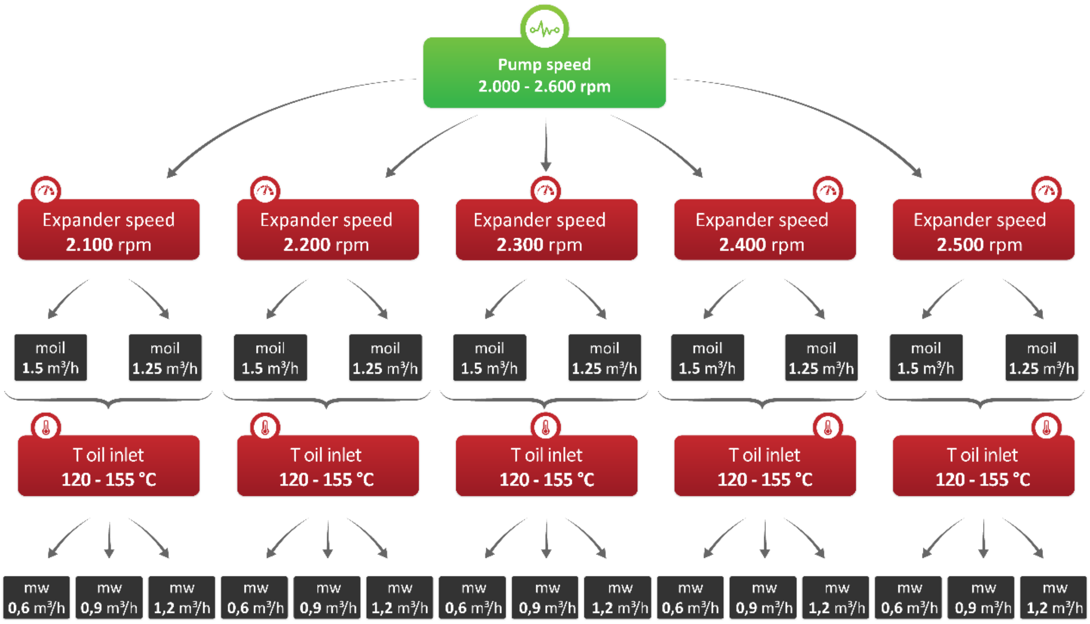

Figure 3: Tree structure of the experimental campaign

3.2 Methodology

Measurements of the ORC system provide information about temperature and pressure on the key points of the cycle, power produced by the generator, power consumption of the pump and volume flow rate

of the cooling water (Figure 2). On the other hand, the operation of the biomass boiler could be assessed with data about the temperature of the exhaust gases at boiler stack, the activation time of the auger (i.e. feeding rate of pellet), the oil temperature at the outlet and the rotational speed of the exhaust fan. The registered data were then used to calculate the quantities of interest for the evaluation of the system performance. In particular, intervals of steady-state operation were identified and mean values of the measured data have been used as reference values for the experimental and uncertainty analyses.
Performance evaluation is based on the calculation of efficiencies and energy utilization factors.
The electric efficiency of the ORC system gives an indication of how much thermal power absorbed by the evaporator (Q_{eva}) is transformed into electric power (1):

$$\eta_{el} = \frac{P_{e,out} - P_{pump}}{Q_{eva}} \tag{1}$$

where $P_{e,out}$ is the power generated by the alternator, P_{pump} is the electric power consumption of the pump and Q_{eva} is defined as (2):

$$Q_{eva} = \dot{m}_{oil} \cdot c_{p,oil} \cdot \left(T_{in,oil} - T_{out,oil}\right) \tag{2}$$

with $\dot{m}_{oil}$, $c_{p,oil}$ and T standing for mass flow rate, specific heat and temperature of the thermal oil, respectively. The efficiency of the scroll expander is assessed by a global efficiency indicator (3), being a direct measurement of the mechanical power generated by the expander not possible,

$$\eta_{exp} = \frac{P_{e,out}}{\dot{m}_{R245fa} \cdot \Delta h_{is}} \tag{3}$$

This indicator is the ratio between the electric power at the outlet of the alternator and the isentropic work expressed as the product between the mass flow rate of the working fluid and the isentropic enthalpy drop. Two energy utilization factors have been used in the evaluation of the cogeneration performance: the ORC ($\mathcal{E}_{ORC}$) and the total ($\mathcal{E}_{tot}$) utilization factors, defined in (4) and (5), respectively.

$$\mathcal{E}_{ORC} = \frac{P_{net,ORC} + Q_{cond}}{Q_{eva}} \tag{4}$$

$$\mathcal{E}_{tot} = \frac{P_{net,tot} + Q_{cond}}{\dot{m}_{pellet} \cdot LHV} \tag{5}$$

$P_{net,tot}$ is the net electric power of the whole system, in which the net power produced by the ORC unit ($P_{net,ORC}$) is further reduced by the electric consumption of the oil circulation pump. The thermal power released to the water in the condenser (Q_{cond}) is calculated by (6):

$$Q_{cond} = \dot{m}_w \cdot c_{p,w} \cdot \left(T_{w,out} - T_{w,in}\right) \tag{6}$$

where $\dot{m}_w$, $c_{p,w}$ and T_w are mass flow rate, specific heat and temperature of the water.

4. RESULTS AND DISCUSSION

In this section the experimental results are organised and discussed, starting from the different datasets acquired during the tests (Figure 3). First, the different operating assets of the ORC unit (i.e. different pump and expander speeds) are compared. Subsequently, the most representative indexes of the system performance are evaluated for the most promising operating asset identified in the first step.

4.1 Performance of different operating assets

Given the two systems (biomass boiler and ORC unit), this section aims at identifying the values of those parameters that can maximize the performance of the total plant in terms of electric and thermal power production. Within the logic of burning biomass when available, the ORC unit is in general more flexible than the boiler during operation, also because of lower inertias. Thus, pump and expander speeds have been identified as crucial parameters for managing the operation of the system. Their variations result in different performance of the system in the same range of temperatures of the oil feeding the evaporator (for the same set of temperature and mass flow rate of the cooling water, and mass flow rate of the thermal oil). In Figure 4, electric efficiency (η_{el}) and total utilization factor (ε_{tot}) are shown for different expander rotational speeds while the pump speed is kept at 2250 rpm. The electric efficiency is reported in Figure 4a as a function of the oil temperature at the inlet of the ORC evaporator. Significant values (≥6%) are found for oil temperatures higher than 140°C. Apart from the expander speed of 2300 rpm, only slight differences can be noted between the efficiencies calculated for different expander speed. Indeed, when the expander speed is 2300 rpm, the efficiencies are at least 0.5% higher than those obtained with the other speeds for temperatures above 146°C. Values of the total energy utilization factor (Figure 4b) are around 55-60 % for oil temperatures at the inlet of evaporator in the range between 130 °C and 155°C. In general, for all the speeds this factor slightly increases as the oil temperature increases. The highest values are found for expander speeds of 2300 and 2400 rpm with peaks of about 65%. In contrast, values just above 50% are obtained for the lowest temperatures (130-135°C) and speeds (2100-2200 rpm).

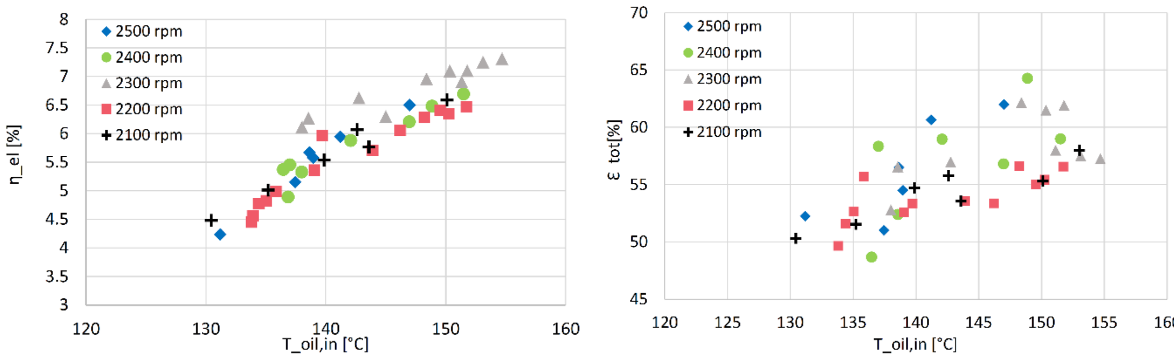

Figure 4: a) Electric efficiency and b)total utilization factor at fixed pump speed and variable expander speed

As a result, for a fixed intermediate speed of the pump (2250 rpm), the expander speed of 2300 rpm slightly outperforms the other speeds in the evaluation of both efficiencies. Thus, the expander speed is fixed at 2300 rpm and the efficiency indicators are analyzed under variable pump speed and increasing oil temperature (Figure 5). In particular, Figure 5a a compares the electric efficiencies at three different rotational speed of the pump: 2050, 2250 and 2450 rpm. A clear hierarchy appears, with separate trends of electric efficiency for each pump speed. In ascending order, the trends related to the operation at 2450, 2050 and 2250 rpm are found. Highest values of around 7% are reached with pump speeds of 2050 and 2250 rpm and oil temperatures higher than 150°C. For each pump speed, an improvement of about 2.5% is observed with an increase of about 20°C of the oil temperature. The highest pump speed shows the lowest trend of efficiency, suggesting a borderline condition for the operation match with the biomass boiler. In fact, an increase in the pump speed (from 2050 to 2250 rpm) means initially an increase of the efficiency, but the further increase to the highest tested speed shows detrimental effects because of the limitation in the maximum power of the boiler. A higher speed entails a higher mass flow rate of the working fluid that, in turn, needs higher heat transfer in the evaporator, acting therefore as a higher load for the boiler. These limitations are evident in the attempt to reach high temperatures: at maximum power output of the boiler, a maximum temperature of 149°C can be achieved (no blue points are obtained for temperatures above 150°C). The total utilization factor in Figure 5b show values around 55% for each pump speed, with a slight rise towards 60% from 140°C to 152°C. These relatively low values of the utilization factor of the whole system are due to two main aspects: loss of heat in the oil circuit (especially in the open expansion tank) and ineffective heat exchange in the exhaust gases-oil heat exchanger. Indeed, during operation at maximum power, the temperature of the exhaust gases in the chimney exceeds 240°C.

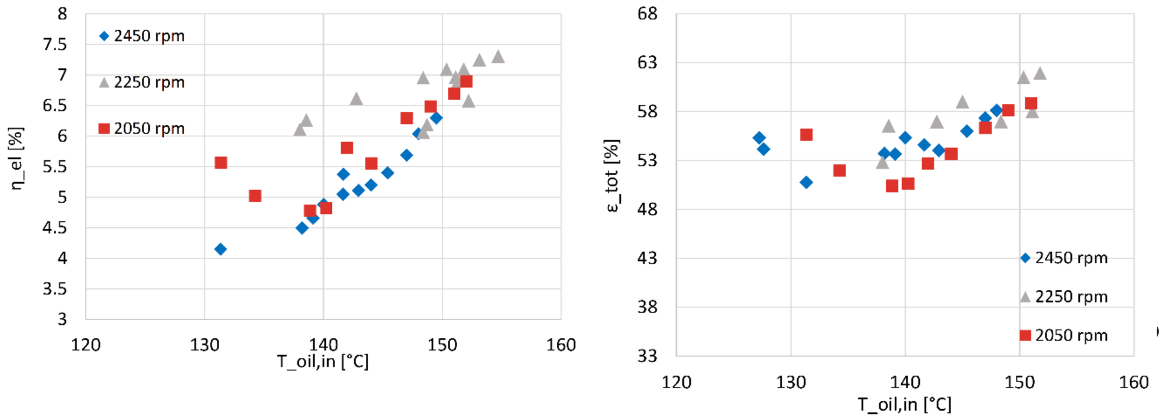

Figure 5: a) Electric efficiency and b) total utilization factor at fixed expander speed and variable pump speed

4.2 Assessment of the micro ORC unit

The previous analysis of different operating assets of the ORC unit suggested some guidelines in the choice of the most suitable combinations of expander and pump rotational speeds to exploit at best the thermal power produced by the biomass boiler. Here, for the best combination of pump speed (2250 rpm) and expander speed (2300 rpm), the performance of the ORC unit is investigated under variable boundary conditions. An improvement of the ORC electric efficiency is observed, especially at lower oil temperatures, if the oil mass flow rate is increased. Figure 6 shows that, in the temperature range 135-145°C, an oil flow rate of 1.5 m^3/h brings about efficiencies around 6%, which are 1% higher than those obtained with a flow rate of 1.25 m^3/h in the same range of temperatures. This gap reduces for temperatures higher than 148°C, where the trend related to the highest flow rate is just above the other one. The maximum value of 7.3% is obtained at an oil temperature of 154.6°C. Similarly, to the effect of a higher mass flow rate of oil, an increase of the mass flow rate of the cooling water is also beneficial for electric power production, as confirmed by Figure 6b. About 500W are gained while switching from a mass flow rate of water of 0.12 kg/s to a mass flow rate of 0.3 kg/s. The analysis of this figure shows that, for operating ranges of pump and expander speeds out of the nominal values (Section 2.2), new optimal equilibrium points are found during operation, which are not necessarily characterized by nominal values of mass flow rates in the heat exchangers (evaporator and condenser).

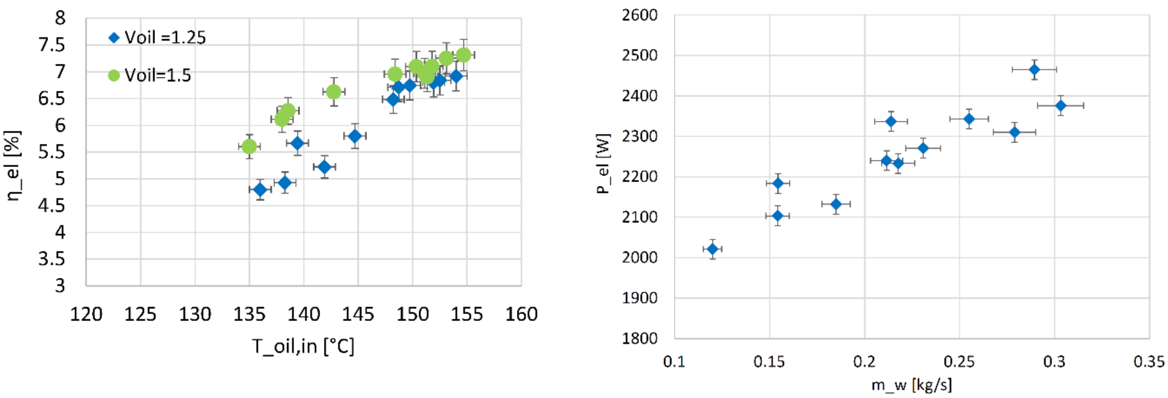

Figure 6: a) ORC electric efficiency as a function of the oil temperature and b) electric power as a function of the water mass flow rate.

The influence of the same mass flow rates of oil is also considered in the evaluation of the ORC energy utilization factor (Figure 7a). An increase of about 10% (from 75% to 85% and from 85% to 95%) is observed with a temperature increase from 130°C to 155°C for the two mass flow rates of oil. Peak values of 95% are obtained with the highest mass flow rate and for temperatures around 150°C. The same figure contains also information on the variation of the ORC utilization factor with different

volumetric flow rates of the cooling water. For the same oil temperature (148°C), two values of the water flow rate in the condenser has been considered, one higher (1.2 m^3/h – blue point) and one lower (0.66 m^3/h – orange point) than the nominal value (0.9 m^3/h – red point). An increase of water flow rate from 0.66 to 1.2 m^3/h results in an increase of the ORC energy utilization factor that gains more than 5% (from 80 to 85%). In contrast, the global efficiency of the expander shows an opposite trend for the same variations of water flow rate (Figure 7b). In particular, a decrease of the water flow rate from 1.2 to 0.66 m^3/h leads to an efficiency improvement of 7%, for the same oil temperature of 148°C. This behaviour give insights on the shape of the efficiency map of the scroll expander. Indeed, for given working conditions, a decrease of the water flow rate implies a decrease of the pressure ratio across the expander (i.e. the condensation pressure increases for equal evaporation pressure). Thus, the global efficiency of the expander appears to decrease with the increase of the pressure ratio within the tested range. This trend is confirmed by Figure 7c that shows the decrease of the expander global efficiency as the pressure ratio (β) increases for the expander speeds of 2300 rpm and 2500 rpm.
During operation at the pump speed of 2250 rpm and at expander speed of 2300 rpm, the working fluid temperature at the expander inlet ranges from 110°C to 125°C and that at the expander outlet from 70°C to 79°C, highlighting that the expander causes a temperature drop of 35-40°C. In these working conditions, the pressure drop across the expander varies between 5.6 and 6.2, showing efficiency values in the low-end part of the diagram in Figure 7c. The built-in volume ratio of the scroll expander is 3.1 and does not match properly with such high-pressure ratios, causing non-negligible under-expansion losses. These losses lead to a significant decrease of the expander efficiency that, in turn, affects the electric efficiency of the whole ORC system (Figure 6a).

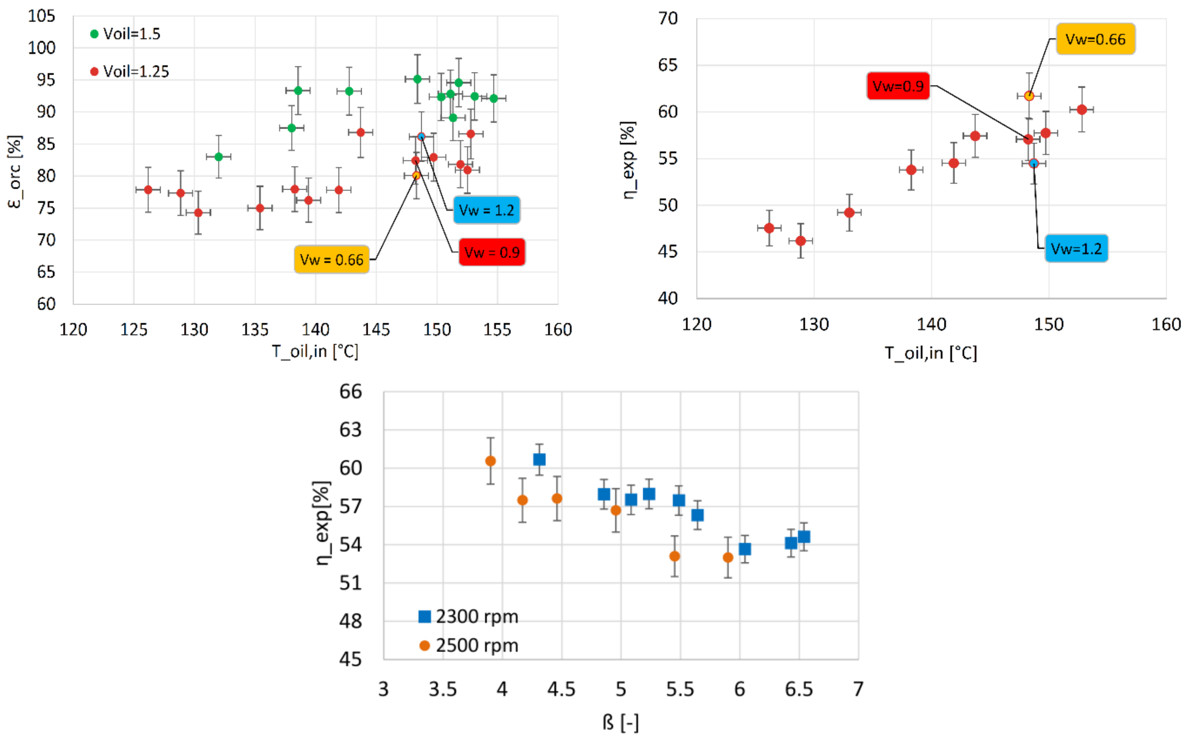

Figure 7: a) ORC utilization factor, b) global efficiency of the expander as functions of the oil temperature and c) global efficiency of the expander as function of the pressure ratio

5. CONCLUSIONS

A micro-cogeneration unit composed by a biomass boiler and a micro-ORC system has been proposed in this paper. An experimental evaluation of its performance has been carried out, focusing on the system as a whole and on the micro-ORC unit separately. The design of the total system has been conceived following the criteria of simplicity and low specific cost. The challenge regards the choice of components that can be at the same time reliable, efficient and cheap. In small size units, to keep the investment cost low, it may be acceptable to loose few percentage points of efficiency.

The experimental campaign of the micro-CHP system has been planned considering a hierarchy dictated by the degree of influence of each key parameter on the operation. As a first step, the system performance has been assessed under variations of the rotational speeds of ORC pump and expander, being the two parameters that greatly affect the operation of the system. Maximum values of electrical efficiency (7.4%) and total utilization factor (62%) are found for the pump speed of 2250 rpm and the expander speed of 2300 rpm. So, the influence of temperature and mass flow rate of oil and of mass flow rate of water on the operation of the ORC unit have been analysed keeping these speeds constant (i.e. fixing the operating asset of the ORC system). The highest performances have been reached with the oil temperature of 150°C, the oil flow rate of 1.5 m^3/h and with a water mass flow rate of 0.27 kg/s. In these working conditions, the electric efficiency is 7.5%, the power production 2530 W, the ORC utilization factor 93% and the expander global efficiency 57%. These results combined with the simplicity and cheapness of the micro-CHP system confirm its potential to face the market, especially when the cost for biomass supply is null, as in small farms or small villages in developing countries.

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