AN INTEGRATED ENERGY SYSTEM BASED ON MICRO GAS TURBINE AND ORC WITH GASIFICATION: NUMERICAL STUDY AND PERFORMANCE ANALYSIS

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Abstract
The opportunities and critical aspects related to the use of low heating value gaseous fuels produced from biomasses in an integrated energy system composed by a micro gas turbine, an ORC as bottom system and a gasification system are analyzed in the paper. The aim is to individuate an efficient strategy to an energetic re-use of organic solid waste with small plants in a distributed energy point of view. The study was carried out through thermodynamic analysis of each component. Results of simulations highlight the possibility of using syngas in commercial MGTs with waste heat recovery when mixed with methane but specially biogas to obtain a full renewable power generation.

Introduction

Cogeneration, i.e., simultaneous generation of electrical and thermal power, based on micro Gas Turbines (MGTs) is an interesting topic for mini/micro smart grid applications due to the characteristics of flexibility, versatility, and low emissions typical of MGTs [1]-[5].
In this context, the efficient recovery of the residual thermal power contained in engine exhausts into electrical power (waste heat recovery, WHR) lead to higher overall efficiency and, hence, to a reduction of fuel consumption and pollutant emissions. WHR systems based on Organic Rankine Cycle (ORC) represent a technology of great interest for applications in the low-grade energy recovery due to their typical property [6]-[7].
Gasification systems in small energy systems, is largely analysed in literature, both in case of externally fired gas turbines or not [8],[9]. In the present work, the MGT is fed by using the syngas produced by the gasifier and mixtures with methane and biogas. The discussion will be focused also on the critical aspects concerning the utilization of a gas fuel of very low LHV.

Layout Description

The layout is based on a micro gas turbine coupled with an Organic Rankine Cycle turbine as waste heat recovery system. The MGT is integrated with a gasification system producing the syngas. The solid fuel chosen is a biomass from organic waste. The MGT is the single-shaft Turbec T100 (*Ansaldo Energia AE100*). It is able to generate, by a recuperated cycle, 100 kW of electrical power with a global efficiency close to 30% in standard conditions. Compressor and turbine are of the radial flow type and the nominal values of compression ratio and rotational speed are 4.5 and 70,000 rpm, respectively. The model calibration and the performances related to full load operating conditions have been discussed in a previous paper [10]. The effects of different users load demand are considered through the adoption of off design conditions for each component of the MGT. Compressor and turbine off design operations are modeled through the adoption of characteristic operating maps, taken from literature [11].

The bottom cycle is obtained through the adoption of an Organic Rankin Cycle (ORC). The ORC layout is taken from literature [6]. The working fluid is R1233ze, under consideration in recent years because of a low level of GWP and a consequently lower environmental impact than the organic fluids previously adopted [12]. The ORC pressure levels are between 26 bar and 3.53 bar. The efficiency of the expander is set close to 75%.

Table 1 reports the characteristics and composition of a typical organic waste that was used as solid fuel to be gasified. The gasification system is modeled starting from the assumption that the available solid fuel mass flow is equal to 0.027 kg/s and the air/fuel ratio is equal to 1.96: the resulting equivalence ratio is about 0.3 considering the stoichiometric ratio of the defined fuel. The syngas fuel mass flow is 0.076 kg/s.

Finally, the syngas characteristics are reported in Table 2.

Table 1. Solid fuel data

Weight percent of Ash	14.18	%
Weight percent of Moisture	20	%
Weight percent of Carbon	34.84	%
Weight percent of Hydrogen	3.93	%
Weight percent of Oxygen	24.45	%
Weight percent of Nitrogen	1.46	%
Weight percent of Sulphur	1.14	%
LHV	12483	kJ/kg
HHV	13829	kJ/kg

Table 2. Syngas composition and characteristics

Hydrogen	H_2	14.81	%
Water Vapor	H_2O	12.78	%
Nitrogen	N_2	46.15	%
Carbon Monoxide	CO	14.82	%
Carbon Dioxide	CO_2	10.58	%
Methane	CH_4	0.0004	%
Hydrogen Sulfide	H_2S	0.3027	%
Carbonyl Sulfide	COS	0.0097	%
Argon	Ar	0.5504	%
LHV		3220	kJ/kg
HHV		3718	kJ/kg
Molecular Weight		24.67	

Results

The simulations were carried out using the commercial software Thermoflex provided by Thermoflow.

In case of adoption of syngas as fuel with the hypothesis defined above, MGT can reach minus than 50% of nominal load, because the amount of the primary thermal power available is not adequate to obtain the nominal rated power; moreover, the energetic cost related to the compression of the syngas fuel is very high, being close to 50% of the available power. It must be underlined that this result can be obtained with a combustor capable to burn a very low calorific fuel without any problem: as known from literature and previous authors' papers [16], the T100 combustor is designed for natural gas and cannot operate with low LHV fuels without modifications.

A valuable solution to exploit the syngas from organic waste can be the mixing with another gaseous fuel, such as pure methane or biogas. In particular, biogas can represent an interesting solution since also this fuel is obtained from organic waste, after an anaerobic digestion. The results of numerical simulations with different fuel composition are shown in Table 3.

Fig. 1 shows the integrated energy system layout and the results of the simulation in case of a biogas (80%) - syngas (20%) blend as fuel the plant layout shows also a mixer between two different gaseous fuels and a tank for syngas storage.

The simulations were addressed with the aim of comparing operating points with the same velocity of rotating components and turbine outlet temperature, in addition to the maximum value of available syngas mass flow. The adoption of biogas seems to lead to a slightly better behavior of the energy system: the greater value of fuel compressor power is compensated by higher values of net power for both MGT and ORC.

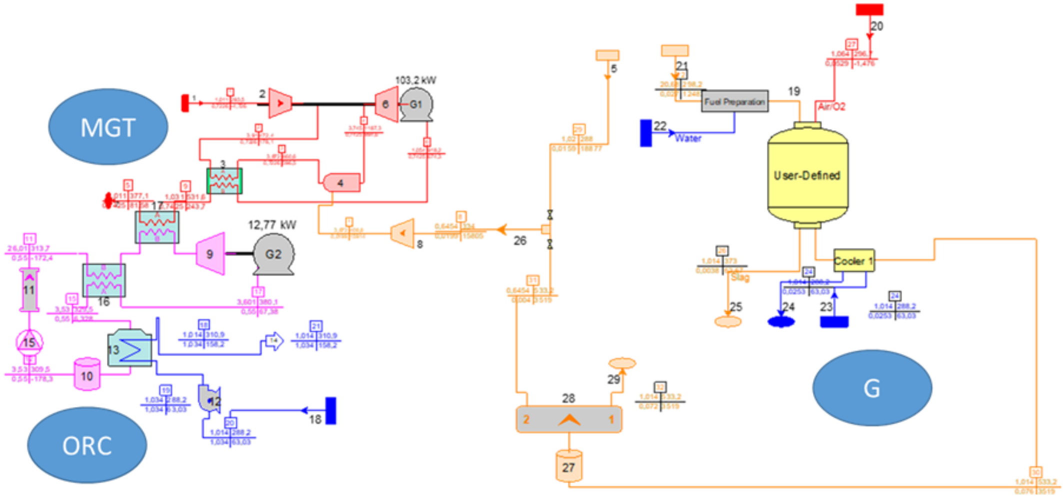

Fig. 1. Integrated energy system layout with results in case of biogas-syngas (80-20%) mixture as fuel

In case of syngas, biogas and methane blends, the relevance of fuel compressor power decreases with the decreasing of syngas percentage, although it remains higher than the base case. Despite the high hydrogen amount in syngas mixtures can lead to combustion anomalies such as flashback into the main swirler of the T100 combustor, preliminary CFD simulations indicate that blends with 20% of syngas in volume can be adopted without risks for the combustor.

Table 3. Powers in kW for the six fuels investigated.

	CH_4	Biogas	Syngas	Syngas 50 Biogas 50	Syngas 20 Biogas 80	Syngas 20 CH_4 80
MGT	95.3	101.4	83.8	106.4	103.2	96.4
ORC	12.2	12.7	11.4	13.5	12.7	12.3
Gross TOT	107.5	114.1	95.2	119.9	115.9	108.7
Fuel Compressor	5.8	7.3	42.7	13.5	12.8	12.3
Net Power	96.9	101.8	47.6	101.5	102.1	97.4
Net fuel input	394	404	337	412	405.7	395.2
Net efficiency	24.6	25.2	14.1	24.6	25.2	24.7

Conclusions

In this work, thermodynamic analyses of an integrated MGT-ORC-gasification energy system have been carried out, investigating the performances of six different fuels. Despite the satisfactory results related to methane and biogas fuels, the adoption of a very low LHV such as syngas from organic waste lead to several critical aspects like a significant increase of fuel compression power. The waste heat exploitation implies the increasing of both overall power and efficiency, and the adoption of a mixing system between syngas and another gaseous fuel, such as methane or biogas, allows an efficient and rational use of this renewable fuel type.
The preliminary analyses performed in this paper represent the basis for future works, which will involve a deeper study of the combustion process through the CFD simulation, since the Turbec T100 combustor cannot operate with syngas without structural modifications.

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Nomenclature

G	Gasifier
GWP	Global Warming Potential
HHV	Higher Heating Value
LHV	Lower Heating Value
MGT	Micro Gas Turbine
ORC	Organic Rankine Cycle
η	Overall efficiency

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