Applied Energy 101 (2013) 423–431

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The IPRP (Integrated Pyrolysis Regenerated Plant) technology: From concept to demonstration

Bruno D'Alessandro [a,1], Michele D'Amico [b,*], Umberto Desideri [c,2], Francesco Fantozzi [c,3]

[a] BIONET – Biomass and New Technologies S.r.l., C. so Tacito 101, 05100 Terni, Italy
[b] Biomass Research Centre, University of Perugia, Via G. Duranti, 06125 Perugia, Italy
[c] University of Perugia, Department of Industrial Engineering, Via G. Duranti 67, 06125 Perugia, Italy

HIGHLIGHTS

- ▶ IPRP technology development for distributed conversion of biomass and wastes.
- ▶ IPRP demonstrative unit combines a rotary kiln pyrolyzer to a 80 kWe microturbine.
- ▶ Main performances and critical issues are pointed out for different residual fuels.

ARTICLE INFO

Article history:
Received 10 October 2011
Received in revised form 20 March 2012
Accepted 19 April 2012
Available online 22 June 2012

Keywords:
Biomass
Wastes
Integrated pyrolysis regenerated plant
Pyrolysis
Microturbine
Rotary kiln

ABSTRACT

The concept of integrated pyrolysis regenerated plant (IPRP) is based on a Gas Turbine (GT) fuelled by pyrogas produced in a rotary kiln slow pyrolysis reactor, where waste heat from GT is used to sustain the pyrolysis process. The IPRP plant provides a unique solution for microscale (below 250 kW) power plants, opening a new and competitive possibility for distributed biomass or wastes to energy conversion systems. The paper summarizes the state of art of the IPRP technology, from preliminary numerical simulation to pilot plant facility, including some new available data on pyrolysis gas from laboratory and pilot plants.

1. Introduction

Biomass and waste to energy conversion is considered as one of the key technologies to reach the ambitious goals of the EU 20-20-20, where 250 TWh of electric energy from biomass is assumed to be a reasonable target by 2020 [1], because it allows to reduce fossil fuels utilization with a zero balance (biomass case) between the CO_2 absorbed during the biomass life cycle and the CO_2 emitted by the power plant. B&W (biomass and wastes) to energy solutions with grate-based combustion and heat recovery for steam production are available and proven with a minimum plant size for economical feasibility above 2 MWe and an average overall efficiency of about 25%. Higher efficiencies may be obtained through an intermediate conversion (gasification) that converts B&W into a medium–low calorific fuel gas that can be used in a high efficiency cycle based on Internal Combustion Engines (ICEs) or Gas Turbines (GTs). These technologies, however, are still at a demonstration phase, and their availability and performance on the long term are still to be proven. They could provide a solution for microscale conversion, which results in lower environmental impact and costs of the supply chain, by taking advantage of the distributed nature of B&W, easy access to waste heat small users for CHP applications and simplified authorization procedures. Yet there are few available technologies for biomass conversion on the microscale mainly based on pyrolysis and gasification [2–6]. Given this background, the authors have proposed, and optimized, an innovative integrated approach, namely the IPRP (Integrated Pyrolysis Regenerated Plant) [7,8], that combines a rotary kiln pyrolyzer and a gas turbine fuelled by the pyrolysis gas produced from the thermal degradation of biomass and waste. This papers resumes the results obtained and the path followed from

* Corresponding author. Tel.: +39 075 5853929; fax: +39 075 5153321.
E-mail addresses: dalessandro@bio-net.it (B. D'Alessandro), damico@crbnet.it (M. D'Amico), umberto.desideri@unipg.it (U. Desideri), francesco.fantozzi@unipg.it (F. Fantozzi).
[1] Tel.: +39 0744 7730896; fax: +39 0744 773110.
[2] Tel.: +39 075 5853743; fax: +39 075 5853736.
[3] Tel.: +39 075 5853775; fax: +39 075 5853736.

0306-2619/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2012.04.036

Nomenclature

AD	aero-derivative	MSW	Municipal Solid Waste
β	manometric compression ratio	PE	polyethylene
B&W	biomass and wastes	PLC	programmable logic controller
GT	Gas Turbine	REC	recuperator
HD	heavy duty	REG	regenerator
ICE	Internal Combustion Engine	RR	Regeneration Ratio (%)
IGCC	Integrated Gasification Combined Cycle	TDC	Top Dead Centre
IPRP	Integrated Pyrolysis Regenerated Plant	TGA	thermo-gravimetric analysis
LHV	lower heating value (kJ/kg)	TIT	Turbine Inlet Temperature (K)
mGT	micro Gas Turbine	Tp	pyrolysis Temperature (K)

preliminary thermodynamic optimization to experimental testing and demonstration.

2. IPRP concept, optimization and performance

The following section describes the IPRP concept and the results of the sensitivity analysis on main thermodynamic parameters to obtain best performing operating points at different scales. Finally overall performance with different fuels are discussed.

2.1. Concept and optimization

The IPRP technology is mainly composed of a Gas Turbine (GT) fuelled by synthesis gas obtained by slow pyrolysis of biomass and/or wastes in an externally heated reactor. The energy required to sustain the pyrolysis process is provided by the exhaust gases of the GT and by combustion of pyrolysis volatiles (tars) and solid (char) byproducts. Fig. 1 shows the flow diagram of the IPRP concept which considers two possible heat recovery schemes to increase plant performance by means of regenerating the heat of the Joule cycle through a double stage air preheating. Thermal energy of exhaust gases at the turbine outlet may be recovered in the regenerator (REG) while thermal energy of the exhaust gases at the pyrolyzer outlet may be recovered in the recuperator (REC). A preliminary thermodynamic optimization of the IPRP technology was carried out [7–8] through software modeling and a sensitivity analysis on main design parameters such as GT compressor ratio (β), Regeneration Ratio (RR), Turbine Inlet Temperature (TIT) and pyrolysis Temperature (Tp) which have a competing effect on overall efficiency. For example, a higher Tp usually yields more syngas, hence more electricity, but less char while requiring more thermal energy, therefore an additional external fuel could be necessary. Similarly, a higher β usually increases the GT efficiency while resulting in a lower exhaust gases temperature, therefore a lower amount of energy is available to the process. The details of the software model and of the calculation method can be found elsewhere [9]. When considering only the β and TIT dependence, the overall efficiency shows trends coherent with those obtainable for simple GT cycles with a typical maximum that is obtained for lower (β) when decreasing the TIT. IPRP technology appears therefore to be suitable at every GT scale because decreasing the TIT (it is typical when reducing the GT size) the best plant efficiency point moves to lower values (also typical of reduced GT size). This shows that IPRP technology is a scalable concept because best efficiency points are obtainable for combinations of operational parameters that are consistent with micro Gas Turbines (mGT), aero-derivative (AD GT) and heavy duty GTs (HD GT). When considering also the effect of Tp it is shown that overall efficiency also increases as long as there is available char and tar, while decreasing abruptly when combustible byproducts are lacking. When considering the effect of the RR the use of the recuperator strongly enhances plant performance while the regenerator has a positive effect only for small values of (β), being appropriate only when using microturbines. Fig. 2 shows the main results of the thermodynamic optimization; the graph shows best efficiency points as a function of Turbine Inlet Temperature (TIT) for two different plant configurations: heat is recovered both from the gas turbine outlet and the pyrolyzer outlet (REC & REG line) and no heat recovery (no REC, no REG line). The values of compression ratio (β) and pyrolysis Temperature (Tp) that yield best efficiency points are shown with white and black points. Varying the TIT, different compression ratio are considered

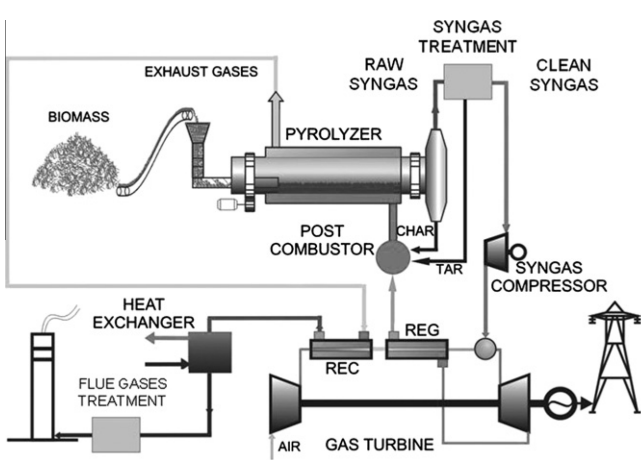

Fig. 1. The IPRP concept layout.

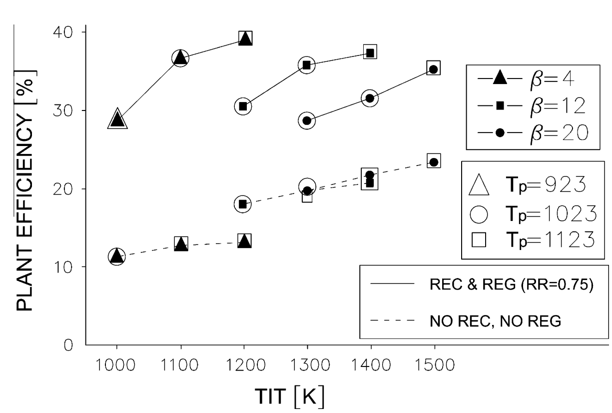

Fig. 2. Simulation results for typical parameters of different GT size on plastic behaving residue [8–9].