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A low-cost pyrogas cleaning system for power generation: Scaling up from lab to pilot

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HIGHLIGHTS

- Oil scrubber and char adsorber for tar removal has been installed to rotary kiln pyrolysis plant.
- Used oil and char will be utilized again as fuel of IC engine and heat source for pyrolysis reactor.
- The demonstrating test was successfully accomplished with 98.7% gravimetric tar removal.

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ABSTRACT

An effective pyrogas cleaning system is necessary for downstream application of biomass pyrolysis technology for power generation. Particularly, tar must be lowered to a satisfying level in order to avoid the problem of tar blockage for preventing damage to the engine and to prolong the engine lifetime. This research was carried out from previous successful research on oil scrubbers and char adsorption for tar removal. Further lab scale experimentation was done to find the appropriate quantity of oil to be used in the scrubber; the results were used for scaling up and showed that the optimum system needed for 0.045 m^3/h pyrogas the quantity of 1 l, during a test lasted 30 min. The 1 l oil scrubber was combined with a 41 g char adsorption bed and 97.6% gravimetric tar removal efficiency was obtained. The combination of the oil scrubber and the char adsorption bed was scaled up and installed into the IPRP (Integrated Pyrolysis Regenerated Plant) at the University of Perugia, with chestnut wood (*Castanea Sativa Miller*) as feedstock, and connected to a 6 kWe Lombardini engine with a power generator and electric load. Pyrogas was sampled at 0.7 m^3/h and connected to the cleaning system, consisting of a 15 l oil scrubber combined with a 922 g char adsorption bed. The demonstrating test was successfully accomplished with 98.7% gravimetric tar removal at the exit of the char adsorption bed. The engine ran smoothly and the electric load was constant.

1. Introduction

The Integrated Pyrolysis Regenerated Plant (IPRP) technology is mainly composed of a Gas Turbine (GT) fuelled by 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 process products, such as volatiles (tars) and solid (char). Good results in thermodynamic optimization lead to the realization of a pilot unit, designed and built at the Terni facility of the University of Perugia and working either with an engine (Caterpillar 3306, 100 kWe) or with a gas microturbine (Elliot T80, 80 kWe). The flow diagram of the IPRP plant is the same as presented in previous papers [1,2]. Biomass is fed through a hopper to the rotary kiln pyrolyser as shown in Fig. 1, which is the reaction chamber where the thermal degradation to pyrogas, char and tars of the biomass is achieved, in the absence of oxygen.

The refractory chamber contains the rotating reactor and an underfed char combustion system. Char combustion provides the heat required for pyrolysis while combustion air is provided either by a dedicated air blower or from gas turbine exhaust gases, depending on operational requirements. A natural gas burner is situated also in the refractory chamber above the char combustor to provide eventual additional heat, for temperature control, and for start-ups. Pyrogas from the pyrolyser is cleaned from particulate in a cyclone and cooled, to condense tars and water in a wet scrub-

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Nomenclature

e	effluent	CV	char volume (l)
i	gas component	FR	flow rate (m^3/h)
0	initial	H	hydrogen (%w)
IC	internal combustion	LHV	low heating value (kJ/kg or kJ/m^3)
IPRP	Integrated Pyrolysis Regenerated Plant	*m*	mass of the adsorbent/absorbent (g)
Micro GC	micro gas chromatograph	*N*	nitrogen (%w)
P.I.D.	Proportional-Integral-Derivative controller	OUR	Oil Usage Rate (l/h)
SEM	Scanning Electron Microscope	S.F.	Safety Factor (–)
SO	sunflower oil	TV	tar volume (l)
db	dry basis	*x*	amount of solute adsorbed (g)
BET	isotherm of Brunauer, Emmett and Teller (m^2/g)	*Y*	volume of combustible gas (%v)
c	concentration (g/m^3)		
C	carbon (%w)		
CUR	Char Usage Rate (g/h)		

bing section, composed of a two stage quencher for temperature abatement, a Venturi scrubber, a two stage scrubber with a demister. Heavy and light tars are extracted from the bottom and the top of the pool and may be returned through a hot pipeline to the char burner in the refractory chamber of the pyrolyser. Pyrogas is drawn from the pyrolyser through the cleaning section by a side channel blower whose rotational speed is regulated to maintain the rotary kiln in slight depression providing the required pressure for the pyrogas compressor of the microturbine. A picture of the reactor is proposed in Fig. 2.

Tars, especially the heavy tar, have been troublesome for the plant operation, due to large amount of water needed for the tar removal and further for the cost of tar-scrubbed water treatment. Besides, the performance of water for tar removal is quite low [3]. There are many possible techniques of tar removal depending on where tar is removed. In primary methods, tar will be removed inside the chamber of pyrolysis process [4] and for secondary methods [5], which are more efficient, economical and easier to control, tar is removed outside the reactor through a gas cleaning section. Gas cleaning methods can also be divided into thermo-chemical (catalytic and non-catalytic such as thermal cracking) and physical (such as adsorption and absorption) processes [6,7]. The physical process is attractive by a technical and economical point of view; moreover it is uncomplicated and adaptable. However, it also depends on gas quality specifications required for specific downstream applications, especially the engines or gas turbines. Han and Kim [8] indicates 5 main reduction or reforming processes: mechanic methods (such as filters, granular beds, rotational particle separators, electrostatic precipitators, and scrubbers), modification of the plant itself, catalytic cracking, thermal cracking and plasma methods. All these methods reach an average tar reduction efficiency comprised from 50% to 74%. Top efficiency technologies

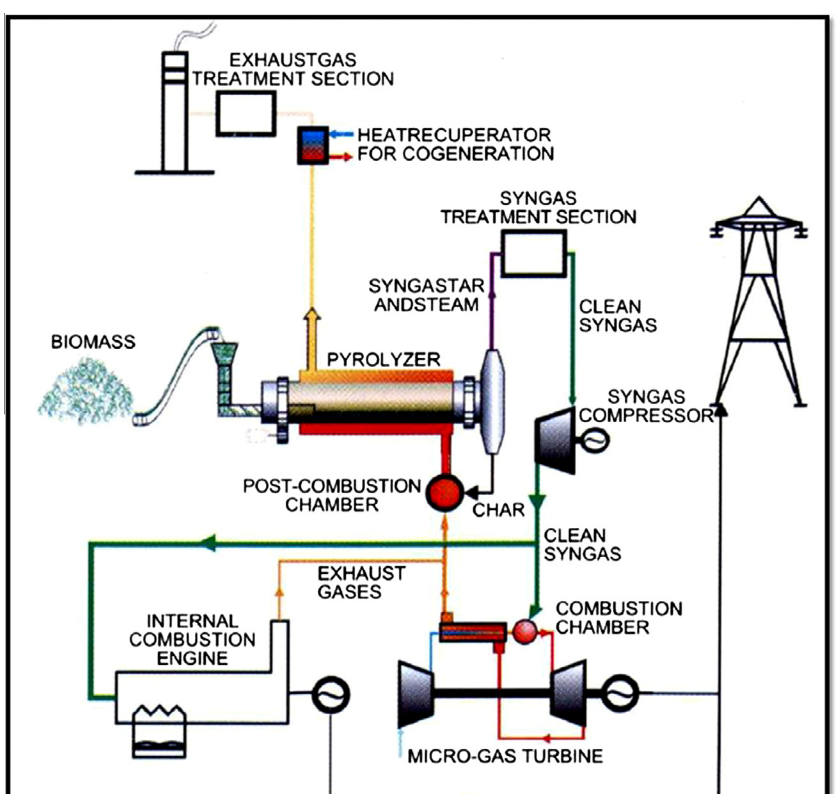

Fig. 1. IPRP (Integrated Pyyrolysis Regenerated Plant) layout.