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Pyrogasification to Produce Biogas and Biomethane from Wood Wastes

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ABSTRACT

This communication contains information on some existing plants in Italy of pyrogasification of woody biomass, there is the treatment at a temperature between 800-1200°C before in absence of oxygen(pyrolysis) and subsequent in lack of oxygen (gasification) to obtain a gas which it then sent to an internal combustion engine which produce electricity and heat. Subsequently we shall report information of two demonstration plants realized in Europe of production of biogas from woody biomass by gasification and consecutive hydrogenation to biomethane. It is also reported a pilot plant realized in Italy of production of biogas by gasification and consecutive hydrogenation to biomethane by hydrogenation with hydrogen produced by electrolysis of water.

1. INTRODUCTION

The technology of pyrogasification, also called simply gasification is to date one of the cleaner and more environmentally sustainable process on the market [1, 2]. It consists of an endothermic chemical process, thanks to which solid fuels rich in carbon are converted into a synthesis gas containing as main components CO, CO_2, H_2, traces of CH_4 and other products, depending from the technology and raw material used (type of biomass, size and water content, etc.). Among the coproducts it is possible to obtain NH_3, H_2SO_4 and HC_l as well a not- gasifiable parts composed of dust and ash [3]. The production of gas (biogas) does not diffuse any emission into the atmosphere and does not produce dangerous liquid wastes. The biogas obtained is used nowadays in many plants in Italy to produce electricity and heat and several demonstrative plants in Europe and a pilot plant in Italy of purification of the biogas and its hydrogenation to biomethane.

2. PYROGASIFICATION

Pyrogasification (or gasification) can be divided into 4 phases: drying, pyrolysis, oxidation and finally in some cases also reduction. The process of pyrolysis can be also of flash pyrolysis, followed by the gasification process and possibly also by other chemical treatments to produce the syngas for the use in endothermic engine to produce energy and heat (2.4). Flash pyrolysis, which is the second stage after that first one of drying, consists in the transformation of biomass between 650-750°C with contact time of less than one second in absence of oxygen to produce 85% of *a* gas (CO_2, CO, H_2), 5% of a liquid and 10% of a solid (biochar). Gasification is the treatment of the products of flash pyrolysis) at temperature between 1000-1300°C in lack of oxygen to transform bio-oil and biochar, obtained in the pyrolysis stage, into CO_2 and H_2O, which immediately after, depending on the type of used reactor they undergo a reduction process on carbon or bio char. The CO produced subsequently reacts with water (water gas shift reaction) to produce CO_2 and H_2 (increasing the caloric value of gas). There are also other secondary reactions such as Boudard reaction($C+CO_2$->CO), the reforming of carbon oxides on organic compounds to produce CO etc. The gas thus obtained is therefore a mixture of other substances, which must be removed before the gas is sent to an internal combustion engine, or more rarely, to a turbine, to produce energy electricity and heat. The heat produced is used both to dry the biomass and for eventually district heating. The production of thermal energy takes place in three stages: from the cooling of gas produced in the reactor from the cooling of water of the radiator and from the cooling of smoke gas. Pyrogasyfcation has also the advantage of allowing the construction of small plants, compatible with the electricity distribution network and with the raw materials that come closely.

2.1 The pyrogasifier of Villanova Mondovi (Italy)

The pyrogasification plant built in Villanova Mondovi (Cuneo-Italy) in 2010 with Pyrox Italia technology [4] produces biogas that it is burned to produce 1200 thermal kW and 995 electric kW consuming 1.2 t/h of dried wood chips with 10-15%H_2O. The woody biomass is supplied by lumberjacks and by sawmills in the neighbouring area, minimizing the economic an environmental impact related to transport. The process is carried out in four stages on the same reactor: drying, ultrafast pyrolysis at 800°C in the absence of oxygen, gasification in lack of oxygen to convert the carbonaceous solid residues products in the previous pyrolysis stage into a gas and a last one reduction stage. The Syngas thus obtained has the following composition: CO 21%, H_2 24% CH 41.6%, N_2 40%, CO_2 12% and ashes 0.8%.

2.2 The pyrogasifier of Borgosesia (Vercelli- Italy)

Terni Energia launched a pyrogasification plant designed and supplied in 2012 by Pyrox Italia powered by woody biomass in municipality of Borgosesia (Vercelli -Italy) [3] which will be able to treat 8000t/y of virgin wood. The woody wastes are transformed into syngas for feeding high efficiency motor which is connected to a generator to produce electric and thermal energy. The plant consists of four phases: wood drying, pyrolysis, cooling and gas purification and finally combustion of the syngas in a combined cycle engine producing 850kw electrical and 1100kw thermal energy.

2.3 Pyrogasifier in Torre Pelice (Torino)

TEA systems built in 2015 a pyrogasification plant at Torre Pelice (Torino-Italy) of biomass to produce 200kW of electricity. The plant consists of four stages realized in a single reactor: drying of biomass till 0% of humidity, ultrafast pyrolysis, gasification in lack of oxygen, a reduction with a bed of active coal and final separation of the char (a solid), The biomass come from undergrowth wood, waste wood, wood used pruning cutting from public green residues of agricultural facilities, agricultural processing residues and wastes of food.

2.4 The pyrogasifier of Bolzano (Italy)

A two stages pyrogasifcation plant was created in 2019 by FON Energy province of Bolzano (Italy) [4] that it produced 200kw of electricity and 300kW of thermal energy. The plant consisted of a stage of oxygen free pyrolysis operating at 700-730℃ and subsequent gasification stage that operate at 1100℃ in lack of oxygen to transform the solid products obtained from pyrolysis in gas which is used to produce energy, The two stages are built in the same reactor. The biomass used are the by products derived from the processing of forest products and the residues of public and private cleaning of green areas. The biomasses used in the system were 225kg /h which were dehumidified to 20% of H_20.

2.5 The pyrogasification plant of Correggio (Italy)

The gasification plant of Correggio (Reggio Emilia -Italy) created by Graziella Greenpower Spa is a modular plant with 7 fixed bed downdraft gasifiers working in parallel and they feed 7 groups of cogeneration plants of 130 kWe each with a consumption of 0.9kg /kWe produced. The Correggio plant started to work in July 2020, but it is arrived to fully operation, due to Covid in the spring of 2021 [4]. The modularity allows always to have a high production even when some lines of production are in maintenance. The biomass, before entering the gasifier, undergoes a screening and drying process fundamental to make the product homogeneous and suitable for the gasification process, which it requires a high degree of consistency as regards the size and humidity.

The biomass in this case is introduced from above in the reactor and meets the 4 phases of the process: drying, pyrolysis, oxydation and reduction. In the gasifier there is a throat in shape of V inside which air is sent, which could also be enriched with oxygen to which internal gasification takes place. The syngas, together with the powdery part, comes out the low of the reactor and is then filtered at high temperature to separate the syngas from the part solid (biochar), then the stream is cooled, to condense the tar and finally it is further cleaned before being sent to an internal combustion engine. The gas obtained has the composition: CO(18-24%), H_2(4-10%), CH_4(2-4%), N_2 50%, CO_2 (8-10%), O_2 and Ar 1-2%.

3. THE PRODUCTION OF BIOMETHANE BY HYDROGENATION OF THE BIOGAS PRODUCED BY GASIFICATION

The biogas produced by gasification of woody biomass after purification in order to transform some impurities in CO and H_2 and to eliminate the impurities that can deactivate the catalyst of hydrogenation of CO and CO_2. Information are reported on two demonstrative plants realized in Europe some year ago. A pilot plant has been realized in Italy where together with a gasification and hydrogenation sector it has been realized a pilot plant of production of H_2 by electrolysis of water to increase the amount of CO and CO_2 hydrogenated to biomethane.

3.1 Production of biomethane in Gothenburg (Sweden) by gasification of woody biomass and consecutive hydrogenation

The world's first plant of production of bio-methane from biomass by hydrogenation of biogas produced by gasification started in Gothenburg in March 2014 with the production of 20mW of biomethane (2200Nm^3/h) [5]. This plant realized in Gothenburg, called Gobigas, was a demonstrative plant of production of biomethane by gasification of wastes of forests and pellets of wood. The gasification plant consists of two fluid bed: in the first fluid bed enters the biomass and water and the products are biogas and tar; in the second fluid bed enters the tar and air to produce the heat necessary for the first gasification bed. The production of biogas by gasification is realized with the flowing plants: 1) a gasifier to produce the biogas; 2) a combustor to burns the tar and to produce heat for the gasification plant; 3) a cyclone to eliminates the great part of tar and ash: 4) a post combustor to control fuel gas emission from the combustion reactor; 5) a gas cooler of biogas to 160-230C; 6) a textile bag filter to remove aromatics with two or more rings; 7) a scrubber with rape methyl ester (RME) to remove completely heavy aromatics; 8) several adsorption plants with activated carbons to eliminate benzene and toluene; 9) a flue gas train to purify the flue gas; 10) a lock hoppers; 11) several compressors. The biogas produced after all these steps has the following composition: H_2(38.3%), CO_2(21.40%), CO(20.82%), CH_4(9.87%), CH2=CH2(2.36%).

The biogas purified in the first section, previously described is transformed in biomethane with the followings plants: 12) hydrogenation of olefin and COS to eliminate sulphur and to produce H2S and also to eliminate any chloride trace components; 13) then gas is sent to a gas scrubber to eliminates H2S and a part of CO_2 with a solution of ammine; 14) then the gas passes through a guard bed to remove all traces of H_2S not removed in the previous plant; 15) a water gas shift reactor to adjust the molar ratio between H_2 and CO by transforming CO with H_20 in H_2 and CO_2; 16) a pre-methanation reactor or which acts as a reformer for all hydrocarbon heavier than methane to produce more CO and H_2 and also some CO and CO_2 are transformed to CH_4; 17) a CO_2 scrubber to remove CO_2 by adsorption with an amine; 18) a methanation reactor with a catalyst to transform CO and CO_2 in methane; 19) a dryer to eliminate water from biomethane before to be fed to

the natural gas grid. The final composition of the gas in volume is the following one: CH_4>94%, N_2<3.5%, CO_2<2.5%, H_2<2%, CO<0.1%, NH_3<20ppm.

3.2 Production of biomethane in Alkmaar (NL) by gasification of woody biomass and consecutive hydrogenation

In Alkmaar (Nl) in 2015 started the production of 2.6 million m^3/a of biomethane that they called Bio-SNG (bio-substituted natural gas) by gasification of woody biomass, while a pilot plant has been realized in 2004 and a pilot plant in 2008 (Figure 1). The plant has been realized with the following advanced technologies: Milena technology for the gasification plant; Olga technology to separate tar and ash from the biogas produced in the gasification plant; ESME technology to produce biomethane by purification and hydrogenation of the biogas [6].

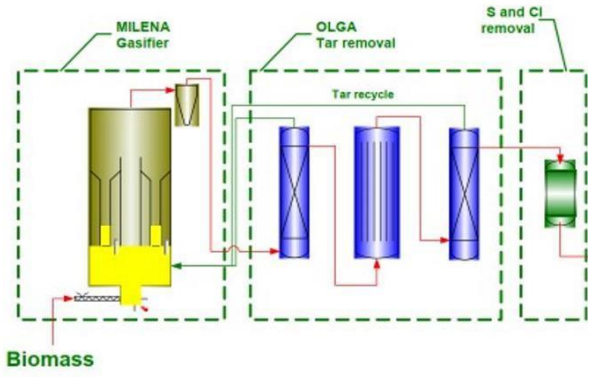

Figure 1. The Alkmaaar plant

The Milena technology, is based on the gasification of woody biomass with steam and oxygen and it utilize *an "indirect" gasification" that is* characterized by the fact that the pyrolysis and combustion reactions are separated, but only one vessel is used to accommodate both reactions. The advantages of this technology is that it separates combustion flue gas exhaust from the biogas, that it is not diluted with the nitrogen present in air and not from CO_2 from the combustion. The heat to the gasification reactor is transported from the combustion reactor that it uses the tar, that is transported from the gasification reactor to the combustion reactor after separation from the biogas. The biogas obtained has the following composition: CO(34%), CO_2(17), CH_4(15), H_2(24), CH_2=CH2(5), BTX (1%), N_2(3%), others as CxHy, NH_3, H_2S(1%).

The Olga Technology is the realisation of the separation of tar from biogas by cooling, filtration and partial oxidation and the tar after cooling is removed and recycled in the combustion reactor.

The ESME technology is the realization of the further purification of biogas and hydrogenation of CO and CO_2 to methane and occurs in the following steps: hydrodesulphurization at 300°C to produce to produce H_2S and hydrocarbons; the use of the adsorbent to eliminate H_2S and HCl to protect the catalyst of methanation; a pre-reformer which operate at 500- 600°C to transform higher alkanes in methane and syngas with nickel based catalyst; elimination of 85% of CO_2 with a scrubber with ammine; methanation of purified biogas to CH_4 and H_20 and the surplus of CO_2 is also hydrogenated to methane; elimination of water by freezing.

3.3 Experimental plant in Casaccia (IT) of production of biomethane by gasification of woody biomass and production of hydrogen

The gasification plant of Casaccia (RM) realized by ENEA in 2018 is a pilot plant integrated with the technology "Power to gas" to produce hydrogen by electrolysis of water in order to increase the amount of CO and CO_2 hydrogenated to methane (Figure 2). The biomethane by the scientists of ENEA was called SNG (Substituted Natural Gas) and the plant was named Gessyca (Generation Sperimental Syngas from Carbon) but not only from carbon but also by biomass [7]. The plant had the followings sections: a gasification reactor with an updraft fixed bed that used woody pellets and some apparatus to eliminate from biogas tar and ash; a combustor of tar to produce energy for the gasification reactor; some purification plants of biogas, a scrubber with H_2O to adsorb nitrogen containing compounds and NH_3, a scrubber with biodiesel to eliminates the traces of tar; a desulphurization column; an adsorption plant with active carbon to eliminate all the traces of impurities; three reactors of hydrogenations of biogas to biomethane (Bio-SNG), a plant of production of hydrogen by electrolysis of water, and introduction of hydrogen in the hydrogenation reactors to increase the amount of methane produced, by hydrogenating also CO_2. The obtained BIO.SNG presented 97% of CH_4.

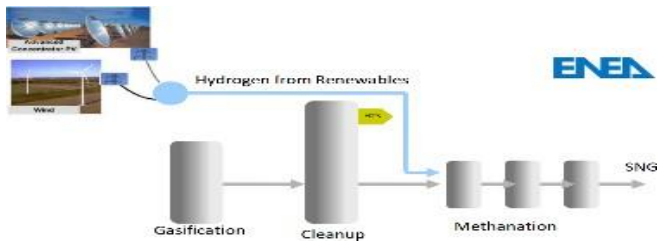

Figure 2. The Casaccia plant

4. CONCLUSIONS

Actually only 10% of biomethane is obtained by gasification of woody biomass 90% is obtained by upgrading of biogas (CH_4 CO_2 and others) obtained by anaerobic digestion of organic wastes (agricultural, urban organic, by product agricultural industries and animal). The biogas is essentially produced to obtain in situ heat and electricity, in Italy there are 2000 plants of production of biogas the fifth country in the world, but only 44 of production of biomethane and 1000 in Europe.

In the world there are several industrial plants of production of biogas by gasification of woody biomass, like in Italy, but essentially only demonstrative plants and pilot planta to produce biomethane, but in the future with the increase of the prize of methane the production of biomethane by gasification and consecutive hydrogenation of woody biomass can become competitive.

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