EXPERIMENTAL STUDIES ON THE GASIFICATION OF THE RESIDUES FROM PRUNE OF APPLE TREES WITH A SPOUTED BED REACTOR

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ABSTRACT: Agricultural residues offer a widespread availability and a suitable potential energy content. For this reason, the residues from the prune of apple trees, which are agricultural residues, were evaluated for their use as feedstock in thermochemical processes in order to obtain energy.The main objective of this study was to investigate the characteristics of the residues from the prune of apple trees when converted to syngas by gasification in a 20kW Spouted Bed pilot reactor. The obtained gases were studied in a quantitative and qualitative way through the evaluation of the key operating parameters for the gasifier: gasification temperature, the biomass feeding rate, air equivalent ratio and the steam-to-biomass ratio. Based on the results, an optimal range for the key operating parameters for the Spouted Bed reactor is recommended.
Keywords: spouted bed, agroindustrial residues, gasification, syngas, fluidized bed

1 INTRODUCTION

Research on fossil fuels and renewable resources indicates that a shift from the former to the lattershould be supported to prevent both climate change and the possible shortage of energy resources. At the same time, agricultural residues offer a widespread availability and a suitable potential energy content.

The treatment of these wastes are attracting numerous researchers. Nowadays, one of the best treatment for them is to burn them with energy recovery or for landfilling. However, both combustion and landfill use cause secondary pollution problems. Novel disposal technologies are in high demand to provide for more energy efficiency and environmental and economical solutions [1].

A potential solution is to gasify the agricultural residues. In particular, the residues from the prune of apple trees, which are agricultural residues, were evaluated for their use as feedstock in order to obtain energy.

Gasification is a process that converts liquid or solid matter in gas through chemical decomposition. This process requires a gasifying medium such as air, oxygen, steam, CO_2 or mixture of these species. This gasifying medium has a double role: it increases mass and heat transport phenomena and it supplies the oxidizing agent. The gasification process typically works at the temperature range of 600-1200°C [2].

Products of gasification processes are syngas, tars, char and ashes. Syngas is a gas mixture mainly composed by CO, CO_2, CH_4, H_2. The difference between pyrogas and syngas is due to the generating process: the first derives from pyrolysis, while the second from gasification. In general terms, gasification is a compromise between endothermic pyrolysis and exothermic combustion, and it is a process that requires proper tuning of operating conditions and feeding compositions [3].

The gasification process takes place in a reactor named gasifier. Gasifiersare usually classified according to their solid handling characteristics, because the solid is the controlling phase in terms of transport phenomena and reaction kinetics. In order of increasing costs, complexity, efficiency and typical sizes, there are moving bed, fluidized bed (FB), bubbling fluidized bed (BFB) and entrained flow gasifiers[2]. For this work, the type of gasifier studied is a Spouted Bed Reactor.

A Spouted Bed Reactor is a fluidized bed device where gas (or occasionally liquid) is injected vertically upwards through a single central orifice into a bed of solid particles. If the flow rate of the fluid is sufficient and the bed depth is less than the ‘‘maximum spouted bed depth’’, the central jet breaks through the upper surface, resulting in a characteristic flow pattern known as spouting. Three regions can be distinguished in a spouted bed reactor: a dilute central jet, called “spout”, in which particles are entrained, a peripheral annular region called "annulus" and a “fountain” region above the bed surface where entrained particles ascend centrally and then return less centrally due to gravity forces to land on the bed surface. In the annulus, fluid percolates outwards and upwards, counter-current to the movement of the particles [4]. The overall bed thereby becomes a composite of a dilute phase central core with upward moving solids entrained by a concurrent flow of fluid and a dense phase annular region with counter-current percolation of the fluid. A systematic cyclic pattern of solid movement is established with effective contact between the gas and the solids. The vessel forming a spouted bed is usually a circular cylinder, but sometimes it may have a square section. To enhance the solid motion and eliminate dead spaces at the bottom of the vessel, it is very common to use a diverging conical (or pyramidal) base [5].

2 MATERIALS

The composition of the residues of the pruning of apple trees was calculated at the laboratories of the Free University of Bolzano. The results are shown in Table I and Table II. The lower heating value is 17.21 MJ/kg.

Table I: Ultimate analysis of the residues of the pruning of apple trees (wt %)

Biomass proprieties	(wt %)
C	48.88
H	5.71
O	42.15
N	0.26
S	0.13
Ash	2.87

Table II: Proximate analysis (wt % dry basis) and moisture content (wt %)of the residues of the pruning of apple trees

Biomass proprieties	(wt %)
Ash	2.87
Volatile Matter	95.9
Fixed Carbon	1.23
Moisture content	8.13

3 SPOUTED BED REACTOR

3.1 Spouted Bed Reactor Pilot Unit

The core of the apparatus is a square based spouted bed unit; the pre-heated fluidizing gas comes from a burner, while the exhaust gasses are cleaned from powders in a cyclone followed by a water scrubber to cool them and remove fines.

The solids feed point in the vertical wall of the reactor is connected to a hopper from which the particles can be continuously fed in the reactor.

The shell of all the equipment, such as the burner, the spouted bed reactor and the water scrubber, is composed by two different types of material: an insulating layer of 60 mm thickness and a refractory concrete based on silica oxides. In this way, the high temperatures generated by the chemical reactions inside the reactor do not represent a serious problem. The only critical point for steel is the connection between the burner and the reactor, but in any case a thermocouple monitors constantly the situation.

3.2 Burner

The spouting gas is generated in the burner. The burner mixes air and propane at the desired ratio, in order to pre-heat the gas flow for fluidization.

The burner is composed of the following modules: burner housing, burner insert and ceramic tube.

3.3 Reactor Body

The reactor body (Fig.1) is a square based spouted bed reactor, with a side of 200 mm and a total high of 2.0 m; the base has an included angle of 60°, while the spouting orifice at its centre has a 21 mm diameter.

Figure 1: Reactor body

The reactor base has a truncated pyramid shape. At the bottom of the pyramid, a metallic cylinder connects the gas inlet. The unit has the possibility to feed and discharge continuously the solids, thanks to these two openings placed in the vertical wall of the reactor at 200 and 350 mm from the base.

The middle section is placed above the base and it extends the bed depth of additional 1.5 m; the main task of this part is to contain the fountain for all its length. For the connection with the solid feeding system, there are two different channels, characterized by a slope of 60 deg to avoid obstructions; the feeding points are placed respectively at 500 and 700 mm from the base. The two pipes for the discharge of solids in continuum are inside the concrete, for this reason the fluid dynamic is not affected and consequentially does not affect the process.

The top section, named also disengagement zone, has a bigger cross sectional area, which passes from 200 mm to 400 mm side, with a 60° slope. This configuration reduces the gas velocity and consequently reduces the elutriation of powders and sand fragments.

In the wall there is an additional manifold connected to a rupture disk of 3 inches, placed for safety reasons. In addition, it is present a connection to a U-manometer to measure the pressure inside the gasifier.

3.4 Cyclone

The gas produced in the reactor contains coarse particles resulting from the sand erosion or residues from the reaction. The first step in order to remove these particles is a stainless steel cyclone (Fig.2). The particles removed are collected in a tank, while the cleaned gas is sent to a water scrubber.

A water sprayer is placed in the pipe that connects the gasifier with the cyclone, in order to cool slightly the temperature if necessary.

Figure 2: Cyclone

3.5Water scrubber

A water scrubber (Fig.3)is mainly used to remove the remaining fine particles from the cyclone.

Figure 3: Scrubber

Another function of the scrubber is to cool down to room temperature the syngas in order to safety discharge it in the environment or to sent it to the analysis instruments.

The scrubber has a parallelepiped structure 400x400x600 mm (LxWxH) and, on the middle of the vertical walls, four sprayers are placed to inject vertically nebulised water, while the hot gas enters in the scrubber through a vertical pipe.

3.6 Solid Feed System

Solid particles are fed continuously in the reactor through a system connected to the lateral wall of the reactor. The feedstock, previously prepared and sized, is charged in a hopper (Fig.4), with a conical shape to help in the discharge. Inside this device, a blade near the walls and a vibrating system remove a possible obstructions. Out of the hopper, the particles pass through a rotary valve that allows dosing the solids inside the gasifier.

Figure 4: Solid Feed System

3.7 Flow-meters

A flow-meter panel was realized in order to regulate and visualize the volumetric flows of all the streams.

3.8 Temperature control

The temperature in the experimental unit is monitored by several thermocouples. The system makes use of probes K type, 3 mm diameter, 300 length.

A data logger connected to all the thermocouplesenables to visualize all the data acquired and to record the temperature evolution.

4 RESULT AND DISCUSSION

The fluidizing gas is generated from the burner and is a mixture of O_2 CO_2 N_2H_2O.Its composition depends on the quantity of O_2 requested in order to have different equivalence ratios (ER) in the gasifier. The ER is the ratio between the available quantity of O_2in the system and the requested quantity of O_2 from the system in order to have a total stoichiometric combustion.

The temperature of the reactor was established around 850 °C.Dry gas composition is analyzed using Gas Chromatograph (GC) coupled with a Thermal Conductivity Detector (TCD). These preliminary results do not consider the quantity of nitrogen in the syngas.

Two different types of experiments were performed: the effect of ER with a constant feeding rate around 50 g/min of residues from pruning of apple trees and the effect of feeding rate of residues from pruning of apple trees with a constant ER in amount of 0,26.

In the first case, three different values of ER were investigated:0.38, 0.26 and 0.14. In Fig.5 is possible to see the obtained results, while Fig.6 shows the results without nitrogen.

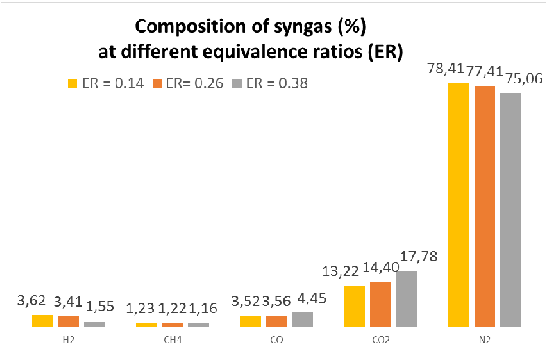

Figure 5: Syngas composition at different ER

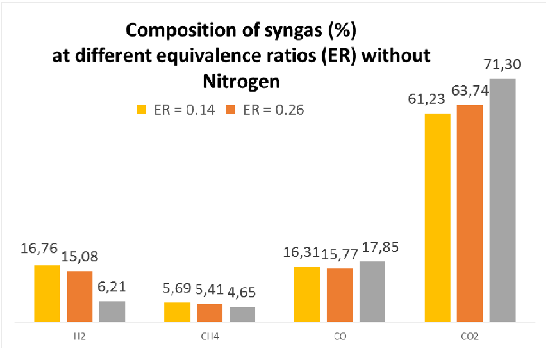

Figure 6: Syngas composition at different ER without nitrogen

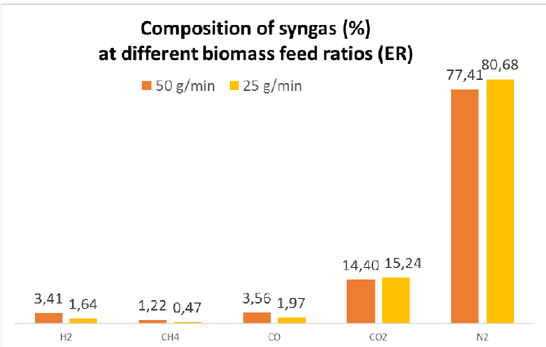

Figure 7: Syngas composition at different biomass feed ratios

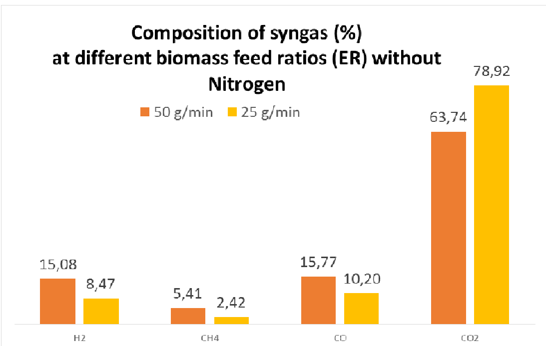

Figure 8: Syngas composition at different biomass feed ratios without nitrogen

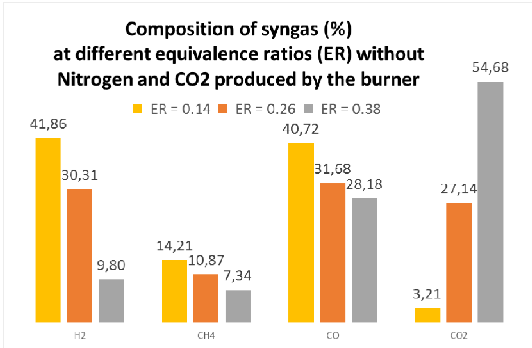

Figure 9: Syngas composition at different equivalence ratios without nitrogen and CO_2 produced by the burner

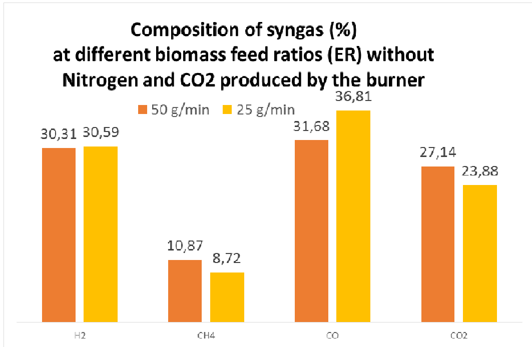

Figure 10: Syngas composition at different biomass feed ratios without nitrogen and CO_2 produced by the burner

In order to vary the ER, the mixture of gasifying gas has been changed in each test to achieve the proper quantity of oxygen.

In the second case, two different values of biomass feeding rates were investigated: 50 g/min and 25 g/min. As in the previous case, Fig.7 and Fig.8 show the composition of syngas with and without nitrogen respectively.

In order to obtain the same ER with two different biomass feed ratios, two different types of mixture of gasifying agent was used.

In the case of 25 g/min the quantity of CO_2 in the mixture was greater than in the case of 50 g/min.

In all experiments other hydrocarbons (such as C_2, C_3 and C_4) were detected.

A potential reason about the great quantity of carbon dioxide is related to the fluidizing agent. In all situations, the gasifying gas is rich in CO_2. To better understand this phenomenon, the composition of the syngas without the CO_2 produced by the burner were calculated. It is possible to see the results respectively in Fig.9 and Fig.10.

5 CONCLUSIONS

These preliminary results show that the residues from pruning of apple trees can be successfully gasified. The syngas obtained contains a great amount of CO_2 due to the nature of the fluidizing agent.

The obtained results put in evidence how, as expected, the quality of the syngas improves when the equivalence ratio decreases.

The forthcoming steps will be to optimisethe thermal control of the system allowing more stable conditions for longer periods of reaction.

Currently,on the basis of these preliminary results, the use of the obtained syngas is proposed as co-fuel in energy recovery processes.

6 REFERENCES

[1] W. A. Wan Ab Karim Ghani, R. A. Moghadam 1, M. A. MohdSalleh and A. B. Alias, Air Gasification of Agricultural Waste in a Fluidized Bed Gasifier: Hydrogen Production Performance, Energies, 2009, 2, 258-268; doi:10.3390/en20200258.

[2] C. Higman, Van der M. Burg,Gasification, 2003 1 ed. Boston: Elsevier Gulf Professional Publishing.

[3] H. Goyal, D. Seal,R. Saxena, Bio-fuels from thermochemical conversion of renewable resources: A review, 2008, Renewable and Sustainable Energy, 12, 504-517.

[4] N. Epstein, J.R. Grace, Spouted and Spout-Fluid Beds. Fundamentals and Applications, 2011, Ed. Cambridge University Press, Cambridge, United Kingdom.

[5] M. Anabtawi, N. Hilal, A. Al-Muftah, M. Khalaf, M. Leaper, M. Hastaoglu, A force balance model of a spouted bed for Darcy and non-Darcy flow in the annulus, 2005, Advanced Powder Technology, 16, 35-48, DOI: 10.1163/1568552053166700