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PRODUCTION OF CLEAN SYNGAS BY THE APPLICATION OF PRIMARY METHOD FOR TAR ELIMINATION IN DOWNDRAFT BIOMASS GASIFICATION REACTOR.

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Abstract. *A primary method for a production of clean syngas in downdraft gasification reactors is presented. The principle of this new technology consist to allow an homogeneous temperature distribution in radial direction in combustion zone; changing the fluid dynamic behavior of the mixture, formed by pyrolysis product and gasification agent in this reaction zone. To achieve the change in the fluid dynamic behavior of the mixture; the entry of gasification agency to combustion zone is opportunely oriented by means of wall nozzles. This modification in combination with the extension of the reduction zone, will allow, to increases the efficiency of the tar thermal cracking inside the gasifier and the extension of the Bounduard reactions. Consequently, the quantity of tar passing through the combustion zone without cracking and the concentration of tar in the final gas, decrease significantly in relation with the common value obtained for this type of reactor, without affecting significantly the heating value of the producer gas. In this work is presented a new design for 15 kW downdraft gasification reactor, with this technology implemented, the tar content obtained in the experiments never overcome 10 mg/Nm^3, with a lower hating value of 4,7 MJ/Nm^3. The operation and maintenance are very simple and can be carried out by non-skilled operators.*

Keywords: *Clean syngas, Biomass Gasification, Downdraft reactor, Tar*

1. INTRODUCTION

Gasification is a thermoconversion process of solid carbonaceous fuel into a combustible gas by partial oxidation. Biomass, is the oldest form of energy used by humans and generally means a relatively dry solid of natural matter that has been specifically grown or has originated as waste or residue from handling such materials (Giltrap,et, al.2003). The thermochemical conversion of biomass (pyrolysis, gasification, combustion) is one of the most promising non-nuclear forms of future energy. It is a renewable source of energy and has many ecological advantages (Babu; Chaurasia, 2003). Tar is a complex mixture of condensable hydrocarbons. Several institutions working on biomass gasification have given many definitions of tar. In the EU/IEA/US-DOE meeting on tar measurement protocol held in Brussels in the year 1998, it was agreed by a number of experts to define tar as all organic contaminants with a molecular weight higher than benzene (Neeft, et.al, 1999). Tar is undesirable because of various problems associated with its condensation, causing problems in the gasification installations as well as in the equipments that use the producer gas as fuel like internal combustion engines and gas turbines. The required gas quality to fuel an internal combustion engine is normally reached easily in the modern downdraft gasifiers, except for the content of dust and tar. Thermal, catalytic or physical processes either within the gasification process (primary methods) or after the process (secondary methods) can remove tars. Primary methods within the gasification process have the advantage that no expensive cleaning system is necessary. In addition, cracking of the tars increases the amount of combustible product gases and therefore, the efficiency of the process. There are some sophisticated options available, which have claimed to reduce tar amount significantly. However, the method must be efficient in terms of tar removal, economically feasible, but more importantly, it should not affect the formation of useful producer gas components (Devi, L. et, al.2003; Machin, E.B, et.al, 2015).

2. PROCESS DESCRIPTION

In the Imbert downdraft gasifier, the gasification agent is fed above a constriction (throat) by nozzles uniformly distributed on the wall of the combustion chamber, oriented toward the centre of the circle, that describe the perimeter of the combustion chamber. In this design, some cool zones are created near to the nozzles, where the temperature is not sufficiently higher to permit the thermal cracking of the tar present in the mixture and to undergo its secondary gasification (Reed T.B, 1998). This is one of the reasons because the tar concentration in the produced gases is not reduced. If tarry gas is produced from this type of gasifier, is common practice reduce the central constriction area, until a gas with low tar content can be produced. However, this area dimensions also play an important role in the gas production rate. In order to avoid the formation of cool zones, it is proposed to modify the fluid dynamic behavior of the mixture formed by the pyrolysis gases and the gasification agent in the combustion chamber.

2.1. The combustion chamber

Swirl flows are widely used to intensify the process of heat and mass transfer between solid particles and airflow in vortex chambers, the advantages of swirl flows has been deeply studied by several authors (Syred N. J, 1974; Lilley, D. G, 1977; Volchkov, et.al,2004; Hui-Fen, et.al, 2009; Hui-Fen, et.al, 2010). The swirl flow of the mixture could be created changing the entry angle of the gasification agent to the combustion chamber.

The Figure 1 shows a top view of the combustion chamber of the reactor, illustrating the inclination of the inlet nozzles of gasification agent.

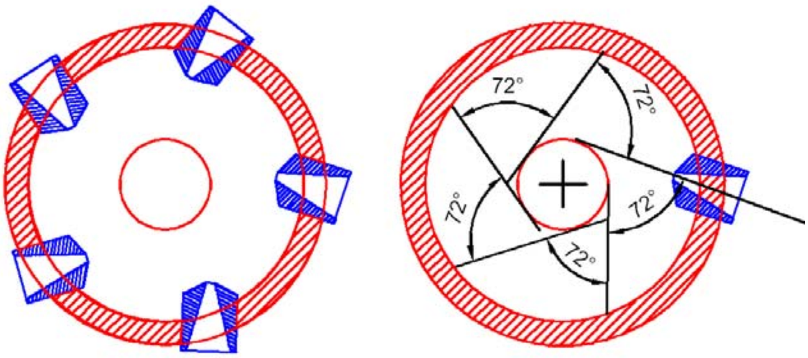

Figure 1 Nozzles inclination in the combustion chamber

3. EXPERIMENTAL APPROACH

The gasification tests were performed using three different woody biomasses, supplied by a wood processing factory. The biomasses used were Peach (*Prunus persica*), Olive (*Olea europaea*) and Pine (*Pinus pinea*).

The scheme of the downdraft wood gasifier is show in Figure 2. The gasifier unit is constituted of two cylindrical coaxial structures constructed using a mild steel sheet. An insulating material coats the external one, while the internal cylinder is provided with additional heat recuperation surfaces to improve the efficiency of the gasification process.

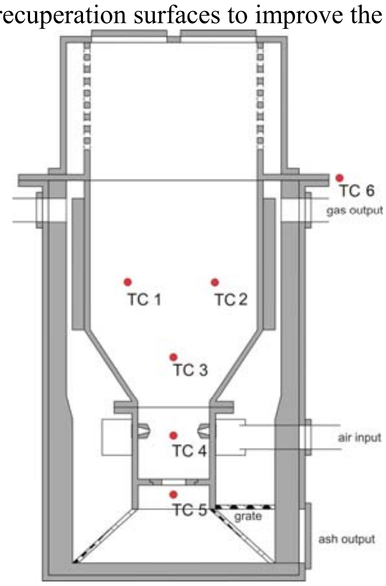

Figure 2 Reactor's scheme

The principle of the test method for gravimetric tar measurement is based on the discontinuous sampling of a gas stream, containing particles and organic compounds (tar) under isokinetic conditions; according to the methodology described in DD CEN/TS 15439:2006 (Devi, L. et, al.2003). The determination is carried out in two steps: sampling and analysis. The equipment for sampling shown in Figure 3, consists of a heated probe (module 1), a heated particle filter (module 2), a condenser, a series of impinger bottles containing a solvent (isopropanol) for tar absorption (module 3), and equipment for pressure and flow rate adjustment and measurement (module 4). Upstream of the condenser, the tubes connecting these parts are heated in order to prevent tar condensation.

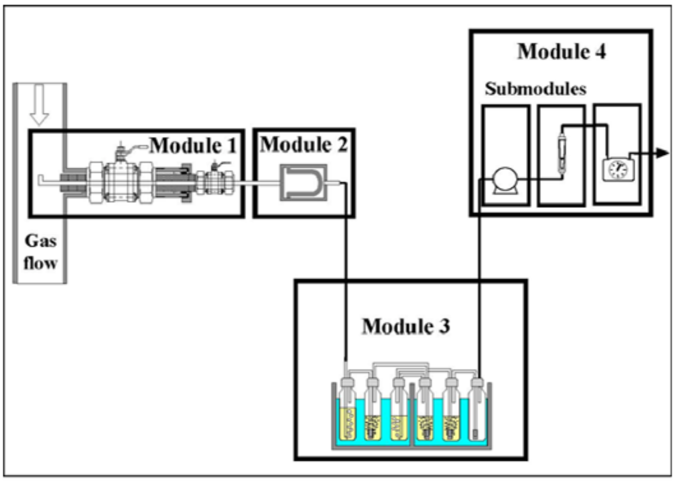

Figure 3 Modular sampling train of tar

The gasifier system was run nine times, for periods between 2.5 and 4 hours. To start the gasifier, initially the fuel biomass is loaded up to the reactor maximum capacity and is closed. Subsequently is introduced a propane gas duct by the air entrance to the reactor, to create a flame inside the combustion chamber, then the vacuum pump was turned on and the propane gas feed is removed. In less than 15 minutes or when the temperature in pyrolysis zone (TC 2 and TC 3) reaches 573 K the ignition step is completed and the record of the profile of reactor temperatures and the gases flow starts. The producer gas analyzer starts when the preset temperature profile in the reactor is reached, due to the high concentration of condensable gases in the producer gas composition during the ignition process. The tar sampling process starts at the same time of the producer gas analyzer, with the installation showed in Figure 3; each tar sampling takes 45 minutes (Pedroso D.T, et.al, 2013; Machin, E.B, et.al, 2015).

4. RESULTS AND DISCUSSION

Figure 4 shows a typical behaviour of the temperature profile in the reactor during the experiments. As it is observed, there is an oscillation of the temperature value in all the bed section during all the experiments, with the exception of the temperature of the producer gas, where the temperature remain more stable.

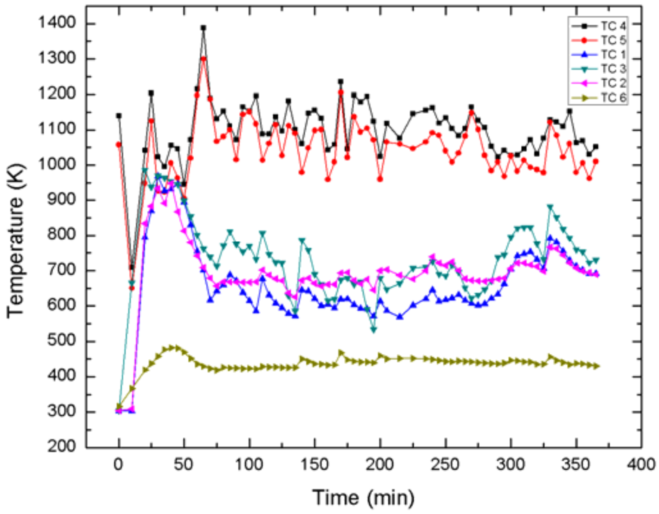

Figure 4 Temperature profile along the reactor height in the 3rd experimental test using Olive

In the Table 1 is shown the results of the tests mades in the laboratory.

Table 1: Tests results

Biomass		**Olive**	**Peach**	**Pine**
Inputs				
Gasifier conditions:				
Feed	(kg/h)	3.3	3.05	2.5
Gasifier air (20°C, 1 bar)	(kg/h)	6.79	6.20	6.45
Outputs				
Dry gas	(kg/h)	9.02	8.60	8.17
Water	(g/Nm^3)	114.5	96.5	102.3
Char – ash	(kg/h)	0.160	0.085	0.128
Tar	(mg/Nm^3)	9,10	4,07	8,73
Error	± 0,01			
SD		0,19	0,19	0,20
Dry gas analysis				
CO	(% vol.)	17.4	17.7	16.0
H_2	(% vol.)	13.2	15.0	12.1
CO_2	(% vol.)	12.4	13.5	11.4
CH_4	(% vol.)	0.8	1.2	0.2
O_2	(% vol.)	1.3	0.9	0.9
N_2	(% vol.)	54.9	51.7	59.4
Dry gas HHV	(MJ/Nm^3)	3.55	3.97	3.65
Gas density	(kg/Nm^3)	1.183	1.167	1.191
Operating ratios				
O_2/ dry biomass		0.45	0.44	0.44
CO/CO_2		1.40	1.31	1.40
H_2/CO		0.76	0.85	0.76
Mass balance and energy efficiency				
Mass in/Mass out		1.01	0.98	0.99
Cold gas efficiency		0.61	0.78	0.58

These results are because the medium content of H_2, CO and CH_4 in the producer gas obtained in the experiments with the tested reactor was slightly lower than the typical composition of the producer gas reported by several authors

(Lilley, D. G, 1977; Bentzen, J.D, 2000; Babu; Chaurasia, 2003; Neeft, et.al, 1999; Pedroso D.T, et.al, 2013; Machin, E.B, et.al, 2015). The O_2 concentration has the same behaviour, showing an increase in the combustion rate of the fuel gas in the reactor as negative effect of the modifications implemented.
The mean tar content of the producer gas obtained in the experiments was 9.10 mg/Nm^3 for Olive, 4.07 mg/Nm^3 for Peach and 8.73 mg/Nm^3 in the case for Pine. Figure 6 compares the tar content in the producer gas obtained by several authors 19-35 mg/Nm^3 (Bhattacharya, S.C. R, et.al, 1999), 5 mg/Nm^3 (Bentzen, J.D, 2000), 97 mg/Nm^3(Walker, M. et.al, 2001), 50 mg/Nm^3 (Reed, T. B; Levie. B, 1985) and 10 mg/Nm^3 (Burhenne L, et.al, 2013); with the content obtained in the studied reactor. The gas quality is comparable with the obtained in experiments with the optimized two stages gasifier, developed by Bentzen. J.D, 2000 (5mg/Nm^3), but with higher HHV. Burhenne et. al. 2013, reported similar gas quality, with a minimum tar content of 10 mg/Nm^3 and HHV between 4.85- 4.48 MJ/m^3 using a multi-staged gasification technology.

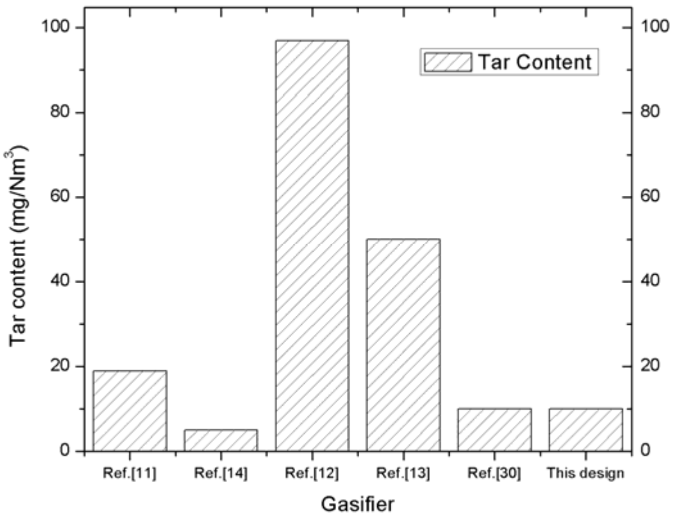

Figure 5 Comparison of the gas quality from different approaches in terms of tar content

The CO/CO_2 and H_2/CO ratios are constant; the heating value of the gas is a direct consequence of its chemical composition, which depends on the reaction conditions, rather than the heating value of the entering biomass, equal for all those experienced. The increase of the residence time of the gas mixture in reactor as consequence of the modification in the combustion chamber also has the undesirable effects of decreasing the efficiency and productivity of the gasifier; that is why these parameters are lower than in commercial gasifier.

5. CONCLUSIONS

A clean producer gas was obtained with a novel downdraft gasifier. A modified combustion chamber that prevents the formation of cool zones inside it and increases the thermal homogenization in this reaction zone was developed. This modification together with an extension of the reduction zone allows diminishing the tar content in the producer gas. The mean values of this parameter in all the experimental tests were lower than 10 mg/Nm^3. The low tar and particle content makes the producer gas obtained in this reactor suitable to the use in cycle Otto engines.

6. ACKNOWLEDGMENTS

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