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# Tar reduction in downdraft biomass gasifier using a primary method

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ABSTRACT

This work present a novel primary method, for tar reduction in downdraft gasification. The principle of this new technology is to change the fluid dynamic behaviour of the mixture, formed by pyrolysis product and gasification agent in combustion zone; allowing a homogeneous temperature distribution in radial direction in this reaction zone. To achieve the change in the fluid dynamic behaviour of the mixture; the entry of gasification agent to combustion zone is oriented by means of wall nozzles in order to form a swirl flow. 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 Boudouard 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 heating value of 3.97 MJ/Nm$^3$.



## 1. Introduction

Biomass, mainly in the form of wood, is the oldest form of energy used by humans. Biomass 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 [1]. The thermochemical conversion of biomass (pyrolysis, gasification, combustion) is one of the most promising non-nuclear forms of future energy. Biomass is a renewable source of energy and has many ecological advantages [2]. Gasification is the key technology of biomass based power generation; is a high-temperature process (873–1273 K) that decomposes complex biomass hydrocarbons into gaseous molecules, primarily hydrogen, carbon monoxide, and carbon dioxide; also are formed some tars, char, methane, water, and other constituents. 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 [polycyclic aromatic hydrocarbon (PAH)] with a molecular weight higher than benzene [3]. 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 internal combustion engines 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 be applied to remove tars. Primary methods have the advantage that dispenses the use of an expensive cleaning system for producer gas. In addition, cracking of tars in the reactor could increases the amount of combustible gases in the producer gas and therefore, the overall process efficiency. There are some sophisticated options available, which claimed a significantly reduction of the tar content in the producer gas, 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 [4].

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The catalytic cracking and electrostatic filters are two examples of the options, that claim a significant tar reduction in the producer gas, but they increase the cost of the plants, especially in the small ones. Currently, the preferred option for tar reduction is in the gasifier itself through process control and the use of primary measures such as additives and catalysts which modify gasification conditions [4–12]. Theoretically, producer gas with low tar content can be obtained if a high-temperature zone can be created, where the gaseous products of pyrolysis are forced to reside the necessary time to undergo a secondary gasification. Previous works have been developed in order to design a downdraft gasifier, able to increase the efficiency of tar reduction in the producer gas during gasification process. Bui et al. [13] developed a multi-stage reactor design that separates the flaming-pyrolysis zone from the reduction zone. In that design, the tar vapours generated in the first zone are burned or cracked to simple molecules by high temperature in the second zone, improving the gas quality and conversion efficiency. The minimum content of gravimetric tar obtained with this design was 92 mg/Nm$^3$. Susanto and Beenackers [14] developed a downdraft moving bed gasifier with internal recycle and separate combustion of pyrolysis gas with the aim of reduce a tar content in the producer gas; in their experiments a minimum of 48 mg/Nm$^3$ of tar was obtained.

On this background, the main objective of this work is to propose a new downdraft gasifier design, able to generate the producer gas with low tar concentration using a novel primary method without decreasing significantly the heating value of the producer gas.

## 2. Process principle

In the Imbert design of 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 [15]. This is one of the reasons for the presence of tar in the producer gas. 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 in this work to modify the fluid dynamic behaviour 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 [16–20]. The swirl flow of the mixture could be created changing the entry angle of the gasification agent to the combustion chamber. The new angle must be different of the standard 90° in the Imbert design. This modification allow that the circulation $\boldsymbol{\Gamma}$ (Equation (1)) of the velocity vector $\mathbf{V}(\mathbf{r}_o,t)$ of any element of the fluid at any position $\boldsymbol{\rho} \neq 0$ in the plane in which the nozzles are located, or any other parallel plane below this until the diaphragm, is different from zero ($\boldsymbol{\Gamma} \neq 0$).

$$\boldsymbol{\Gamma} = \oint_L V(r_0, t) d\mathbf{l} \quad (1)$$

The circulation of the vector $\mathbf{V}$ ($\mathbf{r}_o$, t) combined with the downward movement of the fluid, caused by absorption from the base of the chamber through the diaphragm, generates a swirl flow. This fluid dynamic behaviour would allow to increase the mixing of the gasifying agent with the pyrolysis gases [21,22]; homogenizing the temperature inside the combustion chamber, diminishing the formation of cool areas between the nozzles as main result. In addition this modification increase the residence time of the gas inside the combustion chamber; thereby increasing the thermal cracking of the tar in this zone, minimizing its passage to the reduction zone, decreasing the tar concentration in the producer gas. Swirl number S may effectively control the residence time distribution of the gas mixture, which is function of the fluid entry angle [18]. The increase of the residence time has the undesirable effects of decreasing the efficiency and productivity of the gasifier, as described by Susanto [13]. Fig. 1 shows a top view of the combustion chamber of the reactor, illustrating the inclination of the inlet nozzles of gasification agent.

## 3. Experimental approach

### 3.1. Investigated samples

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 properties of the woody biomass are shown in Table 1. The elemental compositions were determined using a CHNS-O Elementar Vario GmbH EL III and the Higher Heating Value (HHV) using a calorimeter IKA C-5000 (ASTM D-3286-91a). The moisture and ash composition were determined using the ASTM E-871-82 and ASTM D-3174-82. The results were similar to literature values. For the experiments, the biomasses were chopped in square-based prism pieces with dimensions of about 2 × 1 × 1 cm. The size and shape are very important for the behaviour of biomass in the downdraft gasifier as far as its movement, and bridging and channelling formations. In addition, the height of the oxidation zone and the pressure drop inside the reactor, depend on these characteristics.

### 3.2. Experimental setup

The scheme of the downdraft wood gasifier is show in Fig. 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

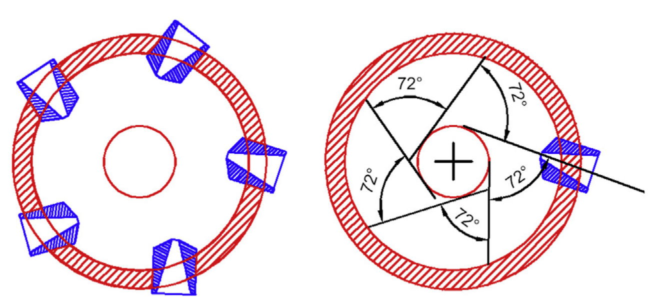


**Fig. 1.** Nozzles inclination in the combustion chamber.