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Experimental study of bottom feed updraft gasifier

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ABSTRACT

The updraft biomass gasifiers currently available produce a gas with high tar content. For almost all downstream applications a substantial reduction of the tar concentration is required. The gravimetric tar concentration behavior in producer gas, obtained at a modified updraft fixed bed gasifier, was studied. The feedstock feeding system was modified respect to the traditional updraft gasification design in order to decrease the tar concentration in the producer gas; the material is feeding continuously through a conduit in the base of the reactor over the grate. The caloric power of the syngas obtained was slightly lower than the typical value for this type of reactor and the highest efficiency obtained for the woodchip gasification was 77%. The highest tar concentration obtained during the experiments was 1652.7 mg N m^{-3} during the first our of experiments, comparable with the smaller value reported for the updraft reactors, this value is reduced significantly after the stabilization of the gasification process in the reactor. The smaller value obtained was 21 mg N m^{-3}.

1. Introduction

The updraft fixed bed gasifier is the oldest form of gasifier and is still used for coal and biomass gasification [1–3]. Typically the design of the updraft reactor, the biomass is fed in at the top of the reactor and moves downwards as a result of its conversion and the removal of ashes through a grate at the bottom of the reactor. The gasification agent entrance is at the bottom below the grate and diffuses up through the bed of biomass and char; the flue gas leaves at the top of reactor. Complete combustion of char takes place at the bottom of the bed, liberating carbon dioxide (CO_2) and water (H_2O). These hot gases (~1000 °C) pass through the bed above, where they are reduced to hydrogen (H_2) and carbon monoxide (CO) and cooled to 750 °C. Continuing up the reactor, the reducing gases (H_2 and CO) pyrolyze the descending dry biomass and finally dry the incoming wet biomass, leaving the reactor at low temperature (~500 °C) [4–6]. The updraft gasifier is also called a counterflow gasifier. The major advantages of this type of gasifier are its simplicity in design, high degree of controllability, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high gasification efficiencies because of the high heat exchange. Due to of the internal heat exchange structure, the fuel is dried at the top of the gasifier and therefore fuels with high moisture content can be used (up to 50% wb.) [5]. This reactor design is also flexible in the size of the biomass feedstock. For most of the applications the efficient and economic removal of tar still presents the main technical barrier to overcome. In this work it will be consider as “tars” the organics compounds present in the gasification product gas excluding gaseous hydrocarbons (C1–C6). The characteristic values for the gravimetric tar concentration in the updraft reactor, ranges between [7] 10 and 100 g N m^{-3} [4], which requires extensive cleanup of a producer gas before engine, turbine or synthesis applications.

Recently the industry has adopted various dry methods to clean the producer gas in modern gasification plants [8,9] and several modified design of this type of reactors had been carried out [10,11] in order to avoid or decrease the high content of tar in the flue gas. However, in the cleaning process of the producer gas, at least 50% of its energy is lost and is mostly environmentally unfriendly.

Against this background, the goal of this paper is to investigate the alternative to increase the thermal cracking of the tar produced in the gasification process by the updraft fixed bed gasifier before the producer gas leaves the gasifier by means of a redesign of this type of reactors. To reach this goal, first the proposal for gasifier design is described and then, the experimental results are discussed.

2. The modified updraft fixed bed reactor

In this study is proposes a gasifier that has a modification, respect to the traditional updraft gasification design; specifically

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referent to the feedstock feeding system. In this reactor the material is feeding continuously through a conduit in the base of the reactor over the grate, as is represented in Fig. 1.

The feed material is then forced upward by the introduction of the feedstock material at the reactor bottom according to the bed height, which is constantly measured by a microwave sensor. The gasifying agent has two entrance in this design, the first in the base of the reactor across the grate, as is typical in this type of reactors and a secondary entrance formed by four nozzles positioned in the middle of the reactor, where is formed the base of the combustion zone in the reactor's bed. In this gasifier, the drying – pyrolysis zone and reduction zones are in inverted position to the combustion zone, respect to the traditional updraft reactors design. As feed material moves upward from the base, reacts with the upward moving gases; according to its position in the reactor as shown in Fig. 1b. In this design the gas produced in the devolatilization region is forced to pass through the combustion and reduction zones before leave the reactor; drawing on the experience with the downdraft reactor designs, where the gas has this route and has the lower tar content between all gasifiers designs. This fact results in less tar in the producer gas, than in other modified updraft gasifiers [9–11]. Fig. 2 shows the tested gasifier.

In this route, most of the tar (consisting of oxygenated organic compounds) formed during pyrolysis is cracked and burnt, in a process called flaming pyrolysis [4]. The flame temperatures are between 1000–1400 °C, but the flame occurs in the interstices of the pyrolyzing particles which have temperatures of 500–700 °C, so that most of the existing tars are burned to supply the energy for pyrolysis and char gasification [4]. Cracking of this tars yields CO, H_2, and other light hydrocarbons. The hot mixture of particulate material and ash descends along the wall of the reactor to the grate at the bottom of the drying zone. The ash is removed from the lower section of the reactor when pass through the grate. The design of this reactor reduces the ash fouling and slagging over the grate, even if the ash produced has a low melting point, because the temperature in this zone is low and the biomass entered is slightly pressed over the grate in the upward movement.

3. Experimental

3.1. Investigated sample

The experimental investigations realized here have been carried out based on woodchips from fully developed trees of Japanese Poplar (*Populus maximowiczii*) originates from the area of Tochigi Prefecture in Japan. The woodchips were supplied from wood processing factories, generally having in average 20 mm in width and less than 10 mm in thickness.

The properties of the woodchips were analyzed and are shown in Table 1. The proximate analysis was carried out using a Thermogravimetric Analyser [Perkin Elmer, Pyris 1 TGA] according to the ASTM E 1131-98; while the moisture content was determined following ASTM E 871-82.

3.2. Experimental setup

The simplified experimental setup for the test of the modified reactor is presented in Fig. 3 and the scheme of the bottom feed wood gasifier is show in Fig. 4. The reactor is designed and constructed using a mild steel sheet with a volume of 0.452 m^3 and circular cross section. The height of the gasifier is 1.80 m and the internal radius is 0.20 m. The fuel tank is designed in such a way that it is able to hold enough woodchips, to work continuously for 6 h. The gasification agent for the experiments (air) is supplied using an electric blower with control valve capable of supplying the required air for the gasification process.

The producer gas sample is filtered, cooled and drained before it is analyzed by Gasboard-3100P mobile gas analyzer. Heatable lines heated up to 180 °C are used to prevent condensation of the producer gas compounds inside the tubing and the measurement device. The temperature is measured by mean of eight thermocouples (type N) located at different height of the reactor bed (Fig. 4). Air and gas flows are measured with an orifice and differential manometer. All the experimental data is recorded by data logger in 1 s intervals.

3.3. Tar sampling principle

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 [12].

The determination is carried out in two steps: sampling and analysis. The equipment for sampling shown in Fig. 5, 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 is

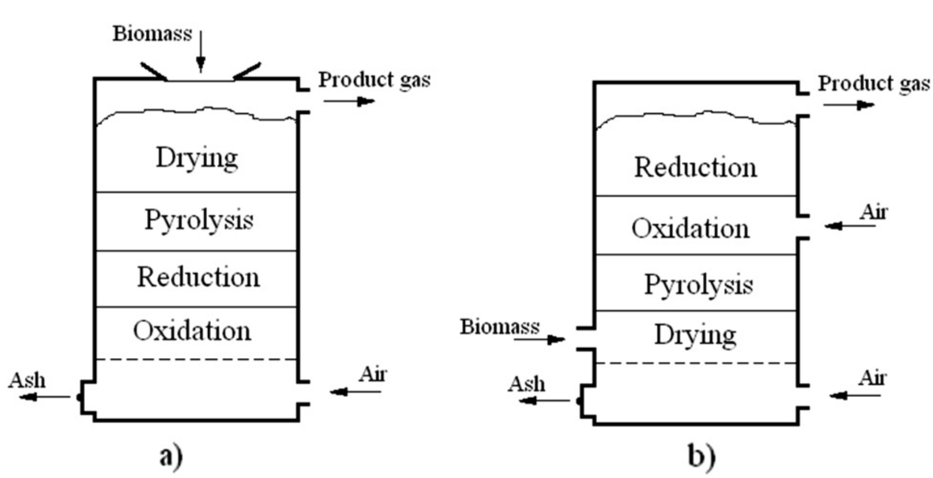

Fig. 1. Updraft gasification reactor: (a) typical design and (b) modified design.