FLETGAS: An optimized fluidized bed gasification system for biomass and waste

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Abstract

Incomplete energetic utilization of the fuel is a problem of conventional fluidized-bed gasification (FBG) of biomass and waste. In addition the gas has high tar content, reducing the potential utilization of the gas in application different from direct firing (without cooling the gas). In the present paper a new process based on a tree-stage fluidized bed gasification system is presented.

Guidelines to be considered for the new development

The main lessons learnt from stand-alone directly-heated FBG constitute the basis for the development of the new gasification system described below, summarized as follows [1,2,3]:

– Increasing the temperature of the gasifier enhances char conversion and the thermal cracking and reforming of tars. In autothermal FBG the temperature is increased by raising the oxygen to fuel ratio, but the increment of oxygen from a given level further burns the light gases, reducing the process efficiency. In the range of temperature achievable in conventional FBG (800-900ºC) the tar compounds are only partially converted in the reactor and the concentration of heavy polyaromatic tars are increased.
– Measures such as stratification of gasification agent by secondary injection or increasing the residence time of tars in the reactor by feeding the fuel at the bottom reduce the total amount of tar in the gas, but leads to more stable and heavy (polyaromatic) tar compounds in the gas, increasing the dew point of the produced gas.
– Addition of cheap solid catalysts (based on mineral rocks) and steam may significantly enhance tar reforming reactions, reducing the tar concentration in the gas, but these measures are not sufficient for the gas quality required for power application (dew point in the range of 20-40ºC). Other catalyst such as those based on nickel are more effective for tar reforming but, besides the high cost, they deactivate rapidly in the bed and contaminated the ash so they are not adequate as in-bed material.
– The contact of steam and oxygen with char and with freshly generated tar could reduce effectively the tars. However, this is not possible in conventional FBG due to the lack of contact time caused by bypassing of gas through bubbles and the low proportion of char in the bed.
– When processing biomasses or wastes whose ash limits the temperature of the gasifier because of the risk for agglomeration (for instance fuels with high proportion of alkali metals in the ash), the gasification efficiency is low due to the high amount of carbon in the ash produced. In addition, in wastes with high ash content extensive bed extraction is necessary to maintain the process pressure (bed inventory), lowering the process efficiency because the high unburnt carbon and sensible heat carried by the extracted material. It is necessary to find a different design to favour char conversion for these cases.

– The staged gasification designs developed up to now are fixed or moving beds. In order to carry out staged gasification, enabling high throughput as well as adaption to a variety of fuel size and quality, fluidized bed is desired.

Fletgas Concept

Following the above guidelines, a drastic separation of regions is made in the new design to distribute the gas and solids in convenient zones of temperature and composition of the gasification agent. The concept presented below is based on the following guidelines: reduction of the temperature in the first stage of the gasifier (devolatilizer), yielding a gas with high yield of fresh tars (they are still not aromatized so the tars present high reactivity to steam reforming). An increase in temperature and steam concentration in the second stage by injection of enriched air and steam. The steam is limited to the temperature achievable by heat exchange with the hot outlet gas, to reproduce real behaviour of industrial autothermal gasifier, approximately 450ºC. The use of char generated (poorly converted due to the low temperature of the devolatilizer) as catalyst filter for tar reduction and gas quenching (the endothermic char gasification reactions lower the gas temperature). Figure 1 resumes the main processes occurring in each part of the system.

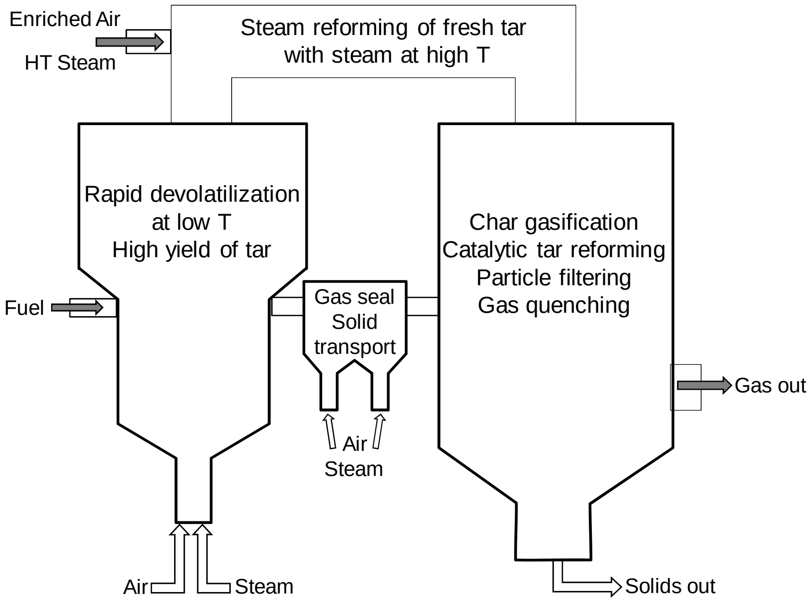

Figure 1: Basis for the conceptual development of FLETGAS process with indication of the essential process occurring in various parts of the system.

Then the gasification concept described is based on three stages: FB devolatilization (first stage), non-catalytic air/steam reforming of the gas coming from the devolatilizer (second stage), and chemical filtering of gas in a moving bed supplied with the char generated in the devolatilizer (third stage). The direction of the flows of solids (biomass, bed material and char) and gas (inlet flow rates of fluidization agent) is indicated in more detail in Fig. 2 (the figure use the arrows for indication of the direction of solid and gas flows). A control valve is included to adjust the residence time of the solids through the control of the solids inventory in the loop.

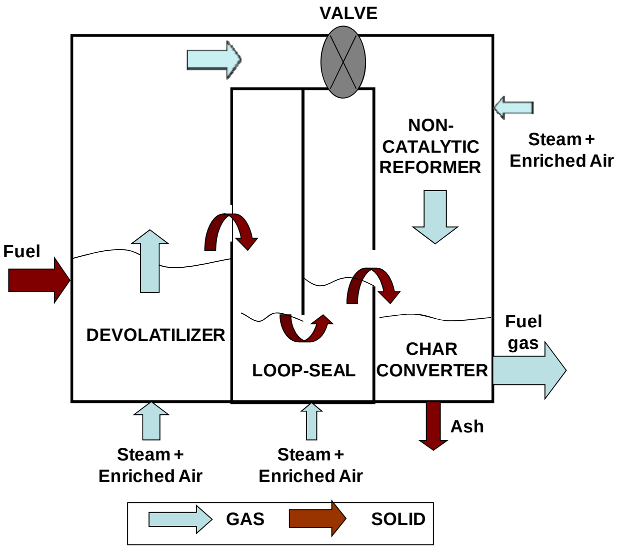

Figure 2: Diagram of the performance of the FLETGAS process with indication of solid and gas flows (with arrows)

Air and steam can be injected at various points (in the devolatilizer, steam reformer and seal) with different proportions of the two reactants. Enriched air, with an oxygen concentration of up to 40% (to keep the price reasonably low, for instance, produced by membranes) can be used instead of air. The fuel is fed near the bed's surface and has to circulate down to the bottom before leaving the bed. The devolatilizer, where a high yield of fresh tar is generated, is operated at relatively low temperature (700-750°C). The fresh tar compounds are drastically reduced in the reformer where a temperature of up to 1200°C is created. The injection of steam into the reformer avoids coking and polymerization of tar. The gas is filtered in a moving bed made of char coming from the loop seal. The loop seal can be operated as an oxidiser (fed with enriched air) or as a light reformer (fed with H_2O) depending on the fuel's reactivity and ash properties. The char filter also cools down the gas (chemical quench) by endothermic char gasification reaction with steam, while it acts as a catalytic filter promoting tar decomposition reactions with steam. The system is especially suitable for high-ash fuels, improving the performance of conventional FBG, where discharge of bed material to maintain the bed pressure leads to poor efficiency.

Challenges for development of Fletgas process

Two main challenges become visible to develop the concept: (i) knowledge of the optimal operation conditions for a given biomass (yields of gas, char and tars), including the understanding of the tar decomposition under different operating conditions (temperature, steam concentration and residence time) and (ii) the fluid-dynamics of the system (movement of gas and char and the capacity of sealing of the loop seal). Dried sewage sludge was taken as reference fuel for the process development because it contains high ash proportion and the ash was found to have certain catalytic activity.

To achieve the appropriate movement of solids and gas a cold model was built [4]. The cold model was scaled-down from an imaginary 2MW_e gasification plant, operating with dried sewage sludge, following the Gliskman laws of scale-up. A fluid-dynamic model was developed to theoretically predict the movement of gas and solids, and the distribution of mass of solids between the bed and loop seal [4].

Tests were conducted to characterize the conversion behavior of various fuels. Devolatilization [5], char gasification [6], and tar conversion [7] tests were conducted in a bench-scale FBG. Some of the tests are still under running.

4.4. Assessment of system performance by modeling

A computational model of the process has been developed to simulate the system under various conditions [8]. Figure 11 shows the model results from the simulation of a single-stage FBG and the proposed three-staged system. The risk of defluidization was observed in previous tests at 820-830ºC during operation at pilot [9] and demonstration scale [10]. Then the simulation of the single stage FBG was made setting the bed at 810ºC in order to be far enough from the risk of defluidization. The most relevant temperatures calculated in the three-staged system are visualized in the figure: 745ºC at the bed, 1200ºC in the homogeneous reformer and 710ºC at the exit. The quench effects is also noted by the temperature drop of 200ºC in the fixed bed. The efficiency, char conversion and tar conversion in the two systems are indicated at the bottom, where it is observed the great improvement expected from the proposed system.

With the experimental and theoretical data a 30 kg/h pilot plant was designed and it is currently under construction and will be start up in at the end of 2011.

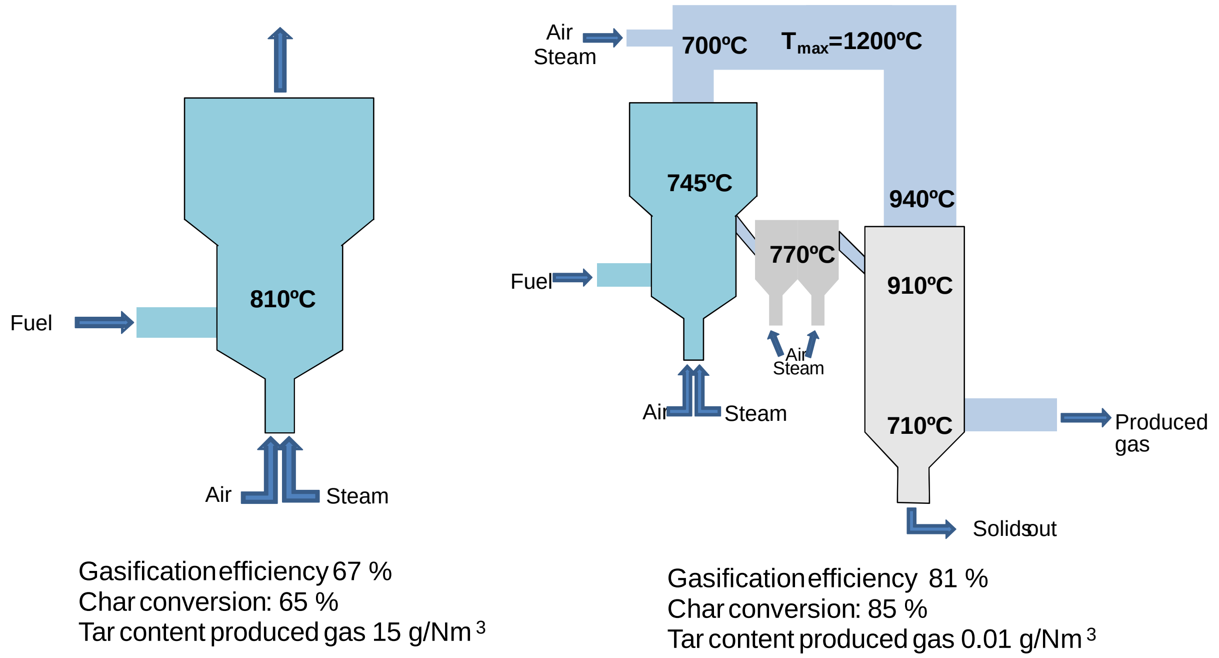

Figure 3: Comparison between single-stage FBG and three-staged FBG system (Fletgas) for sewages sludge gasification (maximum temperature set at the bed =820ºC)

Conclusions

Treatment of tarry gas downstream of the gasifier is complex and expensive for power production in small/medium size gasification plants, so methods to improve tar conversion within the gasifier are preferred for these plants. The optimization of conventional FBG by in-bed catalysts, addition of steam and enriched air as gasification agent and by secondary air injection, although improving the process, is shown to be insufficient to attain the gas purity required for burning the gas in a engine to produce electricity. Staged gasification creates zones in the gasifier, which promote high conversion of char and tar and, therefore, it is an effective and feasible way to conduct gasification. Various developments for small-scale gasification have been proposed over the last decade based on fixed bed, but none of them has still reached commercial status. A new three-stage gasifier (FLETGAS) based on fluid-bed design has been presented here. The new process is promising because it enables to increase the flexibility and capacity of existing staged gasification developments. The FLETGAS process is still under development at pilot scale.

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