Steam Gasification of Coffee Husk in Bubbling Fluidized Bed Gasifier

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Abstract**- Currently, the worldwide demand for fossil fuel is increasing rapidly and, at the same time, known resources are diminishing. In particular, energy resources, such as oil and natural gas, are almost depleted in some parts of the world. In addition, the fact that the climate changes are more severe than before has increased the demand for renewable energy resources. Thus, energy from biomass is one of the potential renewable energy options. The availability of biomass, combined with the recent development of technologies to use it efficiently, with low level of emission, promise to make biomass an increasingly attractive fuel option. Coffee husk is an agricultural waste in coffee processing industries in different parts of Ethiopia that has the potential of exploiting energy via thermo-chemical conversion such as gasification. However, the characteristic properties of this material with regard to thermo-chemical conversion technologies are missing in literature. This study focuses on the experimental investigating of coffee husk in bubbling fluidized bed gasifier. The performance parameters that were investigated during the experiment were tar content and gas composition. The study findings show that the tar content of coffee husk gasification is not disturbing the smooth operation of the gasifier and the gas composition observed was good as compared to wood pellet. Therefore, coffee husk will be promising feedstock in fluidized bed gasification.**

Keywords-coffee husk; tar-content; gas composition; fluidized bed; gasification.

I. INTRODUCTION

As an agricultural country, Ethiopia produces considerable amount of biomass each year. Most of biomass has been utilized for domestic energy purpose, mainly by direct combustion (which converts solid biomass into heat). On the contrary, coffee husk from coffee processing industries is not used as a fuel in most cases due to the poor handling of coffee husk to be used as domestic fuel. However, gasification, which converts solid biomass into fuel gas containing CO and H_2 or so-called synthesis gas, has to be considered as a promising alternative owing to a number of advantages. In the southern part of Ethiopia almost 171,000 tons of processed coffee is supplied to the international market per year. During the process, more than 20,000 tons of residue coffee husk is disposed of. This represents a very good potential for biomass energy.

Apart from gasification for heat production, biomass gasification for electricity or combined heat and electricity production especially at small scales has drawn great attention as a more efficient and economical option compared to conventional combustion steam cycle in Thailand [1]. Unlike air gasification, steam gasification requires an external heat source if steam is used as a sole gasifying agent. Even though using a mixture of steam and air as a gasifying agent is common technology, in this experimental work, the air is used to facilitate the flow of coffee husk. In addition, it is assisted by gravity, since the feed is at the top of the gasifier. Also, the oxygen in the air will help to provide some amount of energy due to the exothermic nature of burning biomass. The elevated temperature will help in the de-volatilization process of biomass to produce various gases. Steam will react with carbon monoxide to produce hydrogen and carbon dioxide.

The coffee husk is processed in an atmospheric bubbling fluidized bed reactor. Because fluidized beds can handle a large variety of feedstocks, they are well suited for this application [2].

The motivation of this study is to investigate the extent to which the gas quality (tar and gas) can influence the operation of the gasifier using coffee husk as a feedstock as compared to that of wood pellet from published data at the same operating conditions.

The present work is organized as follows. The introduction part includes some overview of the availability of raw materials and available technologies to use coffee husk as renewable energy option. The methodology part describes experimental facilities and works that have been conducted at the Institute of Energy System, Technical University of Munich (IES TUM). In the result and discussion part, we present the findings of our experiments. Finally, conclusions are drawn.

Figure 1. Wood pellets

Figure 2. Coffee husks

II. METHODOLOGY

The study of biomass thermo-chemical conversion in fluidized bed reactors is among the most active research studies at the IES TUM. The in-house bubbling fluidized bed (BFB) facilities were developed and are located at the IES TUM as research test bench. The main biomass feedstock used is wood pellet (Figure 1.), which is generated from wood. In our work, coffee husk from coffee processing industries in Ethiopia is used to check whether coffee husk (Figure 2) is a promising biomass to be used in fluidized bed gasification. In addition to this, the institute is well equipped with regard to laboratory facility to analyze the thermo-chemical properties of biomass fuel, online product gas and FID to analyze tar material in the product gas (syngas).

The experimental study was performed in a bubbling fluidized bed (BFB) gasifier which is built at IES TUM. The reactor vessel is made of high temperature resistant steel (German material number 1.4841, AISI SS 310). The dimension of the reactor has an internal diameter of 154 mm and a length of 1.5 m and the schematic diagram of the gasifier is shown in Figure 3. The reactor can be operated up to 850 ^{O}C and pressurized up to 0.5 M Pa. The biomass is fed through a pressurized screw-conveyor into a drop shaft directly to the bottom of the bubbling fluidized bed gasifier. A small amount of air is flushed in to the biomass feeding system to sidestep the entrance of syngas or steam in the feeding system. The syngas as well as the steam flow to feed line should be prevented by all means as steam swells up the feedstock along the feed inlet pipe which leads quickly to obstruction of the feeding system. The bed has a height of approximately 700 mm and is fluidized using steam as fluidizing agent and gasification medium. The heat required for the endothermic gasification reactions is provided by electrical heating and transferred into the bed via four high temperature heat pipes which use sodium as a working fluid. The heat pipes have a diameter of 20 mm and a length of 660 mm inside the fluidized bed.

The heat pipes influence the flow dynamics to some extent and lead to the formation of a slug flow [3] throughout the whole height of the fluidized bed. All pipings are well insulated and the cyclone and the filter are heated up to a temperature of 330 ^{O}C to avoid tar condensation in order to mitigate condensed tar material, since condensed tar will disturb the operating condition of the gasifier. There are 15 thermocouples placed at equal distance along the direction of the reactor. The thermocouples are therefore bundled in a closed small steel tube that is introduced through the top flange of the reactor and sealed with a compression fitting.

The measurement procedure was as follows: the bed was heated up to the required temperature and fluidized with steam while the biomass feeding rate was set to achieve the steam to biomass set point. After observing a stable gas composition half an hour run, three tar samples were taken using the solid phase adsorption (SPA) method. The method uses solid phase extraction tubes filled with aminopropaylsiane phase bounded to silica gel. A detailed description of the SPA sampling and analysis method can be found in [4] Therefore, 100 ml of product gas was drawn with a syringe over an amino phase column. The results of the analysis are given with the assumption that the steam in the gas is condensed in the amino phase and does not enter the syringe in vapor form. This value was converted into g/m3 at standard conditions.

The selected operating temperature for coffee husk gasification in the fluidized bed gasifier was 800 ^{O}C. An increase in temperature will face ash sintering problem due to the coffee husk ash melting point which is around 815-820 ^{O}C. At the same time, lowering the gasification temperature will result in poor quality of the gasifier products. The selected operating parameters are indicated in Table I.

The synthesis gas (product gas) exits at the top of the reactor and is cleaned by passing the gas through a cyclone and a ceramic candle filter. Subsequently, the syngas is expanded in the pressure control valve to atmospheric pressure. At this point, the sample was taken to check the tar material. Finally, the gas was analyzed online for the main components H_2, CO, CO_2, and CH_4.

Silica sand (SiO_2) is used as a bed material in this experiment. The average particle size is 0.25 mm and minimum fluidization velocity is v_{mf} = 0.034 m/s. During this study the bed materials wed filled to the height of 0.39m of the reactor.

The feedstock characteristic of coffee husk was analyzed at the chemical laboratory which belongs to the IES, TUM. Therefore, Table II depicts the fuel characteristic of coffee husk. The study of thermo-chemical properties provides information about the quality of biomass material in terms of proximate and ultimate analyses, and heating values. The samples of coffee husks were taken from Gedeo zone, southern part of Ethiopia. Proximate analysis of biomass gives the weight fractions of volatiles, ash, and fixed carbon. The content of volatiles and ash has an influence on the thermo-chemical conversion, syngas composition and tar

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materials. Ultimate analysis is carried out to determine the composition of hydrogen, carbon, nitrogen, oxygen and sulfur in a given biomass material. The heating value, also called calorific value or heat of combustion, defines the energy content of a given fuel. It is one of the most important parameters for design calculations and numerical simulations of thermal systems. The gasification products of a given biomass material are influenced by its thermo-chemical properties. The coffee husk size distribution was not uniform but less than 5mm. In the case of the wood pellet the size was uniform. Therefore, this step will incur some additional cost compared to coffee husk.

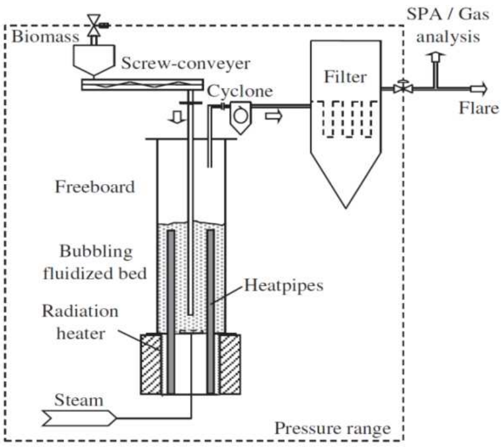

Fig.3 Schematic Diagram of the Bubbling Fluidized Bed Gasifier

TABLE I. OPERATING CONDITION OF BUBBLING FLUIDIZED BED GASIFIER

Properties	Operating Condition
Temperature (^{O}C)	800
Pressure	Atmospheric
Steam/biomass	0.83

TABLE II. COFFEE HUSK (GEDEO ZONE, ETHIOPIA) CHARACTERISTICS

Parameters	Values
Water content	8.36%
Lower heating value	17.2 MJ/kg
Proximate analysis (% wight dry basis)	
Ash content	6.99 wt. % db
Voletiles	72.30 wt. % db
Fixed carbon	20.71 wt. % db
Ultimate analysis (% weight, dry-ash-free basis)	
C	48.09 wt.% db
H	5.24 wt. % db
N	1.69 wt. % db
S	5.50 wt. % db
O	33.39 wt. % db

III. RESULT AND DISCUSSION

Three different tar samples are presented in Figure 4 to check whether or not the tar material affects the smooth operation of the gasification process. Generally, tars are hydrocarbon containing mixtures, which can form liquid or highly viscose to solid deposits by cooling of the gaseous phase down to ambient temperature. In addition to the main elements carbon (C) and hydrogen (H) other elements like oxygen (O), nitrogen (N) or sulfur (S) are found in tar. Tars are generally assumed to be largely aromatic [5]. Several researchers have worked on various tar classifications such as the division in primary, secondary and tertiary tar [6 - 8]. Tar materials from wood pellet can be referred to from the published data of Pletka et al. [2].

Over 800° C, tertiary tar can be found and tertiary tars are also called recombination or high temperature tars [9]. As the operating temperature of the test bench is at this temperature rage, most tar material in the analysis is tertiary tars. Figure 4 shows tar components in the product gas from coffee husk gasification. As the gasification process proceeds almost all tar contents are reduced. Thus, coffee husk gasification suffers little from tar challenge.

From the syngas evolution profiles presented, it can be seen that steam gasification consistently evolved major gas components H_2, CO, CO_2 and CH_4 with the respective percentages of 40%, 21%, 20% and 6%. Being combustible hydrogen, carbon monoxide and methane are desired component of the syngas whereas carbon dioxide is not desired as it plays a negative role on syngas heating value. The syngas heating value can be calculated based on these combustible gas components. Therefore, the syngas compositions are compared with wood-pellet gasification which is done in the same test bench and the same operation condition (pressure, temperature and steam to biomass ratio) from the published data [2].

Figure 5 shows the species from the gasification of wood pellet and coffee husk. From the bar-graph one can observe that CO, CO_2, CH_4 and H_2 compositions have no influential difference between the two feedstocks. Therefore, coffee husk is a good feedstock option for gasification in BFB gasifier.

Coffee husk gasification has dual advantage. The first advantage is economical advantage, since coffee husk should not be pelletized. Moreover, it is an agricultural residue from coffee husk processing industry (typically in the case of Ethiopia). The second advantage of using the feedstock will mitigate the environmental challenge arising from the dumping of the coffee husk to the environment by consuming this residue.

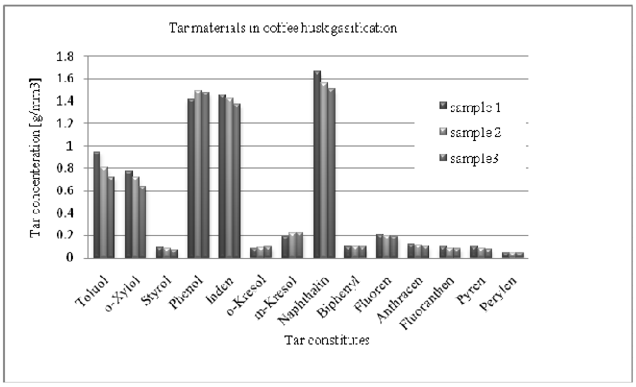

Figure 4. Tar compositions from coffee husk gasification

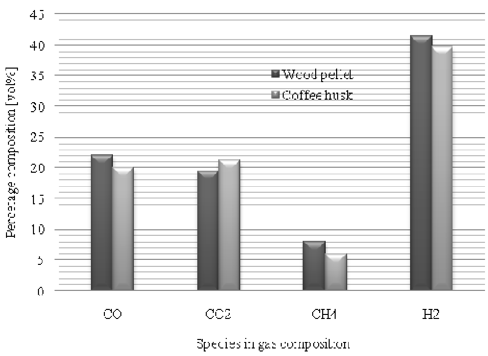

Figure 5. Species composition from wood pellet and coffee husk gasification

IV. CONCLUSION AND FUTURE WORKS

In this work, experimental results are reported regarding the influence of tar material in the smooth operation of the gasifier and gas composition during fluidized bed steam gasification using coffee husk as a feedstock.

The study findings show that the tar content of coffee husk can be gasified in bubbling fluidized bed without problems and the gas composition observed was good as compared to wood pellet. Therefore, coffee husk will be encouraging feedstock to be used in fluidized bed gasifier for biomass energy option.

Important future work will include performing experiments with various operating parameters.

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