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Fluidized Bed Gasification of Coal/Biomass Slurries

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The paper deals with the setup of a fluidized bed facility for gasification of valuable fuel slurries. A wet biomass residue, Indonesian coal and rape seed oil were used for the preparation of a stable slurry having a water content of around 45% by mass. A preliminary test of gasification was successfully carried out at 800 °C with generation of a gas having a moderate content of H_2, CO and CH_4. The comparison with computed data of a thermodynamic equilibrium model shows that the conversion of the slurry can be improved by optimization of operating conditions and reduction of the water content in the slurry.

1. Introduction

The depletion of fossil fuel is currently driving the research toward the individuation of alternative and abundant energy sources, with a possible neutral effect on carbon dioxide emission in the atmosphere.

In this framework some liquid mixtures and waste (slurries) from chemical and food processes having residual content of combustible species could represent a valuable energy resource, provided that no dangerous contaminants are present. For instance, concentrated waste waters from olive oil production, wine distillation by-products or wet sewage sludge can be taken into account for thermo-chemical processes like combustion, gasification and pyrolysis (Werther et al., 2000; Miccio and Miccio, 2009). Furthermore, the addition of pulverized coal and/or oil could significantly improve the energetic content without altering the rheological properties of the slurry.

Wet fuels are suitable for thermo-chemical processes in both atmospheric and pressurized fluidized bed units (Wardell, 1995; Xu et al., 2006), thanks to the efficiency and flexibility of this technology (Basu, 2006). The combustion of a slurry enriched with coal was successfully carried out at pilot scale by Miccio and Miccio (1997), who also reported the benefits of carbon deposition on the bed particles, upon the injection, drying and pyrolysis of the wet fuel. Up today, no relevant experiences of slurry gasification are reported in the literature, although this approach would make possible the steam gasification with the inherent water of the fuel.

The present paper reports on the setup of a pilot-scale fluidized bed facility for the gasification of coal/biomass slurries as well as on the procedure for slurry preparation. An explorative test of gasification has been carried out, which provided the complete set

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of standard measurements, namely the concentration of major gas species, tar yield and elutriation rate of fines. The experimental results are discussed in the paper and compared with predicted data from a thermodynamic gasification model.

2. Experimental

2.1 Experimental Facility

The scheme of the gasification facility is displayed in Figure 1. The fluidized bed reactor consists of a 140 mm ID stainless steel column operating under bubbling regime. It is equipped with a reverted conical gas distributor having a 1” central socket for the passage of an injector. The whole fluidization column is heated by means of electric resistances that supply a total power of around 25 kW. The facility was already used for gasification tests of solid fuels including woody biomasses, coal/wood blends and wastes (Ruoppolo et al., 2009, Ruoppolo et al., 2010).

The fuel slurry is directly fed into the fluidized bed by means of a vertical air-assisted injector 10 mm ID that is located in the conical distributor. A volumetric pump with adjustable speed is used for dosing the slurry in a flow rate range 4-10 kg/h.

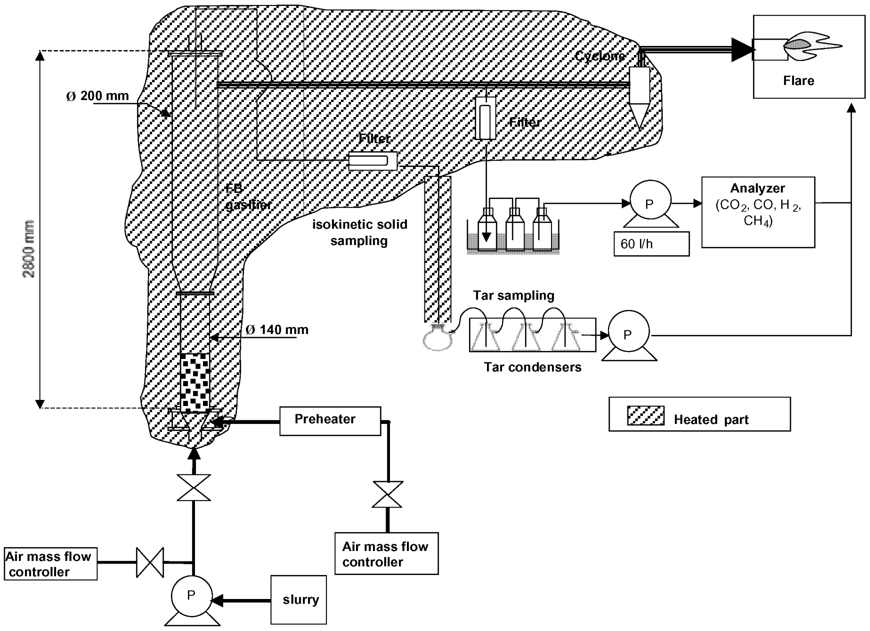

Figure 1: schematics of the experimental facility

The gasification products are isokinetically sampled inside the reactor and passed through a hot quartz fiber thimble to collect solid particles and in sequence through a condenser system to trap tars and water. The concentration of permanent gases is measured on-line by means of continuous analyzers for H_2, CO, CO_2, CH_4. Gaseous samples are also taken in 3L bags and off-line subjected to a gas chromatograph FID analysis for determination of other hydrocarbon species. Collected condensed tars are analyzed off-line and subjected to a further gas-chromatographic characterization.

Quartzite sand (density =2600 kg/m^3; average size=155μm; minimum fluidization velocity 2 cm/s at 800 °C) is used as bed material.

The gasification tests are carried out at a minimum reactor temperature of 800°C. Standard conditions for flow rates are: 5.0 kg/h of slurry and 6.4 kg/h of air corresponding to an equivalent ratio Φ=0. 5. More specifically, 1.6 kg/h of air is fed at the bottom of the gasifier for the pneumatic transport of the slurry, the other part (4.8 kg/h) enters throughout the conical distributor after being preheated at 600°C.

2.2 Slurry Preparation

A slurry was purposely prepared for the experiments. The ingredients are: Indonesian coal, wet olive husk, rape-seed oil, and water. A small amount of surfactant agent (tween-80) was added in order to dissolve the oil. The selected coal, having a narrow size distribution, is hydrophilic for avoiding the inclusion of water inside the particles. The slurry was carefully prepared by adding its ingredient step by step: 1) preparation of the oil-water emulsion in presence of the surfactant; 2) addition of the emulsion to the wet olive husk; 3) gradual addition of the pulverized coal to the mixture. Finally, the slurry was mixed by means of a stirrer. After various trials, a rather stable slurry was obtained by adopting the following mass ratio: coal (20.4%), olive husk (76.3%), oil (3.2%), water (0.2%).

The slurry properties and those of the ingredients used for its preparation are reported in Table 1. Preliminary tests have been performed for determining the minimum water content that assures the possibility of pumping the slurry at flow rates suitable for the experiments. Of course, the water content should be minimized in order to sustain the reactor temperature at reasonable levels (i.e. 800-850 °C). The actual water content of the slurry, as determined in the ultimate analysis was 70.9 wt % by mass.

Table 1: Properties of fuels and slurry

	Indonesian coal	Olive husk	Rape seed oil	Slurry
Particle size, μm	8-120	0-1000	-	0-1000
Moisture, % by mass	10.1	74.3	-	70.9
Volatiles, % by mass dry	36.6	21.0	-	17.8
Fixed C, % by mass dry	42.6	1.8	-	8.6
Ash, % by mass dry	10.7	2.9	-	2.7
Carbon, % by mass dry	68.4	57.5	77.0	60.2
Hydrogen, % by mass dry	6.2	7.5	12.0	7.6
Nitrogen, % by mass dry	1.1	1.7	0	1.5
Oxygen, % by mass dry	24.3	33.3	11.0	30.7
LHV, MJ/kg dry	29.2	19.3	37.0	28.1

3. Theoretical Assessment

The high water content of the slurry poses problems for the process sustainability at a temperature that is high enough for assuring an acceptable conversion rate of both gaseous and solid fractions. Thus a thermodynamic model developed by Miccio et al. (2008) for single and dual fluidized bed gasifiers was used for the preliminary check of the possible gasification regimes. Figure 2 shows the theoretical values of the reactor temperature and the molar fractions of the main gaseous species (dry basis) at changing the equivalence ratio. Data were obtained assuming the composition of the slurry as reported in Table 1, water content of 70.9% and air pre-heating at 600 °C.

From the analysis of Figure 2, keeping the temperature above 800 °C is possible only for equivalence ratios higher than 0.36, even with air pre-heating at 600 °C. This is an obvious consequence of the large enthalpy required for the vaporization of the slurry water. In contrast, the steam that is generated upon slurry feeding allows to shift the reforming reactions of the hydrocarbons toward H_2 and CO, whose predicted molar fractions account for around 30% of the dry producer gas at 800 °C.

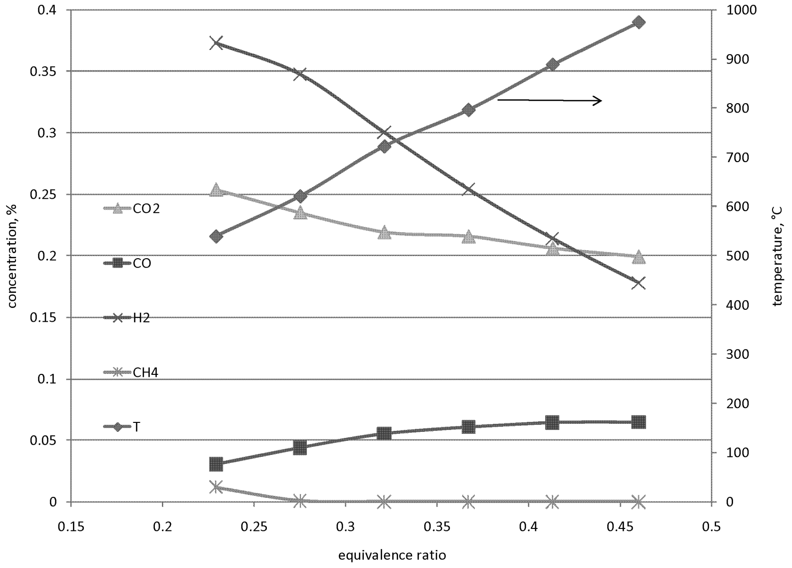

Figure 2: Predicted reactor temperature and molar fractions of CO_2, CO, CH_4 and H_2 at changing the equivalence ratio (temperature of pre-heated air 600 °C)

4. Results

A preliminary test of gasification was successfully carried out in inert bed at temperature 800 °C and equivalence ratio 0.5. The time profiles of the gas concentration for CO_2, CO, CH_4 and H_2 (dry basis) are displayed in Figure 3. It appears that almost stable values of the monitored variables were achieved in a relatively short time (i.e. 10

min.) after starting the slurry feeding (time 400 s). The temperature was stable at the prefixed value of 800°C, thanks to the external heating. The analysis performed offline by micro GC reported the further presence of 1.6% vol. of C_2H_4 and 0.62% vol. of C_2H_6. After the gasification test, the fuel pump was switched off (time 1700 s), so the accumulated char was burned off as indicated by the decaying trend of the CO_2 curve in the Figure 3.

The gravimetric tar concentration obtained during a 10 min sampling interval was 38 g/Nm^3. The most abundant species contained in the sampled tar are: Phenanthrene, 4-Nitrophenol, Fluorene, Acenaphthylene and Antracene. They are typical products of coal pyrolysis.

The comparison with experimental data of steam gasification in the same facility demonstrates that in present case a larger tar content is obtained: 38 g/Nm3 for slurry > 25.7 g/Nm^3 for coal/wood pellets > 19.2 g/Nm^3 for wood pellets (Ruoppolo et al., 2010). This result can be also attributed to the presence of the oil in the slurry.

The elutriation rate of fines at the cyclone was very high, about 140g/h. This is a consequence of the vigorous fluidization induced by the water vaporization in the bottom of the bed. Assuming 50% of carbon content in the elutriated fines, the carbon loss account for around 7% of the total carbon in the fuel. The present elutriation rate turns out much larger with respect to gasification tests with both wood pellets and coal/wood pellets (Ruoppolo et al., 2010), the lower char reactivity and the finer coal particles being responsible for this result.

The comparison of the experimental results with the predicted data of Figure 2 indicates that the process is far from thermodynamic equilibrium, since an appreciable concentration of methane is monitored in the real producer gas (i.e. 4%).

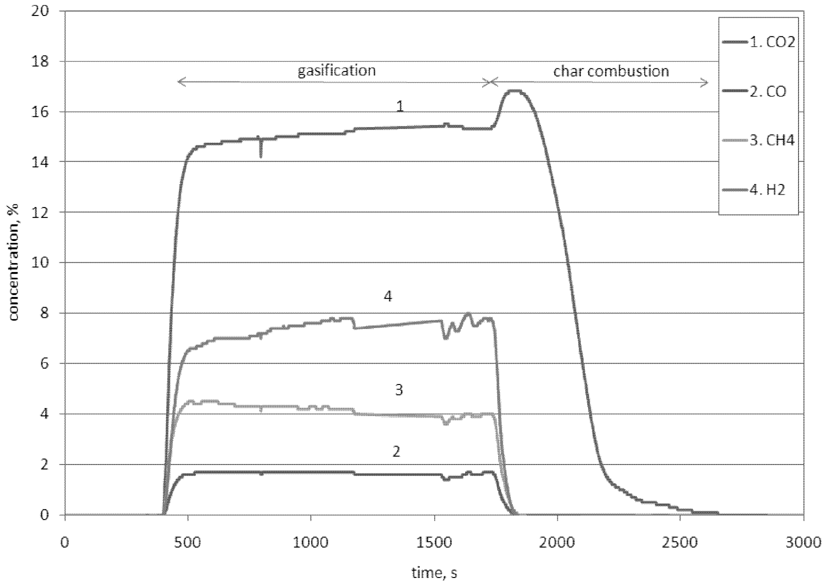

Figure 3: experimental results - time profiles of the gas concentration for CO_2, CO, CH_4 and H_2 (T_{bed}=800 °C)

5. Conclusions

A stable slurry having water content of around 70% was prepared on the basis of olive husk, Indonesian coal and rape seed oil for feeding a fluidized bed gasifier.

A preliminary test of gasification was successfully carried out at 800 °C producing a gas with moderate content of hydrogen, methane and carbon monoxide.

A theoretical assessment demonstrates that the experimental results do not fit the expected thermodynamic equilibrium concentrations, as consequence of the limited reaction kinetics and carbon losses.

The optimization of the studied process can be carried out by reducing the water content of the slurry at minimum levels, increasing the reactor temperature and adopting measures for improving the reaction kinetics (e.g. catalysis).

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