GASIFICATION OF CHAR FROM DRIED SEWAGE SLUDGE WITH STEAM AND CO_2 IN FLUIDIZED BED

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ABSTRACT: Kinetics of gasification of char obtained from dried sewage sludge (DSS) with steam and CO_2 have been measured in a laboratory fluidized bed (FB) reactor at temperatures between 800 and 950 ºC with steam and CO_2. Char was generated in situ in N_2 atmosphere, which is important since cooling of char significantly influences its reactivity. The reaction with steam was found to be three to four times faster than the reaction with CO_2 depending on the operating temperature. Activation energies were determined for the two reactions. The reactivities with steam and CO_2 were found to decrease with increasing char conversion.

1 INTRODUCTION

This work is included in a project for developing a three stage gasification technology for high ash content waste fuels such as DSS. The system consists of a bubbling fluidized bed gasifier, a unit for non catalytic tar reforming and a fixed bed converter. The fixed bed converter is made up solid particles that have been removed from the fluidized bed. It has a double purpose, on one hand, the tar generated in the FB gasifier is converted due to cracking over char particles and secondly, the carbon conversion in the system is increased by increasing solids residence time. In order to design this three stage gasification system, two topics need to be assessed; the flow of solids through the system is characterized studying the fluidodynamics and the performance of the gasification system is estimated from characteristics of solids conversion. The fluidodynamics have been studied using a cold model which is shown in Fig. 1:

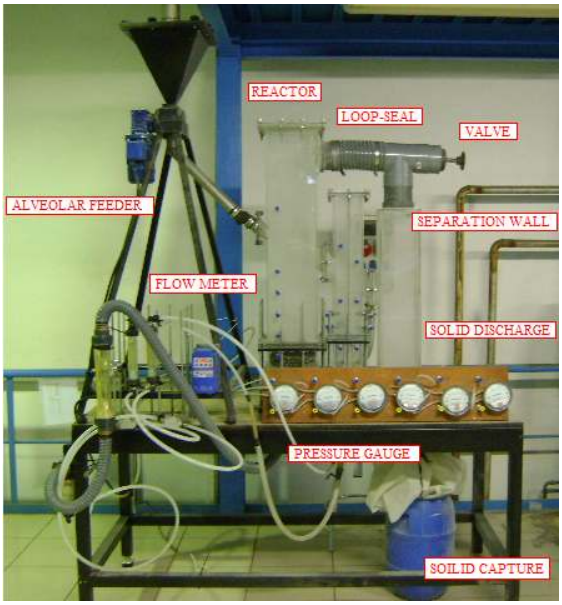


Figure 1: Cold model representing the three stage gasification system.

The fuel conversion includes: devolatilization in FB, secondary tar conversion, gasification of char in FB and tar cracking and char conversion in the fixed bed. The devolatilization of DSS in fluidized bed has been studied in a previous work [1]. In this work, the gasification of char from DSS in fluidized bed is treated. Primary generation and secondary reactions of tar as well as conversion of tar and char in a fixed bed are currently being investigated, but will not be treated here.

A number of different works have been published on the gasification with steam and CO_2 of chars from coal [2-9], biomass [10-13] and residues [14-19] and the results show that reactivity of char depends to a large extent on the type of fuel and on its composition. A number of inorganic species have shown catalytic activity for gasification of char, mainly alkaline and alkaline earth metals and transition metals such as Fe, Co, Ni and Cu [2, 11, 12, 20]. Little work has been published on the gasification of char from DSS [14]. In addition, the composition of especially the inorganic fraction of DSS may vary significantly depending on its origin.

Char from DSS has been found to be much more reactive than chars from coal and other residues [14]. DSS generates a high ash content char with only 10-15% carbon, the remaining part being mainly ash. Therefore, catalytic affects are expected to be important for the gasification of DSS char.

Even though cooling of char has shown to lead to significantly lower reaction rates [2, 6], most studies on gasification of char have employed ex situ generated char that has been cooled down to room temperature before char reactivity measurements [5, 7-9, 13-15].

The method of char preparation also influences the reaction rate, being the most important parameters operating temperature and heating rate [21].

2 EXPERIMENTAL

Experiments have been carried out in a laboratory fluidized reactor with an inner diameter of 51 mm. The experimental setup is represented in Fig. 2. For the reaction with CO_2, DSS of three different particle sizes have been studied; 1-1.4 mm (average 1.2 mm), 2-2.8 mm (average 2.4 mm), 4-5 mm (average 4.5 mm). For the reaction with steam 1.2 mm particles were employed. Experiments are carried out batch wise. The char is first generated under nitrogen atmosphere at the test temperature, 800-950 ºC, and once the devolatilization is completed, the gasification starts by adding steam or CO_2 to the inlet gas. The reaction rate is determined from the CO and CO_2 concentrations in the outlet gas. The gas velocity during the experiments was 0.5 m/s.

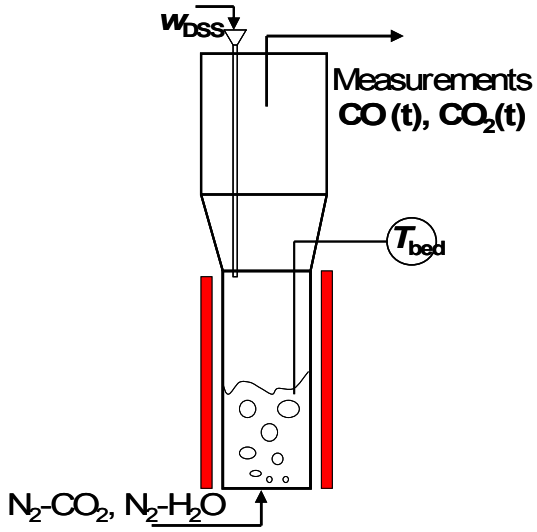


Figure 2: Experimental setup.

Char gasification was carried out for the time necessary for 70-80% of the char to react, 15-45 minutes depending on the operating conditions; temperature, gasification agent and gas concentration. After gasification, the fluidizing gas was switched to air to burn the remaining char.

3 RESULTS

3.1 Effect of cooling

A set of experiments was carried out in order to assess the effect of cooling of the char on the reactivity with CO_2. During these tests, after devolatilization and prior to gasification, the char was cooled down to room temperature under N_2 flow and then heated to the desired test temperature. The results of these tests showed that the reactivity was about 30% lower after cooling of char and therefore it is important to measure the reaction rates employing char that has been generated in situ.

3.2 Char yield during devolatilization

The amount of char generated during devolatilization is influenced by both operating temperature and the particle size. Fig. 3 shows the char yields obtained at different temperatures for the three particle sizes studied.

3.3 Gasification reactivity

The instantaneous reactivity, R is defined by Eq. 1:

$$R = \frac{1}{m}\frac{dm}{dt}$$

Being m the mass of carbon in char.
The kinetics for the reaction with CO_2 were measured for three different particle sizes and no influence of the particle size was observed, even at 950 ºC, the highest temperature studied. Fig. 4 shows the reaction rates measured for DSS of three different particle sizes at 900 ºC and with 20% CO_2 concentration.

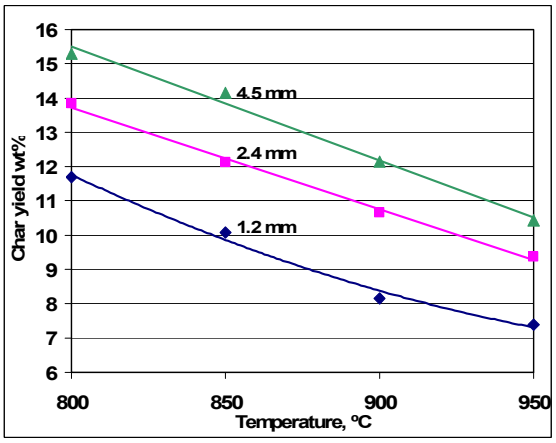


Figure 3: Char yields obtained during devolatilization of DSS of three different particle sizes and at different temperatures.

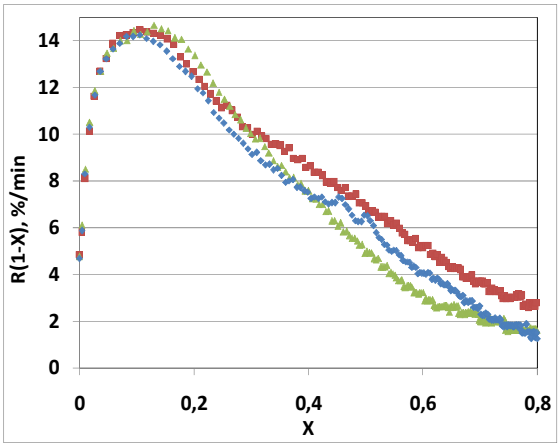


Figure 4: Reaction rates measured for three different particle sizes (1.2 mm, 2.4 mm and 4.5 mm) at 900 ºC and with 20% CO_2.

The reactivities measured with 20% steam/CO_2 at 850 ºC as a function of char conversion are shown in Fig. 5:

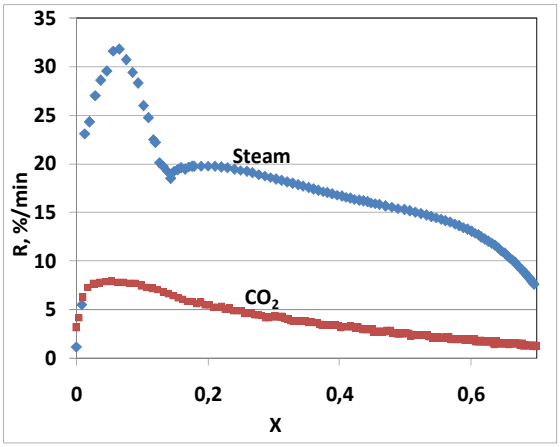


Figure 5: Reactivity as a function of char conversion at 850 ºC with 20% steam/CO_2.

The results show that for both the reaction with steam and CO_2, the reactivity decreases with increasing

conversion. This decrease in reactivity could be due to loss of contact between carbon and catalytic substances or catalyst deactivation [3, 11-13].

The reactivity at 10% conversion measured with 20% steam/CO_2 at different temperatures are shown in Fig. 6:

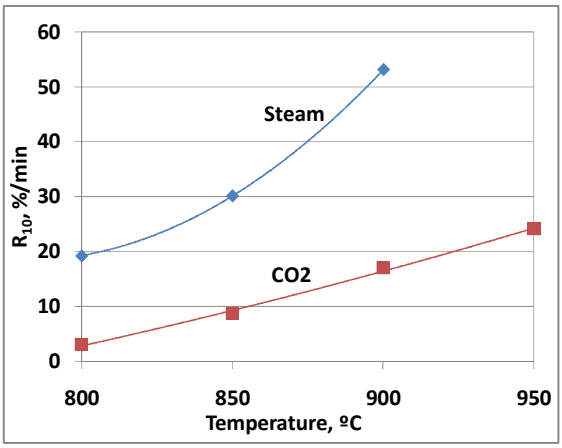
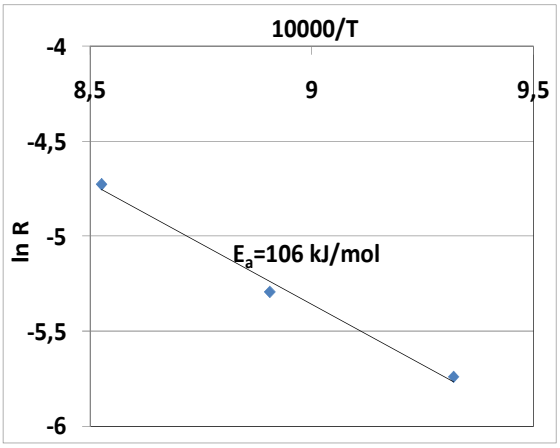


Figure 6: Reactivity at 10% conversion as a function of temperature for the reactions with steam and CO_2, 20% steam/CO_2 concentration.

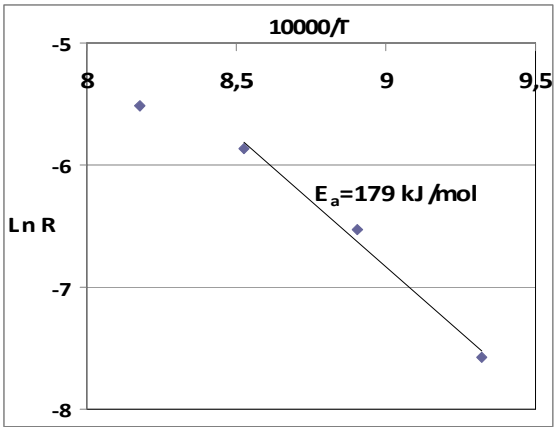
Fig. 6 shows that the reaction with steam is 3 to 4 times faster than the reaction with CO_2.

The reactivities at 10% conversion measured at different temperatures were employed to calculate the activation energy for the reactions with steam and CO_2. The results are shown in Fig. 7. The activation energies obtained here are relatively low compared to some data found in literature [5, 10, 14, 15]. This can be due to the existence of important catalytic effects and because the activation energy includes the effects of severity of heat treatment. High temperatures can cause loss of catalytic activity due to evaporation, sintering or agglomeration of catalytic substances [2, 5, 11, 16, 17, 19].

For gasification with CO_2 the reactivity at 950 ºC is lower than expected from the activation energy calculated at lower temperatures. This is probably due to effects of severe heat treatment rather than mass transfer limitations, since the particle size did not affect the reactivity.



(a)



(b)

Figure 7: Arrhenius plots for the gasification reactions with steam (a) and CO_2 (b).

4 CONCLUSIONS AND FUTURE WORK

- The reactivity of char from DSS decreases significantly if it is cooled to room temperature and therefore it is important that the reactivity is measured employing a char generated in-situ.
- The reaction with steam is roughly 3-4 times faster than the reaction with CO_2 and therefore heat transfer limitations may be important for this reaction. In the future steam gasification experiments will be carried out using different particle sizes of DSS.
- For gasification with both steam and CO_2, the reactivity decreases with increasing char conversion, at least for the conversion range investigated here; 0-80%. The variations of char reactivity with conversion showed the same trends at the different temperatures studied and the reactivity may be approximately be expressed using Eq. 2:

$$R = R_x(T, P_{H_2O}, P_{CO_2})f(x)$$

  Being R_x the reactivity with CO_2 or steam at a certain conversion, which is dependent on both temperature and gas composition and f(x) is a function that gives the effect of char conversion on the reactivity and is independent of temperature and gas composition and is the same for the reactions with steam and CO_2. By using Eq. 2 to express the reactivity, the calculation of the char conversion obtained in a FB gasifier is simplified.
- Future work also includes experiments where both devolatilization and char gasification are carried out under a gas atmosphere with different concentrations of H_2O, CO_2, CO, H_2 and N_2 typical for FB gasification. CO and H_2 are known to inhibit the gasification reactions with CO_2 and steam respectively. In addition, the composition of the gas atmosphere may affect the chemical form of inorganic species and alter their catalytic activity [6, 16].

5 REFERENCES

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6 ACKNOWLEDGEMENTS

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