PYROLYSIS AND COMBUSTION OF PULVERIZED WHEAT IN A PRESSURIZED ENTRAINED FLOW REACTOR

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INTRODUCTION

During recent years there has been an increasing interest for pressurized combustion and gasification of solid fuels in power plants due to the potential for high efficiency. The utilization of new types of solid fuels for pressurized combustion and gasification depends on the reactivity at relevant conditions. Risø's pressurized laboratory was established in 1992 with the aim of studying pressurized pyrolysis, combustion and gasification of solid fuels. At present the laboratory comprises a Pressurized Entrained Flow Reactor (PEFR) and a Pressurized Thermogravimetric Analyzer (PTGA) for the study of reactivity of solid fuels at high pressure. In the present paper the PEFR facility is presented and pyrolysis and combustion of pulverized straw at elevated pressure are shown.

EXPERIMENTAL

The PEFR facility

Pyrolysis and combustion of pulverized wheat were performed in a PEFR [1]. The reactor is operated differentially, which means that the reactant gas flow is large compared to the particle flow. This implies that during combustion or gasification of solid fuels, the bulk concentration and temperature are well controlled. The system layout of the facility is seen on Figure 1. The main components are the gas mixing system, pressure vessels, furnace, moveable probe, gas outlet and conditioning system. The systems consists of a vertical cylindric furnace fed with a reaction gas of a specified composition. The furnace consists of three parts; a gas preheater section and two half cylinder reactor sections each with Super Kanthal heating elements which can give a maximum reactor temperature of 1500°C.

The fuel is fed pneumatically by the primary gas through a narrow ceramic tube and enters near the top of the reaction tube. The fuel tube is mounted through the centre of the gas preheater and cooled by water to avoid reaction of the fuel in the preheating section. The reactor tube is approximately 7 cm ID and 2 m long. The probe can be positioned to collect particles at various distances and thereby various residence times. The probe is water cooled and nitrogen quench gas is added to the top of the probe to stop the chemical reaction instantaneously as soon as the particles enter the probe. The collected particles are trapped on a filter, and they are analyzed for moisture, volatiles and ash content in the TGA. The conversion of the particles is determined using the ash tracer technique.

The furnace is built into a 100 bar pressure vessel. The reaction gas is a mixture of various gases N_2, O_2, H_2, CO_2, CO, CH_4 and H_2O (as steam). The reaction gas is added to the top of the furnace after being preheated to the furnace temperature. The flow is estimated to give the wanted gas velocity in the furnace at the actual furnace temperature and pressure. An average gas velocity of 0.3 m/s is used in all experiments. Assuming a laminar parabolic velocity distribution, the 0.3 m/s average gas velocity corresponds to a gas velocity of 0.6 m/s centrally in the reactor.

The performance of the facility is listed in table 1.

Fuel selection and preparation

The biomass selected for this study was Danish wheat, which were pulverized [2] and sieved with an Alpine sieve. The size distribution based on mass can be seen in Table 2, while the proximate and ultimate analysis are shown in Table 2 and 3, respectively [3].

RESULTS AND DISCUSSION

In the PEFR experiments samples were taken out at five different locations representing a residence time of 0.5 to 2.5 s. The residence time is based on a velocity of 0.6 m/s. All samples have been double analyzed for ash percentage in the TGA, and the conversion is calculated using the ash tracer technique. The results are presented as m/m0, which is the collected DAF (Dried and Ash Free) mass divided by the initial DAF mass.

Pyrolysis

The pyrolysis experiments were performed at 10 bars total pressure in an atmosphere of pure nitrogen, and at temperatures of 700, 800, 900 and 1000°C. Figure 2 shows the m/m0 value plotted versus time for the 1000°C case. The experiments resolved a mass loss profile showing that the m/m0 value is decreasing towards the end point at 2.5 s. The final values for the 700 to 1000°C experiments were 0.14, 0.12, 0.10 and 0.11. For the 900 and 1000°C cases approximate constant m/m0 values were found at the last three probe positions which corresponds to a residence time of 1.2, 1.6 and 2.5 s. By averaging the results from these three probe positions the m/m0 value became 0.10 for both cases. The proximative analysis gave a pyrolysis yield of 81.5%, while in the present experiments the yield is increased to 90%.

Combustion

Combustion experiments were performed in an atmosphere of nitrogen and oxygen at 800°C and 10 bar and at 1000°C using both 10 and 20 bars total pressure. The mass loss profile for the experiments at 800°C is shown in Figure 3 and the pyrolysis level found above is indicated by a solid line. Figure 3 shows that for a residence time of 0.5 s the m/m0 is below the pyrolysis level, which means that the straw has started to burn. For a residence time of 1.2 s the particle has burned more than 98% (pyrolysis+combustion), and the conversion remains constant with residence time. Figure 4 shows that at 10 bar and 1000°C the pulverized straw has burned 95% at 0.5 s residence time. The final conversion at 2.5 s residence time is 99.5%, which is higher than the 800°C case. At 20 bars pressure the conversion at 0.5 s residence time is only 80% compared to 95% at 10 bars pressure, even though, the oxygen partial pressure is higher for the 20 bars experiments. The final conversion at 2.5 s residence time is 97%. Thus the general trend is that the combustion reactivity is decreased with increasing total pressure.

CONCLUSION

The pyrolysis experiments show that the pulverized straw pyrolysis 90 % of DAF in the PEFR at 1000°C and 10 bars pressure, which is above the volatile yield from the proximative analysis (81.5% of DAF). The pyrolysis in the reactor at 900-1000°C reaches its final values in about 1 s.

The combustion experiments show a high reactivity with oxygen, at 10 bar and 1000°C the pulverized straw has burned 95% at a residence time of 0.5 s. Increasing the absolute pressure from 10 to 20 bar for similar temperature and oxygen partial pressure reduces the conversion of the pulverized straw.

ACKNOWLEDGMENTS

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Table 1. The performance of the PEFR facility

Pressure	0.1 - 80 bar
Primary gas flow	0.3 - 6.0 Nm^3/hr
Reaction gas flow	1.5 - 30 Nm^3/hr
Reaction gas preheating	600 - 1500°C
Reactor temperature	600 - 1500°C
Fuel (coal or biomass) up to 10mm	10 - 300 g/h
Optical ports (Used at moderate pressures)	10 (2 in two levels) (3 in two levels)

Table 2. Size distribution based on mass (sieve method) and proximate analysis of pulverized wheat (wt%)

Size (μm)	wt %
> 1000	0
500 - 1000	0.2
250 - 500	6.2
125 - 250	25.0
63 - 125	14.7
32 - 63	9.5
< 32	44.4

	Dry	DAF
Fixed Carbon	17.5	18.5
Volatiles	77.3	81.5
Ash	5.2	---

Table 3. Ultimate Analysis, wt

C	H	N	S	Cl	Na	K	O
47.2	5.8	0.7	0.17	0.17	0.034	0.70	45.2

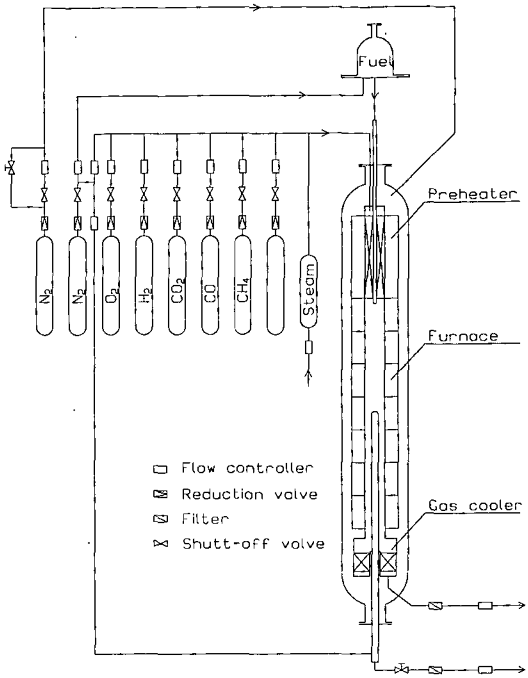

Figure 1. PEFR system layout

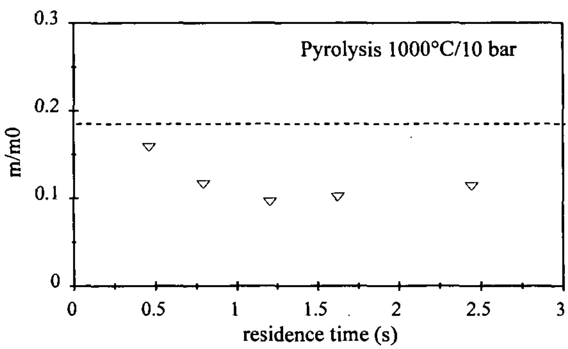

Figure 2. Pyrolysis of pulverized straw at 10 bar and 1000°C. Collected DAF mass divided by the initial DAF mass (m/m0) is plotted versus residence time. The line indicates proximate pyrolysis level.

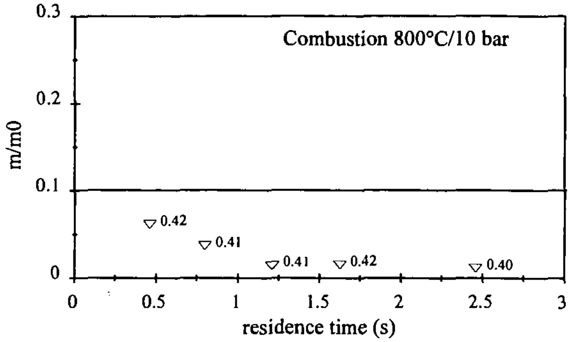

Figure 3. Combustion of pulverized straw at 10 bar and 800°C. Solid line indicates pyrolysis level, and partial pressure of oxygen in bar is written at each point.

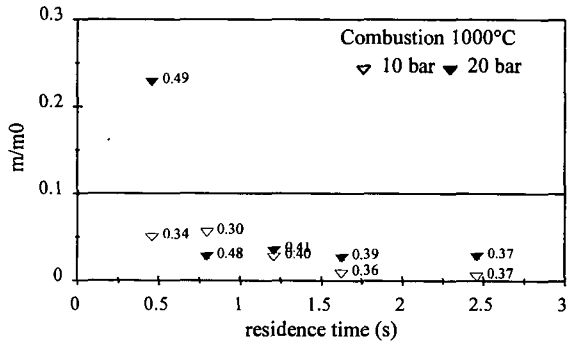

Figure 4. Combustion of pulverized straw at 10 and 20 bar and 1000°C. Solid line indicates pyrolysis level for the 10 bar case, and partial pressure of oxygen in bar is written at each point.