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DESIGN AND PERFORMANCE OF A FLASH PYROLYSER FOR BIOMASS ASSESSMENT OF TYPHA SAP PYROLYSIS

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ABSTRACT

A bench scale continuous flash pyrolyser system for the thermochemical conversion of biomass is described. A counter current flow of an inert gas removes the volatiles and gases outside of the heating zone to pass through a cyclone, condenser and a cold trap. Hard and soft wood samples were used as test materials to set the optimum working conditions. The system is employed to evaluate typha sap as candidate biomass material for Iraq. The pyrolysis was carried out at 723, 773 and 873 K and the results indicated that typha sap gives a gaseous yield that is several times as large as that of hard or soft wood due to the autocatalytic activity of alkali metals within it.

INTRODUCTION

The task of biomass energy extraction receives increasing interest as a means for establishing an inexhaustible resource of fuel and chemicals. Several technologies are to be proposed for use within the next few decades. Thermochemical routes have a good share of the proposed processes and many R&D projects have been carried out since the late seventies [1,2]. These routes include pyrolysis and gasification processes of the dry materials and evaluation of the char, liquids and gaseous products chemically and energetically. Solar energy could be a possible candidate for furnishing the heat requirements of thermochemical methods of biomass conversion [3–5]. Flash pyrolysis systems, however, are gaining more interest than others, as they permit the application of continuous process technology rather than the batch processes [5,6]. The Scientific Research Council is funding a project of the design and performance of a flash pyrolysis/gasification system to be employed for the evaluation of the available plant materials of Iraq as possible energy-rich biomass resources. Basic studies have indicated that the local available materials need less energy for conversion and respond more favourably to catalysis in comparison with soft and hard wood materials [7].

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The aim of the present work is to describe the design and performance of a bench scale flash pyrolyser–gasifier of biomass. Hard wood is employed as a test material. The system is applied to the evaluation of a local cellulosic feedstock, namely, typha sap. This material grows in the southern part of Iraq side by side with reed, as a natural water plant and has the chemical composition (%): C, 46.60; H, 4.68; N, 2.51; and (ppm): Li, 5.4; Na, 9500; K, 4700; Fe, 360 [7].

EXPERIMENTAL

Description of the system

A general schematic diagram of the system is shown in Fig. 1. Biomass is fed downward with the aid of a home-made screw feeder. The feeder was designed to permit work on samples of various sizes (2–1000 g) and can be driven manually or electrically (motor) depending on the capacity of the process. The main body was tilted so that the feeding was aided by gravity.

The biomass enters a pyrex chamber through a vertical passage which leads to a spherical container. A side-tube is fixed to the top of the container as the gas-exit. The base of the container is a cylindrical passage which transfers biomass to the reactor downwards and carries the volatile products

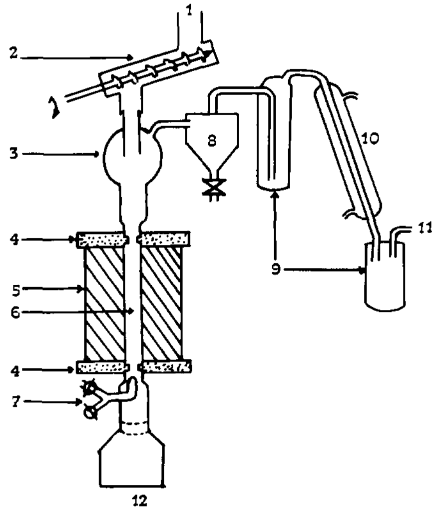

Fig. 1. Schematic diagram of the flash pyrolysis system; (1) biomass supply; (2) screw feeder; (3) biomass inlet and vapour outlet chamber; (4) asbestos blocks; (5) furnace; (6) quartz reactor; (7) working gas inlet; (8) cyclone; (9) cooled traps; (10) water condenser; (11) to gas analysis (GC); (12) char receiver.

upwards. This whole chamber is insulated thermally by a few millimetres thickness of asbestos coating.

The reactor is a commercial grade 21 mm od silica tube 25 cm in length placed inside a cylindrical furnace [8]. The reactor was fixed within the furnace with the aid of two asbestos blocks specially fabricated to assess the fitting of the inlet and outlet pyrex chambers above and below the furnace (Fig. 1). The base of the reactor was fitted with a 30-mm passage within which a combined inlet of two gases was adapted. The inlet of the working gases is governed by stopcocks to allow work to be performed with one gas or both.

The volatile and gaseous products are allowed to enter a home-made pyrex cyclone (Fig. 1) to separate solids and perform an initial separation of heavy components. The cyclone consists of an outer cylindrical container of 5 cm ID and an inner cylinder of ~ 2.5 cm ID. Half of the length of the inner cylinder lies within the outer container and half extends upwards to transfer the gases to the next compartment. Gases loaded with solid biomass particulate enter the cyclone in a tangential stream and turn around the inner cylinder in a helix movement downward where solids settle at the bottom of the outer container and light fractions submerge up inside the inner cylinder. The cyclone is succeeded by a 0.6 m long water condenser and a flask for collection. Finally, the gases are collected in a sampling bulb for the appropriate gas analysis.

Chemical analysis

The gaseous products were analysed on Pye-Unicam GC 104 and GC 204 gas chromatographs equipped with a Spectra Physics Minigrator. Hydrocarbons and alcohols were analysed over a Poropak Q 8/100 GC column, 1.5 m in length and 4 mm OD. A splitter was fitted into the outlet of the column to aid the parallel detection of hydrocarbons and alcohols with FID

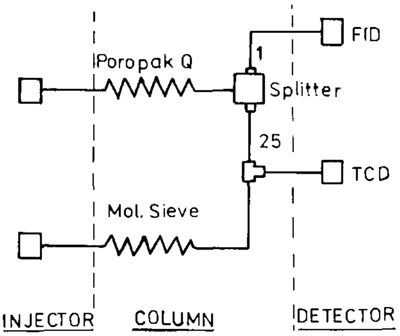

Fig. 2. Gas chromatograph set-up.

and carbon dioxide with TCD. Carbon monoxide was analysed with a molecular sieve 5A column 1.5 m in length and 4 mm OD, and detected on the TCD. The schematic diagram of the column–detector connections is shown in Fig. 2. Helium was used as a carrier gas. The signals from the detector amplifiers were fed into the minigrator via a selector switch to facilitate the recording of the output from either of the two detectors.

The syrups collected in the cyclone were analysed by gas chromatography following their silylation [9].

Feedstock

A large portion of 0.5–1 kg typha sap was collected and cut into small pieces prior to grinding into a fine powder to pass through a sieve giving an average particle size of 300 μm.

Testing of the system

Testing experiments included the calibration of the furnace temperature at flow conditions of nitrogen gas versus an Omega digital thermometer. Thermocouple probes were placed at the centre of the furnace and inside the neck of the feedstock inlet chamber to check for the thermal insulation. At high furnace temperatures ($\sim$ 950°C) the inlet temperature did not exceed 43°C.

Hard wood sawdust was employed as a testing material for leak detection, draft direction monitoring and pyrolysis temperature optimization. Three ranges of particle size distribution were used < 150, 150–300, and > 300 μm.

Starting with the coarse particles (> 300 μ), the screw feeder was driven by a motor at regulated speed to ensure a feed rate of ~ 5 g min^{-1}. The appearance of the material received at the char collecting flask indicated only a slight decomposition of the sawdust particles, due to the short residence time and the very small share of the heat received by each particle to undergo pyrolysis. In the second run, the screw feeder was driven manually to ensure an average rate of 0.25 g min^{-1}. The pyrolysis was improved, since gas evolution was appreciable, and the appearance of the sawdust particles indicated a charring process. The evolved gases passed through the screw feeder in addition to entering the cyclone and a plug was formed at the inlet tube which necessitates the application of a small flow of nitrogen gas (150 ml min^{-1}) inside the screw feeder. This small flow was also useful in preventing the submergence of the gases produced into the screw feeder. The passage of the gases into the screw feeder, however, was advantageous as we discovered a leak in the driving mechanism of the screw feeder. The leak was remedied by the application of Divicon repairing glue to the problem area.

RESULTS AND DISCUSSION

Hard wood pyrolyses at temperatures above 260°C [7], so the starting temperature employed was 300°C. The freely falling particles did not undergo appreciable degradation because of the very short residence time within the hot zone (ca. 0.33 s at the optimum counter current flow rate of nitrogen). This short residence time, therefore, is not sufficient for the particles to attain the degradation temperature.

Similarly, furnace temperatures of 350 and 400°C improved the pyrolysis only slightly. Appreciable degradation occurred at 450°C and GC analysis indicated the formation of some compounds. The test temperature was then fixed at 500°C.

An ordinary experiment consumes 4–6 g of the feedstock and takes 15–25 min. Gas evolution ceases from the terminal vent 40–60 s after the last particle of biomass drops. A gas sampling bulb was flushed first with the product gases for 8–10 min prior to taking a sample for GC analysis. In addition to solid particulate separation, a yellowish syrup-like material could be seen in the cyclone. This material is also seen in the condenser and the distillate collecting flask. To prepare this material for silylation and GC analysis, the cyclone and the condenser were washed with acetone and/or methanol [9] and the washings were combined.

A typical chromatogram of the gas mixture obtained from the pyrolysis of hard wood sawdust (≥ 300 μm) at 500°C is shown in Fig. 3. However, MeOH and H_2O signals were indicative of the efficiency of the condensation system, because with good condensation they become minor. Eleven gaseous materials could be identified and determined quantitatively in a single injection. At the optimum working conditions of temperature, inert gas flow rate and biomass feed rate, the experiments were done for feedstocks with particle sizes of 150–300 and < 150 μm.

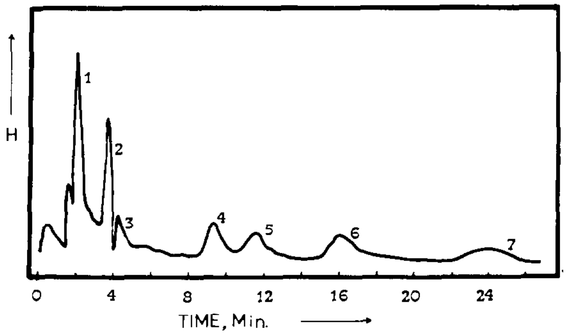

Fig. 3. Chromatogram of the gaseous products from hard wood pyrolysis: (1) methane; (2) ethylene; (3) ethane; (4) propane; (5) methanol; (6) unknown; (7) butanes.

TABLE 1

The dependence of the gas yield on the particle size of the pyrolyzed hard wood [a]

Component	> 300 μm	150–300 μm	<150 μm
CH_4	0.01	0.02	0.03
C_2H_4	0.01	0.01	0.02
C_2H_6	–	–	–
C_3H_8	–	–	0.01
CO	0.50	0.58	0.68
CO_2	0.75	0.84	1.05

[a] The figures represent the calculated percentages using specified standard gas mixtures.

The relative contents of the gases were improved and so was the gas yield as the particle size of the feedstock decreased (Table 1). The increase in the hydrocarbon yield was at the expense of the methanol yield which might suggest a process of interconversion. In spite of the improved yield of hydrocarbon, the use of the fine particles (< 150 μm) may be limited because of the problems encountered with feeding, such as the formation of a plug at the outlet of the screw feeder as a result of the moistening of the feed with the water vapour produced from cellulose decomposition. The other problem is the occurrence of pyrolysis at the uppermost part of the reactor because smaller particles are easier to fluidize in comparison with larger ones. Pyrolysis at this zone resulted in an increase in the content of the oxygenated species, especially carbon dioxide.

The same experiment was performed on soft wood samples of particle sizes > 300 and 150–300 μm and the results were in good agreement with those of hard wood (Table 1). The yield of ethane, C_2H_6, was comparatively smaller than that of ethylene, C_2H_4. The resemblance of the gaseous products from soft and hard woods may lead to the conclusion that the cellulosic composition of the feedstock does not govern the nature of the pyrolysis product.

The relative yields of the syrups of both hard and soft wood samples were higher than those reported [9] because the temperature is lower in present work and oil yield is favoured at moderate temperatures (500°C) [6]. The composition of the syrups was in favour of the higher molecular weight components in comparison with the previous work [9]. This is a consequence of the higher temperature employed [10] which resulted in thermal degradation of the heavy organic compounds [11].

The system, thereafter, was ready for carrying out the main object of this investigation, the thermochemical conversion of local biomass materials, typha sap. Much concern will be given to the gases and vapours and little to the syrups and heavy liquids because the former are indicative of the heat value and, hence, the energy extractable from biomass. Further, most of the

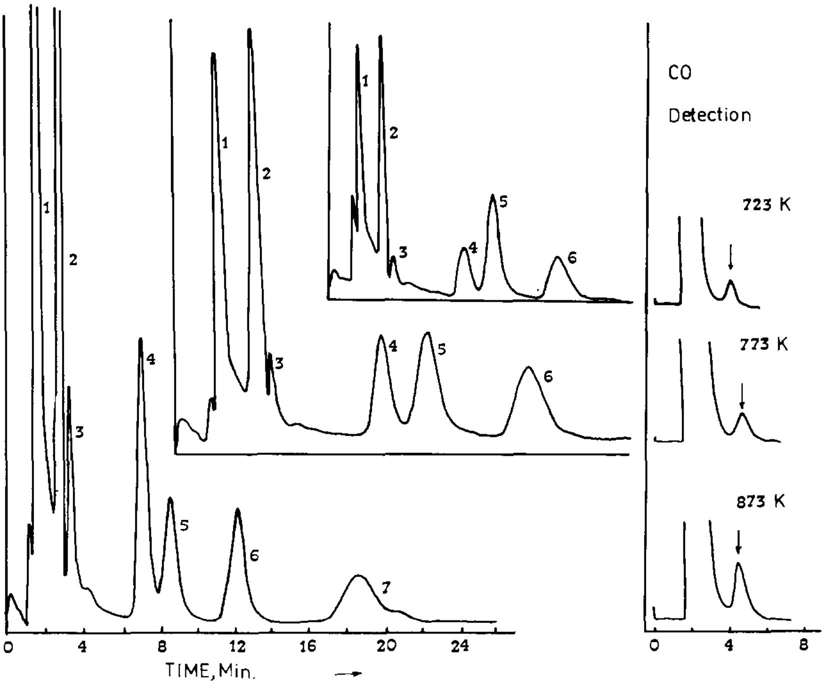

Fig. 4. Chromatograms of the gaseous products from typha sap pyrolysis at 723, 773 and 873 K. (For key, see Fig. 3.) Note the relative peak heights of components 4 (propane) and 5 (methanol).

conversion literature concern these gases [12] rather than the liquid products [9,13], which makes comparative work easier with respect to heat values of the feedstocks.

TABLE 2

The composition of the gaseous product from the pyrolysis of typha sap at different temperatures [a]

Component	723 K	773 K	873 K
CH_4	5.22	6.80	9.50
C_2H_4	4.68	5.91	7.23
C_2H_6	0.95	1.45	2.80
C_3H_8	1.52	2.70	3.35
CH_3OH	3.50	1.55	0.11
Unknown [b]	4.25	3.65	3.12
C_4	trace	trace	trace
CO	26.85	37.10	40.01
CO_2	50.65	45.02	28.25
H_2	0.84	2.5	6.15

[a] May be affected by the exothermicity or endothermicity of the reaction.

[b] Could be formaldehyde or acetaldehyde.

Flash pyrolysis of typha sap

The typha sap (> 300 μm) particles were pyrolysed at 450, 500 and 600°C under identical operating conditions. The gas chromatograms of the gaseous products are given in Fig. 4. The quantitative analysis is shown in Table 2. It is clear that the gas yield is improved several times with the increase in temperature and the gas composition is altered. The higher temperature pyrolysis is in favour of the hydrocarbons, hydrogen and carbon monoxide at the expense of methanol and carbon dioxide. This may be attributed to the secondary reactions of the gaseous products with the solid char or with each other in addition to the decomposition of tar [14]. This last could well be indicated by the decreased tar yield with increasing temperature.

In comparison with hard and soft wood pyrolysis, vide supra, typha sap is considered superior in its gas yield which may be correlated with the relatively high concentration of alkali metals [7]. Alkali metals are known to catalyse the gasification and pyrolysis of biomass [14].

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