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Syngas production from coal in presence of steam using filtration combustion

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ABSTRACT

Empirical studies were performed over the effects of volume fractions of coal, steam concentrations, and air flows during filtration combustion of mixtures from an inert solid (alumina spheres) and coal, normally referred as hybrid filtration combustion. Temperature, velocity, and concentration of gaseous products of the combustion wave were reported as function of different operational conditions. The results showed that maximum temperature increases were achieved with a high fraction of coal (<50%), a minor decrease of temperature was observed when increasing the steam concentration of the oxidant gas, and no changes were detected while changing the air flow in the feed stream. Downstream propagation velocities were recorded for each parameter of interest. Experiments showed that a maximum production of syngas was attained under the following conditions: a) 80% of steam concentration with 8 l/min of air flow and 50% volume fraction of coal in the hybrid mixture achieving concentrations of 26.92% of H_2 and 17.08% of CO; b) 70% volume fraction of coal with 20% of steam and 8 l/min of air flow reaching a 11.81% and 17.12% of H_2 and CO, respectively; c) 10 l/min of air flow with 50% volume fraction of coal and 20% of steam reaching a 10.13% and 11.60%, of H_2 and CO respectively. The results show that filtration combustion technology can be used to gasify coal into syngas.

Introduction

The current energy crisis is a direct consequence of worldwide over population and industrialization [1–5]. Fossil fuels are currently the main energy source (over 85%) used around the globe and its dependence shall remain unchanged unless concrete countermeasures are implemented [6]. It is foreseen that total primary energy demand is expected to increase by doubling or even a trebling in most conventional energy sources before 2050 relative to this day. Moreover a substantial depletion of fossil fuels is predicted to take place within the end of this century [7,8].

Hydrogen (H_2) is considered the fuel of the future as a possible replacement for conventional hydrocarbons. It is an environmentally clean fuel, due to its pollution-free combustion process. It has more energy per unit mass than any other fuel and applications of H_2 as an energy source include the generation of electricity via fuel cell [9]. Nonetheless there are known disadvantages to the use of hydrogen as an energy source, such as low energy content per unit volume, designing expensive and technically challenging storage units for its

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liquid or compressed forms, and others safety aspects. Hydrogen production from renewable or non-renewable sources requires high temperatures for carrying out this conversion (to H_2) [10,11]. Therefore, innovation is required for reaching simpler and more efficient processes to produce H_2.

There has been an increasing interest on control and reduction of gaseous pollutants released into the atmosphere, and an efficient use of fuels. Coal has been acknowledge worldwide as the major source of fuel currently in use and has the largest reserve in the globe, its use contributes with an 41.5% of the world electricity [6,12]. Nowadays, coal gasification is used to produce syngas (H_2 + carbon monoxide (CO)) [13–15], and provide fuel in power plants [16]. Currently, several researchers have devoted themselves to study the benefits of combustion in packed reactors with a porous matrix for the production of syngas. This technology combines the benefits of filtration combustion using a homogenous mixture composed of an inert porous media and a solid fuel called hybrid filtration combustion [17–22]. Thus, converting solid and gas fuels into syngas simultaneously [23]. The main advantages of filtration combustion include: a wider power range, higher efficiency, higher energy concentration per unit of volume, stable combustion over a wide range of equivalence ratios, due to the capacity of the porous media to recirculate the heat within the reactor. Therefore, temperatures exceeding adiabatic values can be attained at equilibrium, due to a larger superficial area offered by the porous media, which is responsible for heat transfer between gaseous and inert solid phases [24–27]. However, above researchers indicate that further studies are still required in order to optimize syngas production using hybrid filtration combustion, varying parameters such as: air flow, steam concentration, and volume fraction of coal in the hybrid mixture.

The aim of this research was to quantify the syngas production using filtration combustion of a hybrid mixture, composed of coal and an inert material (alumina spheres). The parameters studied were volume fraction of coal, steam concentration in the oxidant gas, and air flow. Temperature, velocity, and concentration of gaseous products (H_2, CO, and CO_2) of the combustion wave are presented and discussed.

2. Experimental apparatus and procedure

Filtration combustion was studied in a cylindrical reactor of quartz with 355 mm in length and 39.3 mm in ID (Fig. 1). To minimize heat losses, the reactor wall was insulated with a layer of Fiberfrax. A hybrid mixture consisting of particles of coal (4–6 mm of particle size) and alumina spheres (5.6 mm D) was packed in the reactor. Alumina was used as an inert material. The volume fraction of coal used in the mixture ranged from 20 to 70%. The hybrid bed had 40% porosity. Proximate analysis of the coal used reported a calorific value of 28678 kJ/kg, 8.6% of moisture, 1.65% and 45.81% of ash and volatile matter content, respectively.

Five S-type (platinum/rhodium, OMEGA Engineering, Inc., Stamford, USA) thermocouples were used for temperature measurements along the reactor and thus enabling the analysis of the filtration combustion wave through temperature profiles. The thermocouple junctions were placed equally

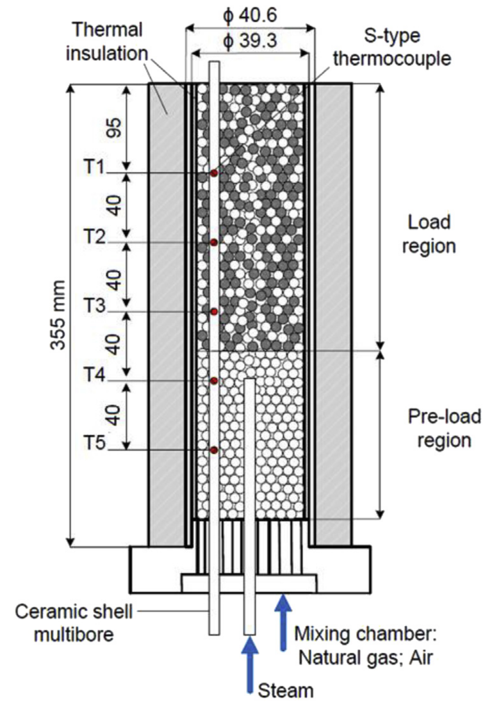

Fig. 1 – Schematic of the experimental setup.

spaced at 40 mm interval along a multi-bore ceramic tube (Fig. 1). Recorded temperatures in the junctions were very close to temperatures of the solid phase. Voltages measured by the thermocouples were recorded by an OMB DAQ 54 data acquisition module and converted by the Personal DaqView Software (OMEGA Engineering, Inc., Stamford, USA). Velocity of the filtration combustion wave propagation was determined via displacements of thermal profiles along the reactor, distance between thermocouples and the time intervals needed by the wave front to pass through each thermocouple.

The gaseous oxidants were air and steam. Air was fed by means of an industrial air compressor (Qualitas, Florida, USA) and was regulated with a mass flow control unit (Aalborg, Orangeburg, USA). The flow rate of air used ranged from 7 to 12 l/min. Both streams were mixed before entering the reactor, assuring a homogeneous gaseous mixture. The flow rate of steam ranged from 0 to 8 l/min, or fractions of 0–4.76 (H_2O/O_2) in the oxidant. The mixture was fed to the bottom of the burner since the reactor is open to the atmosphere at its top end.

The combustion products were collected at the reactor exit setting the sample time immediately after thermocouple T3, located in the hybrid region (see Fig. 1), reaches its maximum temperature. The gaseous products of combustion were quantified by gas chromatography (GC), using a method reported by Araya et al. [28] and Araus et al. [29].

The experiment was ignited by heating the inert bed (preload region, Fig. 1) using a natural gas-air mixture, which was fed to the bottom of the reactor. Once the filtration combustion wave progressed towards the load region, the hybrid mixture was added. After ignition of the starting of the mixture and when the T3 evidenced an increase in the temperature, the natural gas was turn off and the flow rate of air was adjusted at work value. Afterwards, steam is supplied to