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Coupling of an acoustic emissions system to a laboratory torrefaction reactor

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ABSTRACT

This article describes the use and characterization of an acoustic system coupled to a torrefaction reactor. The reactor, including phase shift and frequency, was characterized by applying both Lissajous/Hilbert and cross-spectrum techniques. Optimum acoustic frequencies were identified and an exploratory torrefaction test combining frequencies and temperatures was performed. The results from dynamic solid yields, conversion rates and temperature profiles showed that acoustic fields may improve torrefaction treatment.

1. Introduction

Torrefaction as a pre-treatment process involves the slow heating of biomass in an inert environment to a maximum temperature of approximately 300 °C. It converts biomass into a hydrophobic solid product with an increased energy density [1]. Major factors governing chemical reactions in a porous medium include chemical kinetics and heat and mass transfer, which are decisive in many devices of the chemical and energy industries. Given the development of thicker boundary layers by larger-sized biomass particles during torrefaction, some limitations arise from problems related to heat and mass transfer issues [2]. The motivation for this research work came from the potential use of this wood thermal treatment combined with an acoustic system to improve torrefaction treatment.

Thermoacoustic is responsible for some phenomena such as combustion instabilities (self-excited oscillation due to coupling between unsteady heat release and acoustic waves) [3,4], Rijke tubes [5] and thermoacoustic heat engines [6,7].

Some authors have shown relationships between thermal transfers and acoustic waves. [8] discussed the possibility for enhancement of heat transfer between solids and ambient gas by application of powerful acoustic field. Results showed that the heat transfer rate between a preheated wire and ambient gas can be enhanced under the application of sound waves. The heat transfer coefficient increases with the sound strength in both standing and travelling sound waves. In [9] the interaction between a standing wave acoustic field in a duct and a heated section was experimentally examined to enhance the overall convective heat transfer.

However, no work was found where torrefaction was combined with an acoustic field under pyrolysis or oxidative conditions. The assumption is that an acoustic field in a torrefaction reactor modifies the pressure and particles velocities around the wood sample. The combined effect of heat and acoustics could modify the interaction between reactor gaseous environment and wood sample, modifying degradation processes development.

To that end, an acoustic system was applied inside an existing torrefaction reactor [10] and subsequently characterized. Three different methodologies were used in terms of time and frequency domains. This characterization allowed the measurement of the flow rate and acoustic intensity at the exact spot where the sample was in the reactor. These acoustic results were analysed and used to predict which acoustic frequency and intensity produced the ideal conditions for obtaining higher particles velocities around the wood sample.

Finally, a preliminary torrefaction test was performed to observe the coupling effect of temperature and acoustic waves on temperature, solid yield and conversion rate profiles.

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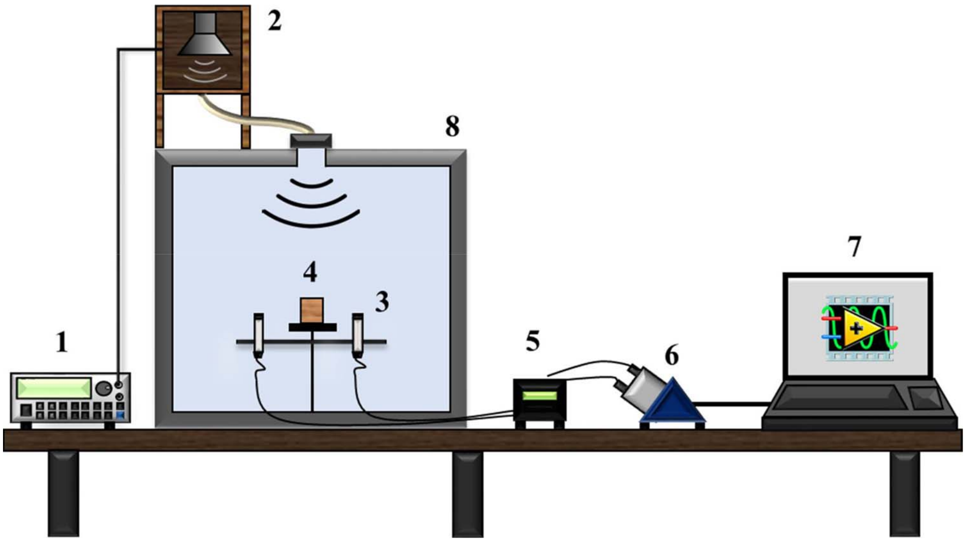

Fig. 1. General scheme of the experimental torrefaction acoustic system. 1) HP 33120A Signal Generator, 2) Selenium D220TI 8 Speaker, 3) Brüel & Kjær Microphones, 4) Wood sample, 5) Nexus Brüel & Kjær Conditioner, 6) CompactDAQ NI9174 and NI9234, 7) Computer (Labview Software), 8) Reactor.

2. Material and methods

2.1. Thermoacoustic torrefaction lab-scale reactor

The acoustic system coupled to the existing reactor [10] is illustrated in Fig. 1.

The acoustic experiment was performed with a humidity of 50%, an average temperature of 24 °C, speed of sound $c = 345\,\mathrm{m\,s^{-1}}$ and an air density of $\rho = 1.23\,\mathrm{kg\,m^{-3}}$. Within the experimental acoustic system, the desired frequencies were produced by an *HP 33120A* wave generator with a broadband frequency of 20 Hz–20 kHz. The acoustic wave was delivered by a *Selenium D220TI 8* speaker connected by a flexible duct [11] to the reactor cavity measuring 41 × 32 × 40 cm. Different acoustic frequencies produce different excitations of the reactor's cavity, hence a different pressure field. Frequencies were explored within a range of 0–3000 Hz.

The acoustic signals were measured and processed by two *Brüel & Kjær* 194537 microphones connected to a *Brüel & Kjær NEXUS* amplifier. Data acquisition was performed by a *National Instruments CompactDAQ NI9174-NI9234* interfaced by a *Labview* device.

2.2. Thermoacoustic torrefaction

The resulting laboratory-scale reactor used to perform a preliminary torrefaction experiment under acoustic influence is illustrated in Fig. 2. The device involved four subsystems: acoustic (A), heat treatment (B), power and recording (C) and gas feeding (D).

The acoustic subsystem was composed of a wave generator and one speaker connected by a flexible duct to deliver the acoustic wave inside the reactor. Oxygen concentration was controlled by N_2 injection. For the heat treatment section, it was composed of a reactor chamber, a support for the wood sample connected to a mass balance (*Sartorius LP2200S*) with an accuracy of 10^{-3} grams, two electric resistances and two type K special thermocouples (*IEC 584-3*) with a bead size of 1 mm and a tolerance value of 1.1 °C to determine the temperatures of the wood surface and wood core. To control the reactor temperatures and heating rate a programmable PID (proportional-integral-derivative) was utilized based on data from a thermal sensor PT100 placed within the system in the centre of the reactor to record atmosphere temperature. The system provide continues acquisition data with a 100 Hz sampling rate (*e.bloxx A4-1TC Multichannel*) recording thermocouples temperature profiles and mass weight during the wood heat treatment.

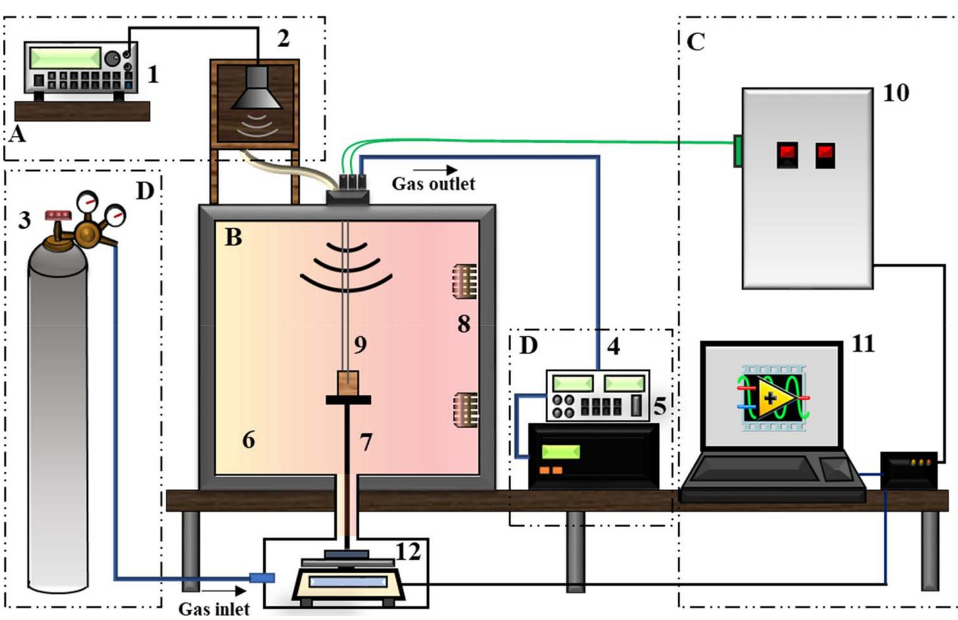

Fig. 2. General diagram of the experimental torrefaction system: 1) Wave generator; 2) Sound speaker 3) N_2 cylinder; 4) Gas pump; 5) O_2 control; 6) Reactor chamber; 7) Wood sample support; 8) Electric resistances for convection heating; 9) Thermocouples; 10) System control; 11) Computer; 12) Electric weight balance.