Energy 74 (2014) 950–955

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Combustion of biodiesel in a large-scale laboratory furnace

Caio Pereira, Gongliang Wang, Mário Costa*

IDMEC, Mechanical Engineering Department, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

ARTICLE INFO

Article history:
Received 8 October 2013
Received in revised form
22 July 2014
Accepted 23 July 2014
Available online 15 August 2014

Keywords:
Combustion
Biodiesel
Large-scale furnace
Pollutant emissions

ABSTRACT

Combustion tests in a large-scale laboratory furnace were carried out to assess the feasibility of using biodiesel as a fuel in industrial furnaces. For comparison purposes, petroleum-based diesel was also used as a fuel. Initially, the performance of the commercial air-assisted atomizer used in the combustion tests was scrutinized under non-reacting conditions. Subsequently, flue gas data, including PM (particulate matter), were obtained for various flame conditions to quantify the effects of the atomization quality and excess air on combustion performance. The combustion data was complemented with in-flame temperature measurements for two representative furnace operating conditions. The results reveal that (i) CO emissions from biodiesel and diesel combustion are rather similar and not affected by the atomization quality; (ii) NO_x emissions increase slightly as spray quality improves for both liquid fuels, but NO_x emissions from biodiesel combustion are always lower than those from diesel combustion; (iii) CO emissions decrease rapidly for both liquid fuels as the excess air level increases up to an O_2 concentration in the flue gas of 2%, beyond which they remain unchanged; (iv) NO_x emissions increase with an increase in the excess air level for both liquid fuels; (v) the quality of the atomization has a significant impact on PM emissions, with the diesel combustion yielding significantly higher PM emissions than biodiesel combustion; and (vi) diesel combustion originates PM with elements such as Cr, Na, Ni and Pb, while biodiesel combustion produces PM with elements such as Ca, Mg and Fe.

1. Introduction

Intense research is being carried out on the combustion of biodiesel, one of the main alternative fuels available in the world market. Biodiesel is commonly produced by transesterification, which transforms different kinds of vegetable oils into FAME (fatty acids methyl esters) [1,2], used as a fuel in various industrial applications. Current concerns are centred on the emissions of gaseous pollutants, such as CO, HC and NO_x, and also in PM (particulate matter) emissions, which can present harmful and non reversible effects on human health. Against this background, it is important to continue developing strategies to minimize both gaseous and PM pollutant emissions from combustion systems.

Related studies include those of Tashtoush et al. [3], Ng and Gan [4], José et al. [5], Bazooyar et al. [6] and Ghorbani et al. [7]. Tashtoush et al. [3] investigated the combustion characteristics and emissions of the ethyl ester of used palm oil and petroleum diesel fuel in a water-cooled furnace. The authors concluded that biodiesel may lead to higher combustion efficiencies and lower pollutant emissions than petroleum diesel. Ng and Gan [4] examined the combustion of palm oil methyl ester and its blends with diesel in a water-cooled combustor. The work demonstrated the potential use of palm oil biodiesels in small-scale liquid fuel burners, although further work is required to establish the optimum operating parameters and biofuel content for best NO_x and CO emissions trade-off. José et al. [5] evaluated the use of biodiesel and petroleum-based diesel mixtures in a conventional boiler and concluded that the maximum performance of the mixtures requires an adjustment of the fuel parameters depending on the oxygen content of the biodiesel and boiler operating conditions. Bazooyar et al. [6] investigated the combustion of petroleum diesel and biodiesels of grape seed, corn, sunflower, soybean, olive and rice bran oils in a water-cooled combustor. The authors observed that, under certain combustor operating conditions, all vegetable based methyl ester could emit lower gaseous emissions than petroleum diesel. Ghorbani et al. [7] compared the combustion of various biodiesel blends with petroleum diesel in an experimental boiler and observed that generally the pollutant emissions from the biodiesel blends were lower than those from the petroleum diesel.

In this work, combustion tests in a large-scale laboratory furnace were carried out to assess the feasibility of using biodiesel

* Corresponding author. Mechanical Engineering Department, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. Tel.: +351 218417186.
E-mail address: mcosta@ist.utl.pt (M. Costa).

http://dx.doi.org/10.1016/j.energy.2014.07.077
0360-5442/

Nomenclature

d_o	diameter of the fuel-injection orifice
U_a	atomizing air velocity
μ_f	liquid dynamic viscosity
ρ_a	air density
ρ_f	liquid density
σ	air surface tension
σ_f	liquid surface tension

Abbreviations

AFR	atomizing air/fuel ratio
ERZ	external recirculation zone
FAME	fatty acids methyl esters
IRZ	internal recirculation zone
PM	particulate matter
SEM	scanning electron microscope
SMD	Sauter mean diameter

as a fuel in industrial furnaces. For comparison purposes, petroleum diesel was also used as a fuel. Initially, the performance of the commercial air-assisted atomizer used in the combustion tests was scrutinized under non-reacting conditions. Subsequently, flue gas data, including PM, were obtained for various flame conditions to quantify the effects of the atomization quality and excess air on combustion performance. The combustion data was complemented with in-flame temperature measurements for two representative furnace operating conditions.

2. Materials and methods

Fig. 1 shows a schematic of the Instituto Superior Técnico large-scale laboratory furnace and its auxiliary equipment. The furnace is a vertical cylinder 0.6 m in diameter and 2.4 m in length, down-fired along its axis by a swirl burner. The furnace roof and the initial 1.2 m length of the cylindrical walls are refractory-lined. The outer surfaces of the refractory walls are surrounded by cooling water jackets. The remaining 1.2 m length of the wall surfaces are water-cooled only. Fig. 2 shows a schematic of the furnace roof and burner arrangement. The burner consists of a central gun and a secondary air supply in a conventional double-concentric configuration, terminating in a refractory quarl. The secondary air stream is fitted with guide vanes of constant cord and angle of 45° for inducing swirl. The burner gun comprises a removable air-assisted atomizer and a co-axial supply of primary air. In this study, a commercial air-assisted atomizer (Schlick model 0/2 form 6) was used, as shown in Fig. 2. The liquid fuels (biodiesel and diesel) were supplied to the burner with the aid of a nitrogen-pressurized tank, with the liquid fuel flow rate being measured with a calibrated rotameter.

Prior to the combustion tests in the large-scale laboratory furnace, a large number of water sprays produced by the atomizer were characterized under isothermal conditions in a spray test rig using the Phantom V4.2 high speed camera and the Malvern Particle Size Analyzer.

Local mean temperature measurements were obtained using uncoated 76-μm-diameter fine-wire platinum/platinum: 13% rhodium thermocouples. The hot junction was installed and supported on 350-μm wires of the same material as that of the junction. The 350-μm-diameter wires were located in a twin-bore alumina sheath with an external diameter of 4 mm and placed inside a stainless steel tube. The thermocouple probe was mounted on a computer-controlled traverse mechanism that allowed for movements along a furnace diameter. The analogue outputs of the thermocouple were transmitted via A/D boards to a computer where the signals were processed and the mean values computed.

Flue gas composition data were obtained with the aid of a stainless steel water-cooled probe placed at the exhaust duct of the furnace. The probe had a central 2 mm inner diameter tube through which quenched samples were evacuated. This central tube was surrounded by two concentric tubes for probe cooling. The analytical instrumentation included a magnetic pressure analyzer for O_2 measurements, a non-dispersive infrared gas analyzer for CO_2 and CO measurements, and a chemiluminescent analyzer for

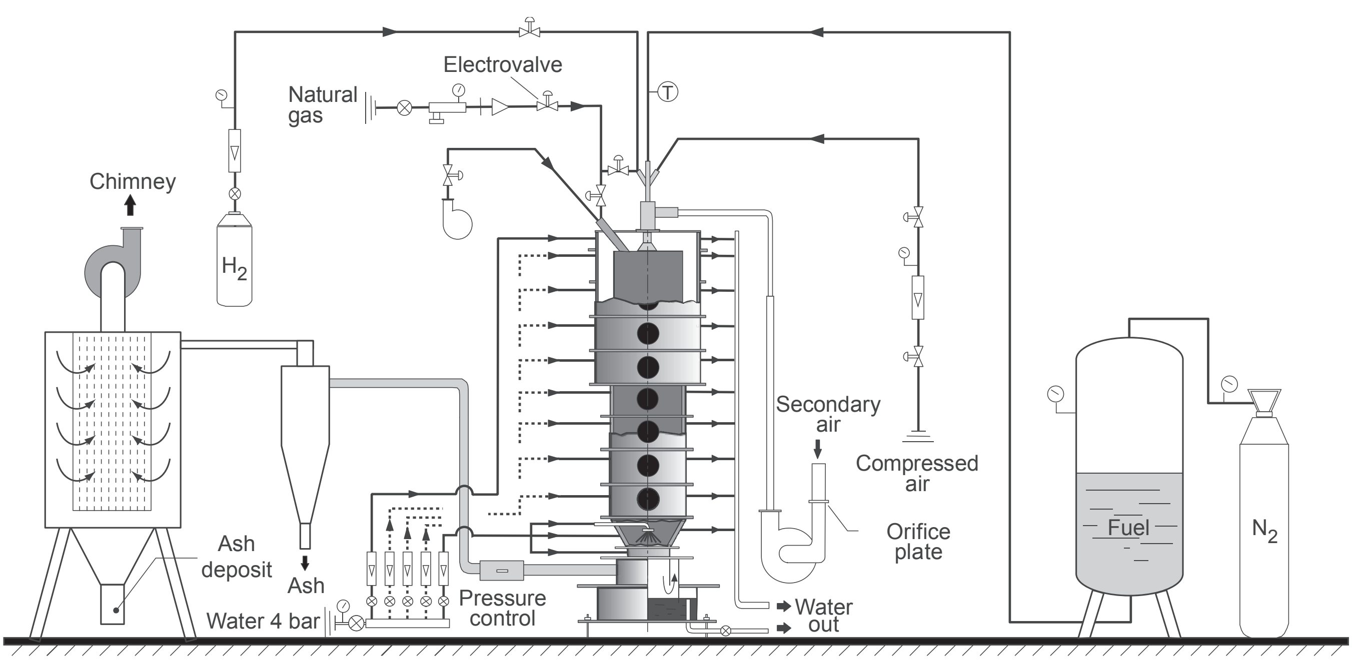

Fig. 1. Schematic of the large-scale furnace and its auxiliary equipment.