Journal of Environmental Chemical Engineering 2 (2014) 1228–1235

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

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

Assessment of pollution levels resulting from biomass gasification

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ARTICLE INFO

Article history:
Received 21 February 2014
Accepted 8 May 2014

Keywords:
Producer gas cooling
Condensate
Biomass
Downdraft gasifier

ABSTRACT

In biomass gasification process the producer gas generated can be cleaned by water scrubbing. Some of the organic compounds generated are entrained together with other flue gas dust particles in to the cooling stream. The treatment/disposal of this waste stream remains a challenge because some of the compounds are toxic to humans and the environment. The objective of this study was to assess pollution levels resulting from organic constituents of flue gas filtration in a downdraft gasifier. The study involved assessment of the concentration of polycyclic aromatic hydrocarbons (PAHs) in the liquid effluence. The impacts on human health and environment are also discussed and recommendations on measures to minimize the pollution levels are provided. A downdraft gasifier fed with maize cobs was used and condensates were collected by cooling of producer gas. Samples were preserved in a cooler at about 2 °C for 24 h before analysis using a capillary gas chromatographer connected to a mass spectrometer (GC–MS). The results were that concentrations of: naphthalene was 204.3 mg/m^3, benzene 17.92 mg/m^3, toluene 182.94 mg/m^3, ethylbenzene 202.43 mg/m^3, 1,2-dimethyl benzene 359.28 mg/m^3 and 1,3+1,4-dimethyl benzene 1016.18 mg/m^3. It was observed that the concentrations of naphthalene and xylene were considerably higher than the recommended permissible exposure limits (PELs) on both human health and the environment. On the other hand, the concentrations of benzene, toluene, and ethylbenzene were below the PEL. Generally this study indicated that the liquid effluent meets regulatory standards, but it would be interesting to carryout tests with different biomass fuel types which this study recommends.

Introduction

Biomass gasification is a thermo-chemical conversion process that converts biomass and other solid fuels into gases [1]. According to Larsen et al. [2], the produced gas mainly consists of: 18–20% hydrogen, 18–20% carbon monoxide, 2–3% methane, 8–10% carbon dioxide, 46–56% nitrogen, and traces of other hydrocarbons. Some residue of char is obtained and a host of hydrocarbon compounds called tars are also formed in the process along with water. In practice, gasification can convert 60–90% of the energy stored in the biomass into the gas generated depending on the type of gasifier and the operating condition used [3].

In Uganda, most of the gasification work is being carried out in research institutions and a few prototypes have been developed and tested. These include installations at Makerere University and Kyambogo University, Kampala; King's College Budo, Wakiso; and Nyabyeya Forestry College, Masindi [4]. Other gasifier installations are being commercially operated for power generation and thermal applications like at Muzizi Tea Factory in Kibaale and Ankole Tea Estate in Bushenyi. Recently, a private entity, Center for Renewable Energy and Energy Conservation (CREEC) acquired three 10 kW gek gasifiers under the Millennium Science Initiative (MSI)-Rural Electrification project implemented by the center in collaboration with Makerere University and Pamoja Energy Ltd. Two of these gasifiers have been installed in off grid areas of Gulu and Mityana in the villages of Opit and Ssekanyonyi, respectively to ease processing of agricultural produce from the local farmers.

As biomass gasification gains popularity as a renewable energy technology, it is necessary to ensure that health, safety and environmental issues do not become hurdles to its acceptance in the market. However, today the large scale introduction is hampered by health, safety and environmental issues, among others, which present considerable challenges in the deployment of this technology [5]. In the filtration of producer gas from biomass gasification using water scrubbing it is cooled thereby increasing its energy density for use in gas engines [6]. For instance, a gas temperature reduction of 10% can increase the maximum output of the engine by about 2% [7]. However, the cooling process enhances the condensation of water vapor and some hydrocarbons from the gas causes contamination of the filtering stream [8]. The hydrocarbons, particularly the PAHs from the

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http://dx.doi.org/10.1016/j.jece.2014.05.013

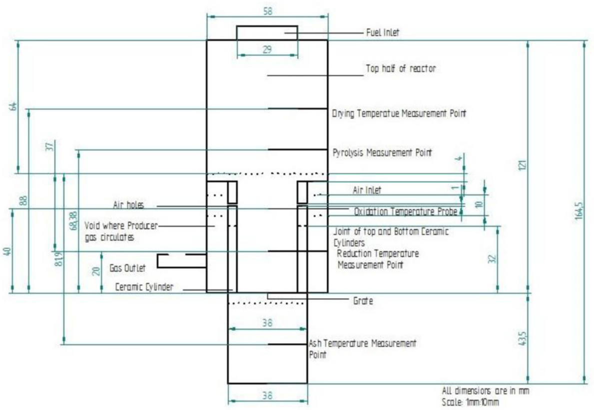

Fig. 1. Sectional view of a downdraft fixed bed gasifier at Makerere University [12].

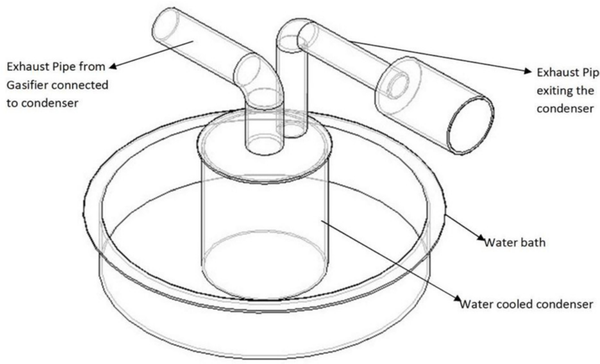

Fig. 2. Water cooled condenser connected to the exhaust pipe.

stream, are carcinogenic and highly toxic that can lead to risks of water pollution, adverse health and environmental effects [9].

The objective of this research was to assess the pollution levels resulting from biomass gasification producer gas filtration effluence. This involved determination of concentration of selected PAHs in the effluence and the comparison with known PEL, the impact on human health and the environment, and proposition measures aimed at minimizing pollution levels resulting from biomass gasification. The study was conducted on a downdraft gasifier test rig at Makerere University using maize cobs as fuel. The downdraft gasifier was chosen because it is suitable for gas engine applications due to the low tar levels it generates compared to the others [6] and is the gasifier type commonly used in small scale applications. The hydrocarbons measured were limited to mono aromatic hydrocarbons and light PAHs that are detectable by gas chromatography [10,11].

Experimentation

Description of gasifier setup and operation

The gasifier system comprised of a reactor, fuel feeding system, air blower connected to a three phase motor, ash collecting system, a gas sampling unit and a condenser coupled to the exhaust pipe. Fig. 1 shows a sectional view of the downdraft fixed bed gasifier that was used to perform the experiments.

The gasifier was first cleaned of tars from previous experiments that had accumulated in it. Charcoal amounting to an average weight of 7 kg was fed into the gasifier to provide a char bed during gasifier start-up. Maize cobs ranging between 9 and 12 kg was then weighed and fed into the reactor. The K-type thermocouples were installed in the pyrolysis zone and gas exit after the cyclone to indicate the temperature variation within the reactor during the gasification process. Temperatures were recorded at 10 min interval using a data acquisition system (87,623 SRP-6-1.5M data logger).

The producer gas generated during gasification of the maize cobs was tested by flaring. The gas samples were then collected for analysis from the gas sampling unit which was turned on once a flare was obtained and ran for more than an hour. In addition, the producer gas was cooled and condensate collected in a condenser that was fabricated and coupled to the exhaust pipe as shown in Fig. 2.

The collected condensate was immediately transferred from the condenser to graduated 250 ml water sampling bottles made of opaque glass to avoid photochemical reactions in water samples. The condensate samples were preserved in a cooler at about 2 °C to minimize the volatilization of the organic compounds with low boiling points and bacterial degradation of the organic compounds. The producer gas exiting the exhaust was flared to avoid emissions into the atmosphere. The operation of the gasifier was stopped once there was a progressive decline in the recommended gasification temperatures of 800–1000 °C [13].

Measurements and analyses

Selected physical and chemical properties of biomass that influence the gasification process were determined. The physical properties included bulk density and particle size. The bulk density was determined according to ASTM E873 while the particle size was determined using a digital vernier caliper. On the other hand, the chemical properties of the biomass were determined by conducting both the proximate and ultimate analyses. The ASTM standard E872 method was used to determine volatile matter. The ash content was determined following the Laboratory analytical procedure (LAP) for determination of ash in biomass developed by the National Renewable Energy Laboratory (NREL/TP-510-42622) [14]. On the other hand the fixed carbon was obtained by difference. The ultimate analysis was conducted to determine the elemental composition (i.e. carbon (C), hydrogen (H) and nitrogen (N)) of maize cobs using ASTM D3178-79 standard. The percentage composition of oxygen was then obtained by difference. The moisture content was determined separately using the oven dry method according to CENT/TS 14774-3 [15].

Producer gas samples were collected using gas sampling bags (Tedlar® bags) with a maximum capacity of 5 l. The samples were then immediately carried to the laboratory for analysis using a gas chromatographer (Shimadzu GC-3BT). Other parameters that were determined included: fuel flow rate, specific load of the reactor, and rate of gas production. See Belonio [16] for details of the procedures.

All chemicals and reagents for analysis were of analytical grade and of highest purity (i.e. >99.999% pure). The use of high purity reagents and solvents helped to minimize interference problems. A PAH reference standard mixture containing the target light PAHs (i.e. naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene) was used in the study. The mixture contained two isotopically labeled PAHs namely, acenaphthalene-d_{10} and phenanthrene-d_{10} as internal standards. For benzene, toluene, ethylbenzene and xylene (BTEX) analysis in the condensate, fluorobenzene (4000 mg/l in methanol) was used as an internal standard while BTEX-gas chromatography standard solution was used as a reference standard mixture. The apparatus used in sample preparation included: measuring cylinders, pipettes, vials, centrifugal tubes, mechanical shaker, centrifuge machine, analytical balance, Agilent GC–MS (6890) in electron ionization mode with split-less injector and capillary column of dimension 30 m × 250 μm × 0.25 μm. Measuring cylinders, vials, pipettes and centrifugal tubes used were cleaned with hexane and dried in an oven at 105 °C. This was done to avoid method interferences due to contaminants in solvents, reagents, glassware, and other sample processing hardware.