Waste Management 34 (2014) 63–66

Contents lists available at ScienceDirect

Waste Management

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

Production of high quality syngas from argon/water plasma gasification of biomass and waste

M. Hlina *, M. Hrabovsky, T. Kavka, M. Konrad

Thermal Plasma Department, Institute of Plasma Physics AS CR, v.v.i, Za Slovankou 1782/3, 182 00 Prague, Czech Republic

ARTICLE INFO

Article history:
Received 27 February 2013
Accepted 18 September 2013
Available online 19 October 2013

Keywords:
Plasma
Gasification
Biomass
Tar

ABSTRACT

Extremely hot thermal plasma was used for the gasification of biomass (spruce sawdust, wood pellets) and waste (waste plastics, pyrolysis oil). The plasma was produced by a plasma torch with DC electric arc using unique hybrid stabilization. The torch input power of 100–110 kW and the mass flow rate of the gasified materials of tens kg/h was set up during experiments. Produced synthetic gas featured very high content of hydrogen and carbon monoxide (together approximately 90%) that is in a good agreement with theory. High quality of the produced gas is given by extreme parameters of used plasma – composition, very high temperature and low mass flow rate.

1. Introduction

The utilization of biomass as one of the sustainable energy sources needs new technologies to gain the energy from biomass in the form of high quality syngas.

Conventional methods such as simple oxidation or partial oxidation without external heating (autothermal) are usually cheap, convenient for heat production, but generally due to lower reaction temperature and dilution by oxidation products unsuitable for chemical production. Existing power plants can utilize biomass energy only by direct co-firing of biomass with coal (van der Meijden et al., 2012).

The necessity of the production of clean syngas with controlled composition has led to technologies based on allothermal processes with external energy supply for materials gasification. Plasma is a medium with the highest energy content and thus substantially lower plasma flow rates are needed to supply sufficient energy for gasification compared with other media used for this purpose. This results in minimum contamination and dilution of produced syngas by plasma gas and easy control of syngas composition (Hlina et al., 2010).

Thermal plasma (plasmas with local thermal equilibrium) offers extreme properties – mainly very high temperature which can be used for gasification. Most thermal plasmas are generated for gasification by either an electric arc or by a radio-frequency induction discharge (Heberlein and Murphy, 2008). In waste treatment, DC arc plasmas dominate because they are relatively insensitive to changes in process conditions. However, some AC plasma torches for biomass gasification are known (Rutberg et al., 2004).

Plasma due to high energy content can directly gasify treated materials without adding any oxidizing media but this scenario would usually lead to carbon production at the expense of synthetic gas production. Therefore, stoichiometric amount of CO_2, H_2O, O_2, air or appropriate mixture is added.

This paper presents the conversion of electrical energy to chemical energy in a medium scale reactor equipped by H_2O/Ar DC plasma torch.

2. Experimental set-up

A DC plasma torch with adjustable arc power was used as the source of energy for gasification. The plasma torch involves the combination of arc stabilization by gas (cathode part), where the cathode is protected against oxidation by Ar flow, followed by water stabilization of the arc. Water is injected tangentially to the arc chamber of the torch and forms a vortex that surrounds the electric arc. An anode is a water cooled rotating copper disc. The arc power was 100–110 kW during experiments. The simplified schema of the torch is in Fig. 1.

Produced plasma features extreme parameters such as very high bulk temperature (18,000 K) together with low mass flow rate (typically around 0.3 g/s H_2O + 0.2 g/s Ar), however, due to combined stabilization, a wide range of plasma properties can be adjusted (Hrabovsky et al., 2006). The ratio of net arc power to the mass flow rate of plasma is up to 200 MJ/kg in a standard regime that is approximately one order of magnitude higher than in the case of other thermal plasma torches used for gasification (e.g. Westinghouse MARC3: 7 MJ/kg). The conjuncture of these

* Corresponding author. Tel.: +420 266 05 33 17.
E-mail addresses: hlina@ipp.cas.cz (M. Hlina), hrabovsky@ipp.cas.cz (M. Hrabovsky), kavka@ipp.cas.cz (T. Kavka), konrad@ipp.cas.cz (M. Konrad).

0956-053X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.wasman.2013.09.018

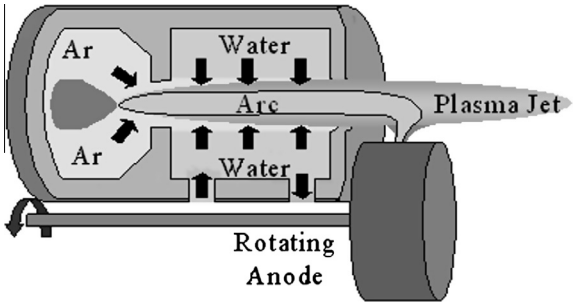

Fig. 1. Schema of the argon/water DC plasma torch.

parameters causes low concentrations of unwanted species such as tars as well as low dilution of produced syngas by plasma gas so well known among conventional gasification plants.

The plasma torch is mounted at the top of a reactor with water cooled jacket. The reactor has 400 mm thick ceramic thermal insulation and an inner volume of 0.22 m^3. The inlet of gasified material is on the top part of the reactor and the outlet of produced gas is in the upper side of the reactor. The hopper for treated material with the volume of 300 l is connected to the reactor by a controlled speed screw feeder. Produced syngas enters a quenching chamber, where the produced gas is cooled down to 300 °C by water spray then enters a filter chamber and subsequently is burnt (Fig. 2). A water ejector has recently been installed between the filter chamber and the syngas burner so the reactor is operated at the slight underpressure of several hundreds of Pa. Reaction temperature is monitored by 8 thermocouples and ranged between 1,200 °C and 1,400 °C during experiments.

The measuring system included monitoring of plasma torch operation parameters, temperatures of inner walls in the reactor, calorimetric measurements of cooling water loops and the flow rate of produced syngas as well as its composition. A sampling probe for composition measurements was located at the reactor output in front of the quenching chamber. This set-up enables the fast quenching of the sampling gas that is similar to the quenching of the main flow of produced gas. A quadrupole mass spectrometer Pfeiffer Vacuum Omnistar GSD 301 with direct inlet was used as a main gas analyzer. A freezing unit is placed between the mass spectrometer and the sampling probe to avoid water condensation and the damaging of the mass spectrometer. For this reason, the efficiency of the gasification process is preferably calculated as a carbon yield.

3. Results and discussion

Several types of materials were used for the gasification process: wood sawdust (spruce, 10.5 % H_2O), wood pellets (spruce, 6 mm diameter, 7.4% H_2O, spruce wood composition was taken accordingly to Vassilev et al. (2010)), waste plastics (pieces of 1–6 mm, 89% HDPE, 10% PP, 1% PET, $CH_{1,99}$ (mole composition)) and pyrolysis oil from thermal decomposition of waste tires (complex mixture of aromatic hydrocarbons, $CH_{1,47}$ (mole composition)). Elements with concentration under 1% (mass) were not taken into account in the computation of theoretical composition. All the materials need adding of a certain amount of oxidizing media (CO_2, O_2, H_2O or appropriate mixture) to achieve a syngas with theoretical composition closely corresponding to the mixture of CO and H_2.

Wooden substances and waste plastics are from the point of pyrolysis temperature similar materials but pyrolysis oil differs. It is the mixture containing wide range of fractions (from petrol fraction to asphalt fraction) and the simulated distillation of pyrolysis oil showed the weight loss of 50% at 204 °C (90% at 417 °C). The lighter fractions of pyrolysis oil should be gasified much easier than other used materials because their evaporation as the first step during gasification is energetically less demanding.

The throughputs of the materials for gasification ranged between 9 and 30 kg/h plus tens to hundreds of slm (standard liter per minute) of CO_2 in case of sawdust, pellets, waste plastics and 11 kg/h of H_2O in case of pyrolysis oil. Results of the gasification are summarized in Table 1.

The concentration of Ar was taken as zero because Ar was used also for syngas flow rate calibration (the concentration of Ar from plasma would affect the composition of syngas by 1–2 vol.%). It can be seen that CO and H_2 form approximately 90% of produced syngas in all presented results. This was caused by extreme properties of the plasma and by low dilution of the syngas by plasma gas (formed mainly by hydrogen and oxygen). Carbon yield in the experiments ranged between 80 and 100%. Lower values were caused by the formation of solid carbon. Materials with smaller particle sizes showed higher carbon yield usually (e.g. sawdust),

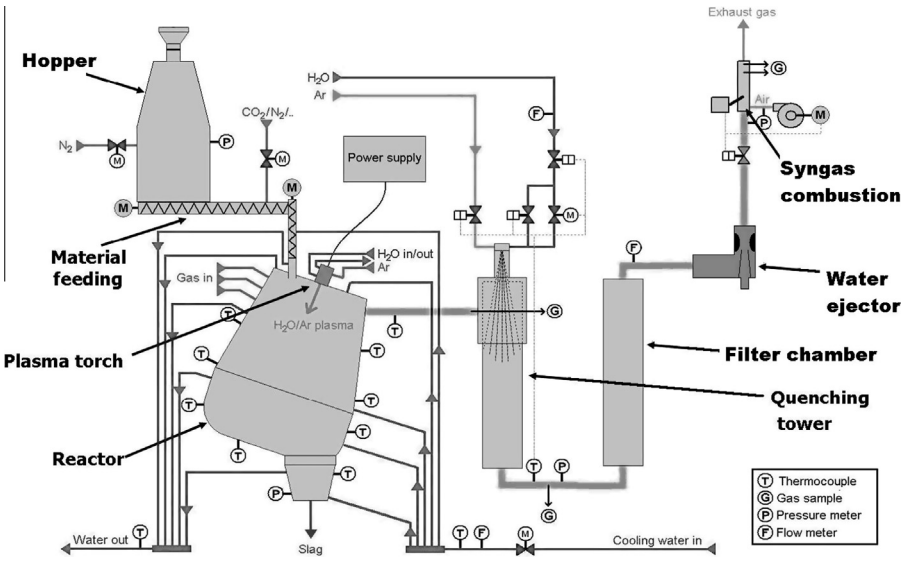

Fig. 2. Schema of the gasification unit (M = manually controlled valve).