Fuel 150 (2015) 664–671

Contents lists available at ScienceDirect

Fuel

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

Extended operability of a commercial air-staged burner using a synthetic mixture of biomass derived gas for application in an externally fired micro gas turbine

Fabiola Baina [a,b,*,1], Anders Malmquist [a,2], Lucio Alejo [b,1], Torsten H. Fransson [a,3]

[a] Department of Energy Technology, School of Industrial Technology and Management (ITM), Royal Institute of Technology (KTH), 100 44 Stockholm, Sweden
[b] Facultad de Ciencias y Tecnología (FCyT), Universidad Mayor de San Simón (UMSS), Cochabamba, Bolivia

HIGHLIGHTS

- A two staged diffusion burner was used for combustion tests of simulated biomass derived gas.
- Benzene was injected at two concentrations in the fuel tested to represent tar.
- An optimum equivalence ratio was found for minimum emissions of CO and UHC.
- NO_X emissions increased with the addition of benzene in the fuel gas.

ARTICLE INFO

Article history:
Received 17 July 2014
Received in revised form 10 February 2015
Accepted 12 February 2015
Available online 24 February 2015

Keywords:
Simulated biomass gasification gas
Two stage combustion
Benzene injection
NO_X emissions
Carbon monoxide
Unburned hydrocarbons

ABSTRACT

Biomass gasification converts solid biomass into a gaseous fuel that is more versatile and can be used in many applications. However, biomass gasification gas contains some contaminants and inert compounds. The contaminants can cause several problems in the downstream equipment and undesirable emissions while the inert compounds can affect the lower heating value of the gas. Because of these characteristics, there have been difficulties in finding a conversion technology using biomass gasification gas for heat and power generation. In this regard, externally fired gas turbines open a possibility for this combustible gas since due to its configuration, combustion takes place outside the conventional gas turbine cycle. For this reason, combustion studies of biomass derived gas are important. In this work the operability of a commercial air-staged natural gas burner is shown in terms of CO, UHC, and NO_X emissions using a synthetic mixture of biomass gasification gas. Two fuel gas mixtures simulating the composition of biomass gasification gas are injected in the combustor. Each fuel gas contains different injection rates of benzene in order to represent tars and to understand their effect on the combustion performance. Additionally, the equivalence ratio is varied in a range of lean conditions in order to find an optimum operation point for the burner studied. The results showed that the presence of polyaromatic hydrocarbons such as benzene reduced the CO concentrations in the exhaust gas while it increased the concentrations of unburned hydrocarbons (UHC) at equivalence ratios lower than 0.68. Additionally, NO_X emissions showed a relatively constant trend over the range of equivalence ratios studied for both fuels. It was also observed that NO_X emissions increase with the addition of benzene in the fuel gas. An optimum point with regards CO and UHC concentrations was found for the fuels tested.

1. Introduction

Biomass gasification is a thermochemical conversion process through which solid biomass is converted into a combustible gaseous fuel. This gas is composed mainly of CO, H_2, N_2, CO_2, CH_4, H_2O (vapor) and light hydrocarbons. In addition, it contains trace amounts of NH_3, HCN, small char particles, tars, and ash known as contaminants [1,2].

* Corresponding author at: Department of Energy Technology, School of Industrial Technology and Management (ITM), Royal Institute of Technology (KTH), 100 44 Stockholm, Sweden. Tel.: +46 8 790 74 42; fax: +46 8 20 41 61.

E-mail addresses: fabiola@kth.se (F. Baina), andmal@kth.se (A. Malmquist), lalejo@fcyt.umss.edu.bo (L. Alejo), fransson@energy.kth.se (T.H. Fransson).

1 Tel.: +591 4 23 36 48; fax: +591 4 23 25 48.
2 Tel.: +46 8 790 74 38; fax: +46 8 20 41 61.
3 Tel.: +46 8 790 74 75; fax: +46 8 20 41 61.

http://dx.doi.org/10.1016/j.fuel.2015.02.048
0016-2361/

Nomenclature

LHV	Lower heating value (MJ/N m^3)
$\dot{m}_{air}$	Air mass flow rate (kg/h)
$\dot{m}_{fuel}$	Fuel mass flow rate (kg/h)
T_{ad}	Adiabatic temperature (K)
UHC	Unburned hydrocarbons (ppm)
Greek	
Φ	Overall equivalence ratio

Compared to solid biomass, biomass gasification gas presents several advantages in application and emissions reduction [3]. The gas phase allows a simpler control and regulation of the combustion process. The use of biomass also reduces CO_2 emissions and dependence on fossil fuels [2,4].

The main disadvantages of biomass gasification gas are the contaminants and the lower heating value of the gas. The contaminants in the producer gas can cause erosion, corrosion, difficulties when burning, internal depositions and emissions. The low heating value embodies challenges in the use of already existing natural gas burners as well as in their design. These disadvantages represent a barrier to find a conversion technology capable to use producer gas for heat and electricity generation [1,2].

At small scales biomass gasification gas can be used in combination with internal combustion engines and gas turbines to generate heat and power. However, there are several challenges in these systems. The application of syngas with internal combustion engines and gas turbines shows technical difficulties due to the contaminants present in the combustible gas. Cleaning the producer gas can overcome these difficulties [1]. However, the system becomes complex and costly with the addition of cleaning steps [5]. An externally fired gas turbine is another technology that offers an option with regard to the contaminants in the combustible gas. The configuration of externally fired gas turbines is such that combustion takes place outside the cycle at atmospheric pressure. Fig. 1 shows a schematic of an externally fired gas turbine. The flue gas heats the compressed air that later expands in the turbine. In this way, the flue gas is not in direct contact with the turbine. This characteristic opens the possibility of using biomass gasification gas without the strict requirements of high quality fuels as it is the case for internal combustion engines and conventional gas turbines [6].

The system shown in Fig. 1 corresponds to an externally fired micro gas turbine prototype designed for a target of 5 kW electrical and 17 kW thermal power. The prototype was built by Compower AB. This system was initially designed and tested for natural gas. However, in order to apply biomass gasification gas in such a system, investigation regarding its combustion is necessary. Syngas combustion has been studied for premixed flames, for diffusion flames and for a mix of both. Lean premixed flames are used to lower the emissions and it is especially interesting when using natural gas. However, for syngas, flashback is likely to occur. Flashback is caused by the high diffusivity of hydrogen. Diffusion flames on the other hand, offer combustion stability compared to lean premixed flames. However, diffusion flames are also known to produce higher amounts of thermal NO_X compared to lean premixed flames [7,8]. This characteristic of diffusion flames can be handled by wet and dry NO_X control methods [7]. Among these methods, air stage combustion is one of the effective methods to be used in diffusion flames for NO_X control [9].

Studies using syngas in diffusion flames with and without air staging are summarized as follows. Adouane et al. [10] studied the conversion of ammonia to NO using an air-staged combustor named Winnox-TUD. Ammonia was used to represent fuel-bound nitrogen from biomass derived gas. Additionally, the effect of primary air–fuel equivalence ratio and methane on ammonia conversion was evaluated. A minimum conversion of NH_3 to NO was reported at an air–fuel equivalence ratio of 0.7. The addition of methane increased the conversion of NH_3 to NO while no substantial effect was reported when varying the secondary air [10]. Similar results were reported by Hasegawa et al. [11] with regards to the effect of methane addition to the conversion of NH_3 to NO [11]. The reaction mechanisms of syngas combustion were simulated by Chacartegui et al. [12] based on a diffusion combustor with special emphasis in injection of steam in the combustion chamber. The simulation was able to predict gaseous emissions in three different heavy duty gas turbines. The results showed that steam injection reduced NO_X formation in all the cases. Also, syngas fuels containing higher amounts of CO were reported to show higher NO_X emissions. It was also concluded that CO, unburned hydrocarbons and NO_X showed to be dependent on the residence time [12]. Huynh and Kong [13] studied NO_X emissions of biomass syngas derived from three different types of biomass and three different oxygen enriched gasification conditions. A linear decreasing trend was reported for NO_X emissions as the combustion became leaner for two of the biomass feedstock tested (pine wood and maple-oak wood) while a peak NO_X was shown for seed corn, the third biomass feedstock studied. Seed corn was also reported to produce the highest ammonia concentration in the fuel gas giving the highest NO_X emissions [13]. Giles et al. [14] studied the dilution effect of N_2, H_2O, and CO_2 in NO_X emissions of syngas diffusion flames. The results showed that CO_2 and H_2O are more effective diluents to reduce NO_X than N_2. The effectiveness of H_2O was addressed to its high specific heat reducing the concentration of CH radicals and hence prompt NO [14].

As can be seen from previous studies, the main concerns in combustion of biomass gasification gas are related to the stability of combustion and emission levels. Diffusion flames are a current option for stability problems of syngas combustion until lean-premixed combustors are able to overcome the stability issues of syngas. Regarding combustion performance of producer gas, most of the studies considering a synthetic mixture of biomass gasification gas did not deal with a tar representative component. Additionally, studying the effect of tars is suggested by Huynh and Kong [13].

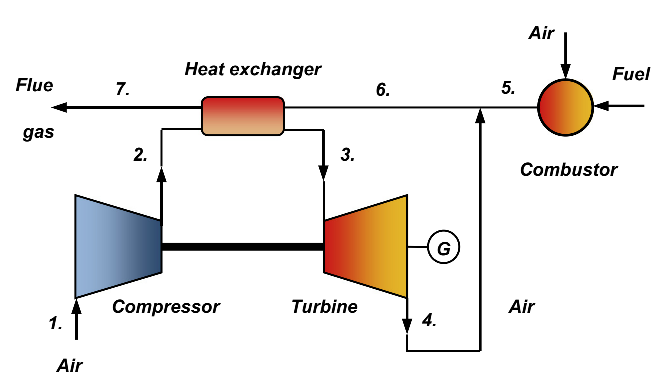

Fig. 1. Schematic of an externally fired gas turbine.