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ScienceDirect

Energy Procedia 75 (2015) 240 – 245

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Biomass gasification plant and syngas clean-up system

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Abstract

Gasification is recognized as one of the most promising technologies to convert low quality fuels into more valuable ones. The principal problem related with the use of biomass in gasification processes is the high amount of tar released during the pyrolysis step. It is thus necessary to recover tar and to transform it in lighter combustible gas species such as CH_4, CO and H_2. In this work the experimental results of a medium industrial scale plant fed with olive husk and having a capacity of 250 kWt are presented. The gasifier is composed by a up-draft reactor which is followed by a secondary fixed bed reactor filled with alluminium oxide spheres having high porosity dedicated to the tar conversion reactions. The syngas is then used to feed an internal combustion engine with a production of 60 kWe.

Keywords: Gasification; syngas clean-up; biomass.

1. Introduction

The interest on the exploitation of biomass as source of energy has continuously increased in the last decade. Biomass has been recognized as one of the most attractive alternatives to fossil fuel, even if is not yet competitive. Many research efforts have been successfully made to develop efficient and convenient process for biomass exploitation [1]. However, biomass is a low-grade energy fuel and has limited uses as a direct feedstock to produce energy. For this reason the study of innovative thermochemical processes, such as gasification and pyrolysis, to transform the solid biomass into more valuable fuels is of fundamental importance for the success of biomass exploitation. Gasification converts the low-grade solid biomass under high temperature into gaseous fuel called syngas. The biomass-generated syngas consists mainly of CO, H_2, CO_2, CH_4, N_2 (if air is used as an oxidizing agent), and impurities such as tar, H_2O, NH_3 and H_2S. Even though gasification is a well-established technology for coal, its adaptation to biomass feed is not straightforward. During biomass gasification, indeed, high amount of tar is produced; tar is a

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doi:10.1016/j.egypro.2015.07.318

complex mixture of condensable hydrocarbons, comprising single-ring to 5-ring aromatic compounds and other oxygen-containing organic molecules [2]. The presence of tar can cause operative problems to the gasification plants, such as pipes and filters obstruction and reduction of the heat exchange efficiency due to its condensation on the downstream section. Tar tolerance limit varies depending on syngas applications; the limit is ~500 mg/Nm^3, ~100 mg/Nm^3 and 5 mg/Nm^3 for compressors, internal combustion systems, and direct-fired industrial gas turbines, respectively [3]. Therefore the most difficult challenge in designing a suitable reactor for biomass gasification is to minimize the presence of tar within the syngas. To this aim different methods have been developed [4]. The conversion of tar into valuable lighter species such as CH_4, CO and H_2 by means of thermal cracking and steam reforming seems to be an interesting solution. Thermal cracking and steam reforming are endothermic processes that occur at temperature higher than 700 °C, the reactions taking place are reported below. The particulate dragged from the gasifier is converted into carbon monoxide by the Boudouard reaction.

$C_nH_m = (m/2)CH_4 + (n-m/4)C$ cracking reaction

$C_nH_m + nH_2O = nCO + (n+m/2)H_2$ steam reforming reaction

$C + CO_2 = 2CO$ Boudouard reaction

In this way the tar is not only removed from the syngas but it contributes to increase the syngas quantity and quality.

In this work the experimental results of a medium industrial scale plant fed with olive husk and having a capacity of 250 kW_t are presented. The gasifier is composed by a up-draft reactor which is followed by a secondary fixed bed reactor filled with alluminium oxide spheres having high porosity and dedicated to the tar conversion reactions. The Al_2O_3 is often used for this kind of applications due to its resistance to high temperature and to the high surface area that allows to increase the residence time of the tar vapor into the reactor. In a previous work the efficacy of the Al_2O_3 for the tar removal was demonstrated [5]. After the two reactors the plant is equipped with a cooling section that allows also the further purification of the syngas from the residual tar and the dragged solid particles. The plant works in continuous and the syngas is then fed to an internal combustion engine coupled with an electric generator producing 60 kWe.

2. Experimental plant

The gasification plant is composed by two reactors in series followed by a syngas cooling and cleaning section equipped with a cyclone to remove the dragged particulates and with a direct contact condenser to cool the gas from about 350 °C (at the exit of the air preheater heat exchanger) to about 50°C. This cooling system works also as water scrubber eliminating the residual particulates and tar. To be easily transported, the plant is placed on three skids: for the preparation of the feedstock, for the gasification plant, and for the engine, respectively. In Fig. 1 the scheme of the plant is reported and in Fig. 2 a picture of the two reactors placed on the skid is showed.

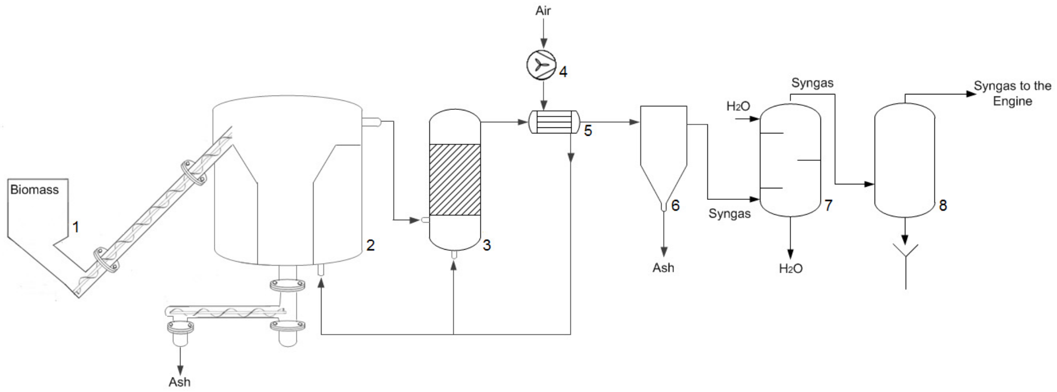

Fig. 1. Scheme of the gasification plant. 1 hopper with screw feeder, 2 gasifier, 3 secondary reactor, 4 air fan, 5 air preheater, 6 cyclone, 7 cooling and scrubbing system, 8 equalization tank.

Fig. 2. Picture of the plant in the skid.

The gasifier is a up-draft reactor where the solid feed and the gas flow in countercurrent. The reactor is 1.6 m height and 1,3 m in diameter. The air is injected from the bottom of the reactor and the biomass is fed, by means of a screw, from the top with a flow rate of 50 kg/h. The air enters in the reactor with an Equivalent Ratio of 0.5 and is heated by the syngas exiting from the second reactor to a temperature of about 400 °C. The ashes are discharged at regular interval, every 1 hour, with a screw from the bottom of the reactor. To avoid the ash agglomeration and melting an agitator is employed to keep the material in constant movement.

The syngas with the tar and the dragged particulates exit at 550 °C from the top of the gasifier and are sent to the second reactor where the endothermic cracking and reforming reactions take place. The syngas is fed at the bottom of this reactor and is forced to pass through a 80 cm height bed of commercial Al_2O_3 (S_{BET}=230 m^2/g, pore volume=0.66 cm^3/g) in form of sphere 5 mm in diameter. An injection of secondary air is performed to keep the reactor at a constant temperature of 800 °C. The flow rate of the secondary air, ranging between 7-10 % of the primary air flow rate, is thus controlled by the internal reactor temperature. The operative conditions of the plant are reported in Table 1.

Table 1. Operative conditions

Operative conditions	
Plant capacity (kW_{th})	250
Biomass flow rate (kg/h)	50
Primary air flow rate (kg/h)	150
Average T of the gasifier (°C)	700
T of the second reactor (°C)	800

The syngas exiting form the second reactor with a flow rate of about 280 kg/h is cooled down from 800 °C to 350 °C by heating the gasifying air and passes through a cyclone to remove the dragged particulates. A water direct contact heat exchanger, having a capacity of 60 L, is used to further purify the syngas from the residual tar. The clean syngas is sent to an equalization tank necessary to maintain a constant syngas flow rate to the engine and to separate the water dragged from the scrubber. Finally the syngas feeds the engine at a temperature of 50 °C.

The plant is equipped with three syngas sampling ports; the first at the exit of the gasifier, the second on the line between the tar removal reactor and the cooling/cleaning section and the third at the exit of the cooling/cleaning section. To measure the amount of tar and particulates the syngas passes through a hot quartz filter to collect the dragged solid and then is sent to three iced cooled traps where the tar condenses, as specified by the CEN/BT/TF143. The composition of the purified syngas is analyzed with a gas chromatograph in terms of H_2, CO, CH_4 and CO_2 concentrations. Five thermocouples are used to measure the internal temperature of the gasifier.

The properties of the olive husk are reported in Table 2.

Table 2. Feed main characteristics

Proximate analysis	
Moisture (% wt.)	10-20
Volatiles (% dry)	55
Fixed carbon (% dry)	41
Ash (% dry)	4
Elemental analysis (% dry.)	
C	48.00
H	5.95
N	1.54
O (diff)	40.51
Calorific value (MJ/kg)	17.70

3. Results and discussion

The temperature profile reported in Fig. 3 is typical of up-draft gasifier, with the maximum temperature of 1030 °C reached where the exothermic combustion reactions occur. Because of the specific design of the interior of the reactor, the produced ashes are carbon free, whereas the gas exit temperature is still higher than typical up-draft gasifier.

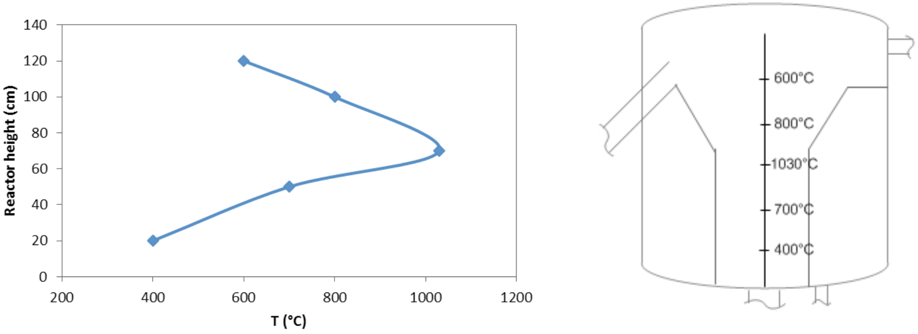

Fig. 3. Temperature profile in the gasifier.

To study the efficiencies of each stage of the tar abatement systems on the global performances of the plant, the amounts of tar and particulates were measured at the three syngas collecting points.

The results, reported in Table 3, demonstrate that the second reactor is very efficient in the tar removal process. The tar abatement is more than 50 %. The second reactor has also a great influence on the removal of the dragged particulates, showing a decrease of 80 %. In this reactor the dragged particles are burnt by the secondary air and then the alumina bed acts as a filter for the residual ashes. Ashes accumulation inside the reactor can cause clogging in the alumina bed with a consequent increase of the pressure drop. Thus during continuous operational mode it is necessary to provide a periodical bed regeneration.

The clean-up system contributes to a further tar removal, after the cooling/cleaning system the tar is, in fact, about 100 mg/Nm^3. This amount is even more decreased in the equalization tank where the water entrained from the scrubber together with the residual tar is removed from the syngas.

It can be noticed that at the end of the plant the tar amount is below the law limit for internal combustion systems.

Table 3. Tar and particulate amounts

	after gasifier	after Al_2O_3 reactor	after cooling/cleaning
Tar amount (mg/Nm^3)	768	310	98
Particulate amount (mg/Nm^3)	502	76	38

The syngas obtained from this plant has a composition typical of biomass air gasification performed with up-draft reactor (Table 4).

Table 4. Syngas composition

CO (% vol.)	13.9
CO_2 (% vol.)	13.2
H_2 (% vol.)	14.1
CH_4 (% vol.)	2.9
N_2 by diff. (% vol.)	55.9
Calorific value (MJ/Nm^3)	4.1

4. Conclusions

In this work the performances of a medium industrial scale gasification plant, having a capacity of 250 kWt, are presented. The heart of the plant is composed by a up-draft gasifier and a second fixed bed reactor for tar removal. The second reactor has demonstrated a high efficiency in tar removal, with a decrease of more than 50 %. In the following clean-up section a further abatement of the tar takes place. The very low tar content exiting within the syngas, less than 100 mg/Nm^3, allows its direct use in many syngas applications without the necessity of further expensive and energy consuming purification treatments.

In the analyzed plant the syngas feeds an internal combustion engine producing 60 kWe. The plant efficiency is about 25 %, that is a high value for this kind of plant.

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