BIOMASS AND BIOENERGY XXX (2014) 1–12

Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

BIOMASS & BIOENERGY

Gasification of tea (*Camellia sinensis* (L.) O. Kuntze) shrubs for black tea manufacturing process heat generation in Assam, India

Partha Pratim Dutta [a,*], *Debendra Chandra Baruah* [b]

[a] *Department of Mechanical Engineering, Tezpur (Central) University, Assam, 784028, India*
[b] *Department of Energy, Tezpur (Central) University, Assam, 784028, India*

ARTICLE INFO

Article history:
Received 1 May 2012
Received in revised form
29 March 2014
Accepted 31 March 2014
Available online xxx

Keywords:
Biomass
Gasification
Shrubs
Tea drying
Process heat
Payback period

ABSTRACT

Gasification of uprooted tea shrub (*Camellia sinensis* (L.) O. Kuntze) is an attractive option for partial substitution of thermal energy in tea manufacturing industries. Chopped and dried uprooted tea branches with moisture content ($X < 20\%$) have high energy contents suitable to generate process heat. Good number of tea processing units in Assam use old design and inefficient coal fired furnace and air heater with a low overall efficiency. Gasification of uprooted tea shrubs may be beneficial partially to substitute these old design coal fired furnaces. The calorific values of uprooted tea branches and generated producer gas were found 18.50 MJ kg^{-1} and 4.2 MJ m^{-3}, yielded products at 65% cold gasification efficiency. Fermented tea samples with an average moisture content of 60% could be dried to 3% moisture using biomass gasifier and tea dryer setup. Simple economic analysis shows gasifier cum tea dryer technology may be economically favorable option with an annual saving of 21,067 $ in a medium scale tea factory (990 t per year made tea) if 28% of total thermal energy requirement is substituted by biomass gasification.

1. Introduction

Tea cultivation and processing units are second most important after oil and gas industries in Assam. Assam black tea production in the year 2010–11 was estimated as 0.488 Mt which alone accounted for about 50% of all India production [1]. Tea drying is a highly energy intensive chemical engineering unit operation amongst all the tea manufacturing operations. The sources of thermal energy for tea drying process in factories located in Assam has been fossil fuel consisting natural gas, furnace oil (known as tea drying oil) and coal. One or more than one sources are used based on local availability and economy. The specific energy consumption (coal) in commercial tea drying has been reported within the range of (0.8 to 1.13) kg kg^{-1} of made tea. The reported variation could be due to varying level of performances and overall efficiency of energy conversion devices. Variations of specific energy requirements for tea processing were also observed amongst the fuel types. Specific energy consumptions while using tea drying oil, coal and natural gas had been reported as (23.88, 43.72 and 27.49) MJ kg^{-1} of made tea respectively [2]. Overall, based on production and average specific energy consumption rate, an estimated 9.42 PJ equivalent thermal energy was found to consume annually for drying operation in tea factories of Assam. The volatile prices and other environmental factors of fossil fuels have caused uncertainties to continue relying on these fossil

* Corresponding author.
E-mail address: ppdutta06@gmail.com (P.P. Dutta).
http://dx.doi.org/10.1016/j.biombioe.2014.03.062
0961-9534/

fuels for tea processing in Assam. This has necessitated searching for a reliable and sustainable thermal energy system for tea drying. Uses of biomass as an alternative to conventional fossil fuels have been attempted in many cases with success. However, success of such effort would require comprehensive testing and analysis considering the fuel and related technologies.

Combustion of cashew nut shell in furnace, semi open pit and other open burning was poor with lower combustion efficiency, high smoke emission, therefore efficient process control was not convenient in such a situation [3]. Gasification of biomass using a reactor (gasifier) to convert solid biomass into gaseous fuel is almost a matured technology. However, the application of biomass gasification technology as a source of thermal energy for tea drying is only in research and development stage till now. There are literature available with reports of research and development on gasification technology covering (i) efficacy of thermal energy generation, (ii) performance analysis and (iii) economic feasibility analysis. Some of such related research works are highlighted below.

Rubber wood feedstock was used in an 80 kW thermal output downdraft gasifier for tea drying process heat generation. The moisture content of rubber wood was considered as an important parameter which in turn affected gasifier performance through reactor temperature and heat loss. The optimum gasification zone length had to be selected for maximum output in a given range of operating parameters. The principal gasification reactions were pyrolysis, oxidation and reduction and they produce combustible gases like CO, H_2, CH_4, etc. The average calorific values of producer gas were (4.18 to 4.62) MJ m^{-3} [4]. The use of open core gasifier (1.25 GJ h^{-1}) for process heat generation in pharmaceutical industry had been reported in another study and it had stated that (70–80) kg h^{-1} of wood could replace 20 L h^{-1} low density diesel fuel [5]. In another study, babul wood (*Prosopis juliflora*), groundnut shell briquettes, groundnut shell, mixture of wood (*P. juliflora*) and cashew nut shell were satisfactorily gasified in an open core throat less downdraft 50 kW gasifier that indicated fuel dependency on performance [6]. Waste wood (moisture content less than 20%) gasification and thermal energy balance of a 150 kW downdraft gasifier had been performed. An average cold gasification efficiency of 70% was reported [7].

There are also reports of using by-products of coffee industry as fuel for gasification. Coffee grounds were successfully converted into gaseous and volatile matter by fast pyrolysis at a temperature of 1073 K with about 88% conversion efficiency. Further, it was reported that tar separation was done by combustion to produce additional process heat in allothermal gasification [8]. Similarly, coffee husk gasification using high temperature air steam in a batch facility that was maintained at three different gasification temperatures 900 °C, 800 °C, and 700 °C was studied. An increased gasification temperature led to a linear increment of CO concentration in syngas for all gasification conditions. It was also reported that kinetic parameters established the reaction mechanism of zero order with apparent activation energy of 161 kJ mol^{-1} and frequency factor of 6.48×10^2 s^{-1} [9]. In another investigation, a downdraft biomass gasifier with furniture wood chip as feedstock was used to measure equivalence ratio, gas composition, calorific value and gas production rate, etc. A peak was seen at about 0.38 equivalence ratios for optimum CO and CH_4 yields; it showed first increasing then decreasing trends of these constituents. At equivalence ratio 0.38, they observed best performance of the downdraft biomass gasifier. They also observed that gas production per unit weight of fuel increased linearly with equivalence ratio and a maximum cold gas efficiency of 80% was achievable [10].

Techno-economic viability of cashew nut shells gasification was reported for hot water generation in a local food processing factory. They found that cashew nut shells were excellent feedstock for gasification and it had high energy content and similar composition to fuel wood. The payback period for additional investment made in plant and machinery was found less than one year. Studies revealed that 6.5 kg of liquefied petroleum gas was fully replaced by gasification of 38 kg of sized wood on hourly basis. Fuel economic analysis of gasifier showed that the saving was about 13,850 $ for 3000 h of baking operation [11,12].

It is seen from the above discussion that there are several efforts to use gasification technologies in diversified applications including selected food processing industries. Tea estates in Assam generate biomass in the form of uprooted tea branches, pruning litter and branches of shading trees. The uprooting is done at certain intervals of plantation to replant, so as to maintain optimum level of tea productivity. Such uprooted tea branches are generally used as cooking fuel through direct combustion in low efficiency traditional cook stoves. The introduction of improved cook stoves with higher conversion efficiency may lead to a substantial saving of uprooted biomass and this saved biomass may be used for tea manufacturing process heat generation. There are two distinct options for generation of process heat using surplus uprooted tea branches; viz. (1) Direct combustion and (2) Gasification. Direct combustion of biomass in conventional inefficient coal fired furnace of some tea factories has socio-environment problem including greenhouse gas emission and accumulation of tars and shoots in nearby areas. Because the existing coal fired furnaces in the representative tea factories had been observed running with a very low overall efficiency. The reasons behind very low overall efficiency in existing coal fired air heating furnaces are inappropriate control of excess air for combustion, improper insulation in flue gas path, inconsistent quality of coal, inherently low flue gas to air heat exchanger heat transfer rate, frequent fouling of cast iron tube heat exchanger, and old conventional overall design of system. Therefore, flue gases to air heat exchangers have very low effectiveness compared to shell and tube heat exchanger using steam as intermediate heat transferring medium to heat tea drying air. Now, if these uprooted tea branches were utilized through efficient gasification technology, then lesser volume of greenhouse gases will be emitted compared to inefficient fixed bed coal combustion furnace system. This will contribute to a substantial saving of scared fossil fuels such as coal or natural gas by application of renewable energy for tea drying and greenhouse gas emission balance, etc.