Fuel Processing Technology 104 (2012) 144–154

Contents lists available at SciVerse ScienceDirect

Fuel Processing Technology

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

Performance of tar removal by absorption and adsorption for biomass gasification

Anchan Paethanom *, Shota Nakahara, Masataka Kobayashi, Pandji Prawisudha, Kunio Yoshikawa

Department of Environmental Science and Technology, Tokyo Institute of Technology, G5-8, 4259 Nagatsuta, Midori-ku, Yokohama, Kanagawa 226–8502, Japan

ARTICLE INFO

Article history:
Received 26 January 2012
Received in revised form 1 May 2012
Accepted 3 May 2012
Available online 27 May 2012

Keywords:
Biomass gasification
Tar removal
Absorption
Adsorption
Gas cleaning

ABSTRACT

Biomass gasification is an attractive and successful waste-to-energy technology. Even though it has been performing effectively, many troubles are still occurring. For advanced applications, gas needs to be clean enough and tar should extensively be removed. Otherwise, tar in the producer gas will condense at reduced temperature and will cause blocking and fouling of engines. Physical tar removal is proven to be technically and economically attractive approach for gas cleaning. In this paper, three tar removal techniques were investigated for each type of tar; 1) heavy tar removal by absorption using vegetable oil and waste-cooking oil scrubbers, 2) light tar removal by adsorption using rice husk and rice husk char adsorbent bed and 3) heavy tar removal by combination of absorption and adsorption using vegetable oil scrubber and rice husk char adsorbent bed. Temperature of the thermal tar decomposition process was set at 800 °C and temperature of the physical gas cleaning unit ccwas at room temperature. The result showed that the absorption technique was effective for heavy tar removal and the adsorption technique was capable of light tar removal. By combining vegetable oil scrubber and rice husk char adsorbent bed, 95.4% of gravimetric tar could be successfully removed.

1. Introduction

Compared to the costly and rare petroleum fuel, alternative energy resources like biomass, including agriculture wastes, which are continuously increasing with the world population growth and economic development, are considered as highly efficient renewable energy resources for energy needs throughout the world [1,2]. Energy from biomass can significantly reduce the green house gas emissions and problems, which cause global warming and climate change [3].

Nevertheless, even though there are many waste-to-energy technologies, including combustion, gasification and pyrolysis, which have lately been successfully demonstrated [4–9], commercialized or under implementation, still troubles occur during the process and loads of agriculture wastes are still abundant. For that reason, waste-to-energy technologies need to be more studied and researched.

In agricultural countries, lots of agriculture residues or biomass wastes, such as rice husk and woods, are produced in each year [10]. The world annual production of rice husk amounts to more than 120 million tons [11]. These biomass wastes are one of the main resources of renewable energy. Accordingly, biomass gasification is an attractive technology for advanced application such as electricity generation and liquid or gaseous transportation fuel production. For these applications, the producer gas needs to be cooled down, de-dusted and tar should significantly be eliminated. Anyhow, the gasification technology for biomass is still in the development stage. The main technical obstacle is the efficient elimination of tar from the producer gas.

Biomass tar is a complex compound, consisting of hundreds hydrocarbon compositions. Tar could be defined as a complex mixture of organic hydrocarbon compounds, which is benzene and larger than benzene [12,13]. Tar can be characterized into different classifications [14,15], in which two main classifications are light tar and heavy tar. Light tar is a mixture of light heterocyclic compounds, such as phenol and naphthalene, some of which are water-soluble. For heavy tar, it will condense at the reduced gas temperature [16] and cause major clogging, fouling, efficiency loss and unscheduled plant stops [14]. These two main kinds of tar; heavy and light, were both concerned in this research and the most effective system, which is able to remove both kind of tar was aimed. Since the nature of heavy tar, normally presents in the droplet form, and light tar, usually in vapor form, different and individual tar removal techniques had to be investigated.

1.1. Tar removal technique

Many of the tar removal research work have been aimed for development of advanced techniques that able to remove tar effectively such as using catalytic cracking, thermal cracking, advanced oil scrubber technology, or plasma reactor for a range of objective, where most of them are costly and not able to apply to some projects such as gasification for rural electrification. On the contrary, this research is prospective to provide fundamental technique that concern mostly on economically and simply operable system for tar removal with preservation of effectiveness and potential for scaling up. Therefore, waste resources have been used as tar removal mediums.

* Corresponding author. Tel.: +81 45 924 5507; fax: +81 45 924 5518.
E-mail address: paethanom.a.aa@m.titech.ac.jp (A. Paethanom).

0378-3820/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.fuproc.2012.05.006

There are many possible techniques of tar removal depending on where tar is removed [17]. In primary methods, tar will be removed inside the combustion or gasification process and for secondary methods, which is more efficient, economical and easier to control because tar will be removed by outside installed gas cleaning equipments. Gas cleaning methods can also be characterized into chemical (catalytic and non-catalytic such as thermal cracking) and physical (such as adsorption and absorption) processes. The physical process is an attractive, technically and economically feasible tar removal method. Moreover, physical tar removal process is uncomplicated adaptable to any gasification system. However, it also depends on gas quality specifications required for specific downstream applications. Physical tar removal could be characterized as wet system such as spray towers or packed column scrubber and dry system such as cyclone, filters or adsorbents [18].

For wet system, many gasification plants commonly utilize variety of water scrubber structure to remove tar and other gas contaminants such as spray tower, impingement scrubber, packed bed scrubber and venturi scrubber [18–20]. Among all these kind of structures, water spray tower is the simplest and economical scrubber structure. However, using water as scrubber, subsequent to lots of unsatisfied drawback especially expensive expense on wastewater treatment and regeneration. Moreover, due to the hydrophobic characteristic of water, it has shown low solubility of tar compounds. To conquer the weaknesses of water scrubber and for more effective tar removal, oil scrubbers have been widely studied [21–25]. Each type of oil absorbents was deliberated and they performed as high tar absorption mediums at higher than 60% tar removal compared to water, which can only remove hydrophilic tar compounds and only 38.9% hydrophobic tar compounds. The oil scrubber performance resulted as diesel > vegetable oil > biodiesel > engine oil. Nevertheless, the author suggested that vegetable oil should be considered as best and most effective adsorbent among others due to low evaporating point of diesel oil that effected the increasing of the gravimetric tar to the downstream application [21]. For stated demonstration in bigger scale; Güssing Plant, Austria, benzene and remaining tar compounds are greatly removed by rapeseed-methylester (RME) scrubber working at 5 °C [22]. Not only the absorption medium itself, but the conceptual design of scrubbing device technology seems to have made advancement such as OLGA technology, developed by the Energy research Centre of the Netherlands, using special oil absorber tower with striper tower to regenerate the oil by using air or steam to deabsorb tar. OLGA shows more than 99% of heavy and light tar removal performance [14,15]. These advance technologies may suitable for some applications such as fuel cells and chemical synthesis like Fischer–Tropsch. However, concerning high energy required to cool down the RME scrubber and OLGA high production cost, these advanced tar removal technologies may affect the cost feasibility. Simple and economical but effective tar removal method, which is also applicable for some projects such as rural electrification have been the main concerns in this research paper.

Because of the expensive price of vegetable oil, the cost of vegetable oil-based gas cleaning unit operation is high. On the other hand, the rising production of used cooking oil from household, restaurants and industrial sources is causing big environmental problems in the world [26]. This used cooking oil is commonly poured down to the drain as a waste, resulting in problems for wastewater treatment or is integrated into the food chain through animal feeds, accordingly becoming a cause of human health harms. The use of this waste-cooking oil as a scrubber medium for tar removal in biomass gasification systems should be one of the procedures for solving the twin troubles of environment pollution and energy shortage. This technique has not yet been found investigated or reported beforehand at all. Therefore, in this research, each operating conditions of vegetable oil and waste-cooking oil as scrubbing mediums for tar removal have been evaluated due to its hydrophilic property and low cost.

Another physical tar removal technique is a dry system, to particularly remove tar components in vapor phase. Among various physical techniques, adsorption process is considered better as compared to other methods because of convenience, easy operation and simplicity of design. It has been reported that activated carbon performs as an effective adsorbent due to its high porosity property [27–31]. Activated carbon can be prepared from variety of carbon containing materials, such as coal or any biomass. In any thermal or gasification process with biomass as feedstock, biomass char will be produced. For biomass char, it also has been reported to have removal ability for model tar components [32–34]. Biomass char as tar adsorbent investigation has been found in some publications. Pyrolyzed char from wood samples over a hot bed has been used for tar reduction. It was found that the presence of wood char could reduce the amount of tar. The carbon yield in the condensable phases was 37.6 wt.% by pyrolysis at 500 °C down to 15.3 wt.% without char in the 300 mm-long tar cracking zone at 800 °C and further down to 12.9 wt.% by introduction of char in the zone. The heavy condensable phase accounting for 18.4 wt.% of the inputted wood at 500 °C decreased to about 8 wt.% at 800 °C [35]. Biomass char could also be active like catalyst. It was compared with other catalysts such as calcined dolomite, olivine and nickel for the cracking of phenol and naphthalene. The results presented that the char was an effective and low cost catalyst for tar removal [32]. Although phenol and naphthalene are tar components, the real tar generated directly from biomass should be investigated for more reliable results for scaling up. Further research of char for tar removal was also reported with reactor design as the TREC-reactor (Tar REmoval by Char) [36].

Subsequently, waste char generated from rice husk gasification is attractive to be tar removal medium as also a porous carbon material [34] and now considered as waste needed to be taken care of. Considering scaling up for industrial process utilization, authentic biomass tar should be utilized for the evaluation of adsorption medium candidates instead of using model tar components. In addition, most of the tar removal literatures concentrate on individual technique for tar removal such as thermal cracking, catalytic cracking, filter, scrubber or adsorption medium and each technique has different noteworthy in itself. Therefore, the hybrid of multiple tar removal techniques should be investigated.

Normally, for tar adsorption technique, heavy tars in liquid form can easily accumulate on the filter surface that leads to eventually plugging and not easy to clean. To get rid of this problem and prolong tar adsorbent lifetime, the combination of adsorption technique with absorption or wet scrubber should be consider. The wet scrubber using oil material should be installed for heavy tar removal and then the leave light tar in vapor form to be adsorbed by char adsorbent unit.

In this paper, authentic biomass tar generated from pyrolysis process followed by thermal decomposition has been used for evaluating three physical tar removal techniques; 1) heavy tar removal by absorption using vegetable oil and waste-cooking oil scrubbers with the turbulent mixing, 2) light tar removal by adsorption using rice husk and rice husk char adsorbent bed and 3) heavy tar removal by combination of absorption and adsorption using vegetable oil scrubber and rice husk char adsorbent bed. The temperature of the tar thermal decomposition process was set at 800 °C and the temperature of physical gas cleaning was the room temperature. For heavy tar, the results were analyzed and discussed in the term of gravimetric tar removal performances using wet tar measurement method and for light tar, the results were analyzed using the dry tar measurement method.

2. Materials and experimental setup

2.1. Experimental setup

For this tar removal experiment, an externally heated continuous-type pyrolyzer reactor has been used to generate tar from rice husk feedstock. The characterizations of rice husk feedstock are shown in Table 1. The process scheme of the experimental setup is shown in