Tar Removal Performance of Vegetable Oil Scrubber with Turbulent Effect and Its Combination with Rice Husk Char Adsorption

Anchan Paethanom[1,]*, Shota Nakahara[1] and Kunio Yoshikawa[1]

[1] Department of Environmental Science and Technology, Tokyo Institute of Technology,
4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan
* Corresponding Author: Tel: +81 45 924 5507, Fax: +81 45 924 5518
E-mail: paethanom.a.aa@m.titech.ac.jp

Abstract

Biomass gasification has been considered as attractive and successful waste-to-energy technology. Nevertheless many troubles still occur. For advanced applications, which use producer gas as fuel for gas engines with power generators, the 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. Therefore, one of the key problems to deal with is tar removal. The physical tar removal is proven to be technically and economically attractive approach for gas cleaning. Vegetable oil is one of the most effective scrubbers. In this paper, two topics were investigated; 1) the turbulent effect of vegetable oil scrubber and 2) the combination of vegetable oil scrubber with rice husk char as adsorbent. The temperature of the tar decomposition process was set at 800°C. The results showed that 63.6% of gravimetric tar was removed by vegetable oil scrubber with no mixing and 89.8% of gravimetric tar was removed at mixing of 1000 rpm. Once combining 1000 rpm mixing vegetable oil scrubber with rice husk char adsorption bed, 95.4% of gravimetric tar was removed. Therefore, it is found that the combination of vegetable oil scrubber at 1000 rpm mixing with rice husk char adsorption bed showed the best result for tar removal in gasification systems.

Keywords: biomass gasification, vegetable oil scrubber, rice husk char and tar removal.

1. Introduction

Compared to the costly and rare petroleum fuel, alternative energy source like biomass, including agriculture wastes, which continue increasing as of the world population growth and economic development, is considered as high efficiency renewable energy source for energy needs throughout the world. Energy from biomass can significantly reduce the green house gases emission and problems, which cause global warming and climate change.

Nevertheless, even though there are many waste-to-energy technologies, including combustion, gasification, pyrolysis, anaerobic digestion, fermentation, and esterification, which have lately been successfully demonstrated, commercialized and many projects are 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 residue or biomass waste, such as rice husk, sugarcane, corn, rubber tree, woods, oil palm, cassava rhizome, etc, are produced in each year. These biomass wastes are one of the main sources 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, gasification technology for biomass is still in the development stage. The main technical obstacle is the efficient elimination of tar from the producer gas.

Tar is defined as a mixture of organic hydrocarbon compounds, which is larger than benzene and benzene is also included. Tar can be characterized into light tar and heavy tar. Light tar is a mixture of light heterocyclic compounds, such as phenol and naphthalene, which is water-soluble. For heavy tar, it will condense at the reduced gas temperature and cause major clogging, fouling, efficiency loss and unscheduled plant stops [1].

There are many possible techniques of tar removal depending on where tar is removed. In primary methods, tar will be removed inside the combustion or gasifier process and for secondary methods, which is more efficient and economical, tar will be removed by outside installed gas cleaning equipment [3]. Gas cleaning methods can also be characterized to chemical (catalytic and non-catalytic such as thermal cracking) and physical (such as adsorption and absorption) processes. The physical tar removal is technically and economically attractive. It has been reported in many researches that activated carbon is one of the most effective adsorbent due to its high porosity property. Subsequently, char from biomass is being investigated, as also a carbon material as activated carbon and now considered as waste needed to be taken care of. In addition, from the previous experiment [4], vegetable oil has performed effective performance on tar removal.

In this research, two topics were investigated; 1) the turbulent effect of vegetable oil scrubber that influence tar removal performance and 2) the combination of vegetable oil scrubber with rice husk char as adsorbent. The results were analyzed and discussed in term of performances for gravimetric tar removal.

2. Materials and Setup

2.1 Experimental setup

The process scheme of the experimental setup is shown in Fig. 1. The rice husk feedstock sent from Thailand, as shown in Fig. 2, was prepared from crushed and sieved with the mesh size of 0.125-0.250 mm. The feedstock was dried in an oven at 105°C overnight for moisture elimination before packing in the feeder. Feed controller screw controlled feed rate at 0.6g/min continuously.

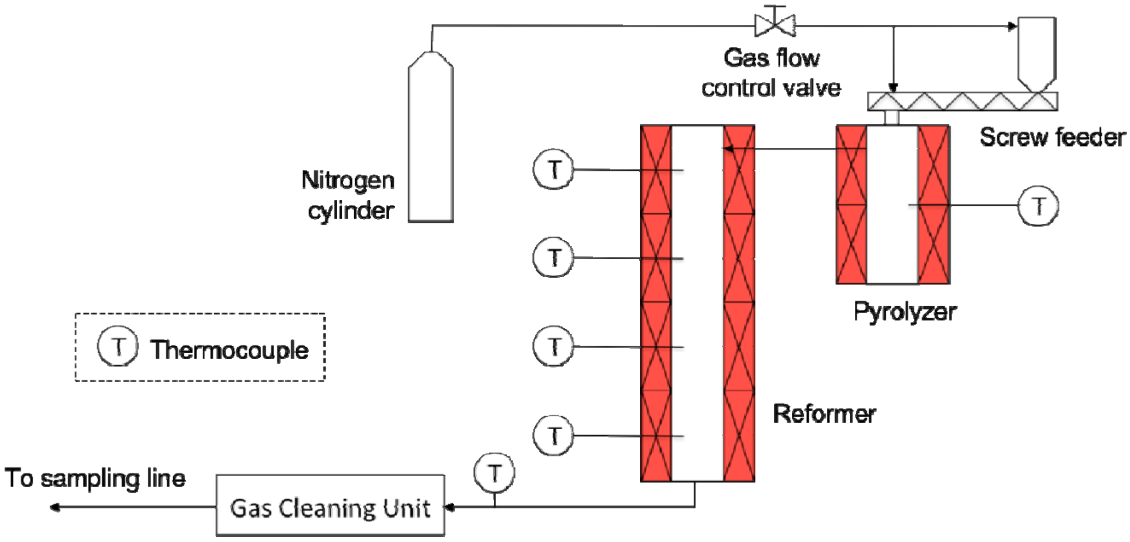


Fig. 1 Process scheme of experimental setup

Fig. 2 Rice husk feedstock, 0.125-0.250 mm.

The pyrolyzer and reformer were made from stainless steel and surrounded by electric heaters. The temperature of 30 x 280 mm pyrolyzer was set at 800 °C and kept for 30 minutes before feeder started. When the feedstock was supplied by screw feeder into the top of pyrolyzer, the volatiles of the feedstock were released as syngas, called producer gas. This tar-contained producer gas with nitrogen as a carrier gas, at the flow rate of 1.5 l/min, entered into the 30 x 1000 mm reformer, which was also kept at 800°C in order to avoid tar decomposition or condensation. The producer gas at the exit of the reformer will flow to the gas cleaning equipments to conduct experiments.

2.2 Absorbent and adsorbent

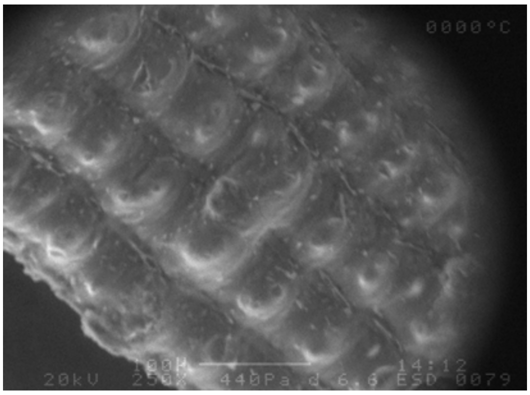
2.2.1 Vegetable oil

Vegetable oil obtained from J-OIL MILLS Ltd. was used as absorbent. The main ingredients are 60% of soybean oil and 40% of canola oil. The volume of vegetable oil used for each experiment was fixed at 500 ml.

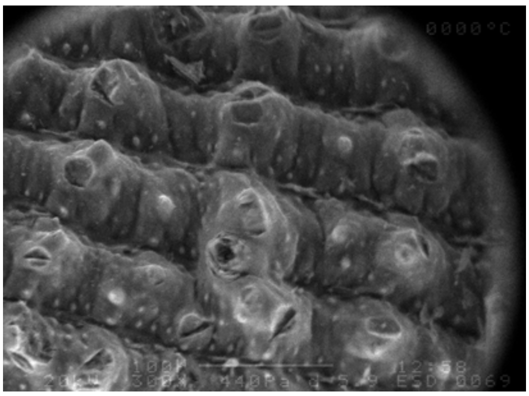
2.2.2 Rice husk char

This rice husk char shown in Fig.3 was residue in a gasification process at 500°C in Thailand. This char was found to have suitable characteristics for adsorbent. Fig.4 shows SEM micrographs of this rice husk char, it can be seen that after high temperature pyrolysis, rice husk char became a highly porous material. The proximate analysis, ultimate analysis and BET specific surface area results of this rice husk char are shown in Table 1. This char was used as adsorbent in this research. It was prepared from crushed and sieved with the mesh size of 0.5-0.1 mm. The adsorbent was dried in an oven at 105°C overnight for moisture elimination before packing in the stainless steel adsorbent bed.

Fig. 3 Rice husk char adsorbent, 0.5-1.0 mm.



(a)



(b)

Fig. 4 SEM micrographs; a) Dried rice husk b) Rice husk char after gasification at 500°C

Table. 1 Characterization of rice husk char for adsorbent

	Wt% dry basis
Ultimate analysis (ash free basis)	
C	16.9%
H	0.6%
N	0.2%
Cl	0.07%
Proximate analysis (wt% dry basis)	
Volatile matter content	13.5%
Fixed carbon	13.9%
Ash	72.6%
BET Specific surface area	48.7m^2/g

2.3 Sampling of gravimetric tar

The measurement of gravimetric tar was carried out using the wet type method referring to ECN-C-02-090 [2]. A series of 10 impinger bottles filled with 100ml isopropanol were used to collect tar by both condensation and absorption as shown in Fig. 5. The sampled producer gas was controlled at the flow rate of approximately 0.8 l/min for 48 minutes. More details about wet type tar sampling and analysis used in this experiment have been described in our pervious paper [5].

2.4 Analysis method

After sampling, all of isopropanol sampling solvent in each impinger bottles were combined together, filtrated and dried by a rotary evaporator in a water bath kept at 40°C. The residue was defined as gravimetric tar.

3. Experiment Procedure

Summarized experimental conditions are shown in Table 2. In this experiment, two gas-cleaning methods were investigated; 1) Scrubber using commercial vegetable oil and 2)

Combination of vegetable oil scrubber with adsorption bed using rice husk char. The position of gas cleaning unit is shown in Fig. 1.

Table. 2 Experimental conditions

Parameters	
Pyrolyzer	800°C
Reformer	800°C
Carrier gas	N_2
Carrier gas rate	1.5l/min
Sampling time	48 minutes
Feedstock	Rice husk
Feedstock size	0.125-0.25 mm
Feed rate	0.6g/min

3.1 Vegetable oil scrubber

The 500 ml. of vegetable oil scrubber was contained in a three-neck flask with a magnetic stirrer inside. The speed of the stirrer was controlled by an adjustable digital magnetic stirrer machine. The scrubber flask was connected between the reformer and the wet type sampling line as shown in Fig. 1. The investigated stirring speeds were 0, 300, 750, 1000 and 1500 rpm.

3.2 Combination of vegetable oil scrubber with rice husk char as adsorbent

Rice husk char was taken into stainless steel cylinder fixed bed reactor with the dimension of 100 mm I.D. x 300 mm height. The reactor containing 200 cm^3 of rice husk char was connected after the 500 ml. of vegetable oil scrubber and before the wet type sampling line. The producer gas passes through the bed from the bottom to top at the ambient temperature.

4. Results and Discussion

4.1 Turbulent effect of vegetable oil scrubber on tar removal

Figs. 6a-6b present the vegetable oil scrubber performance for gravimetric tar removal at each stirring speed and % of gravimetric tar removal, respectively. It can be seen that 93.7 g/m^3 of gravimetric tar contained in the producer gas was reduced to 34.1 g/m^3, which corresponds to 63.6% gravimetric tar removal efficiency by using vegetable oil scrubber with no stirring. Therefore, It was obvious that vegetable oil was capable of tar removal. Due to turbulent effect, tar removal efficiency increased with the increase of the mixing speed,

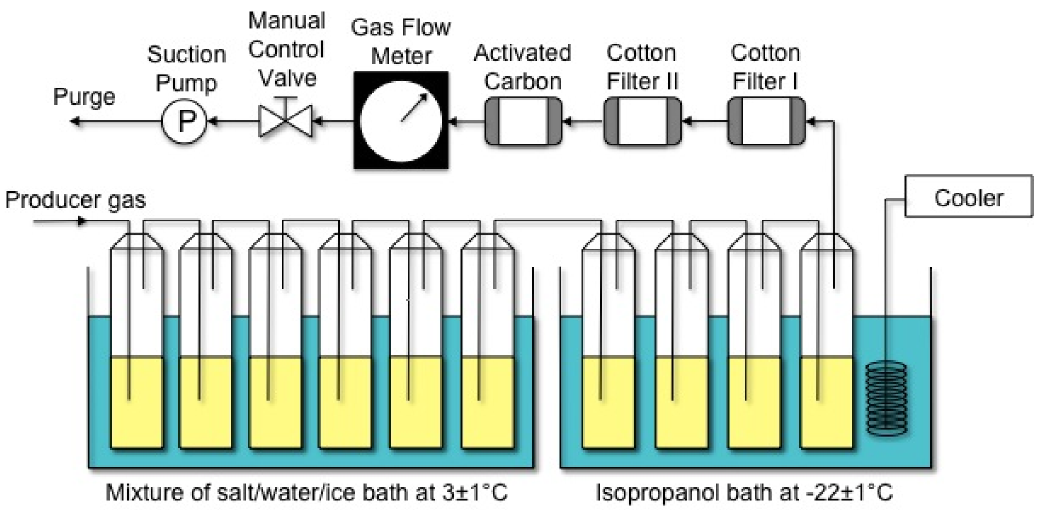


Fig. 5 Wet type sampling method

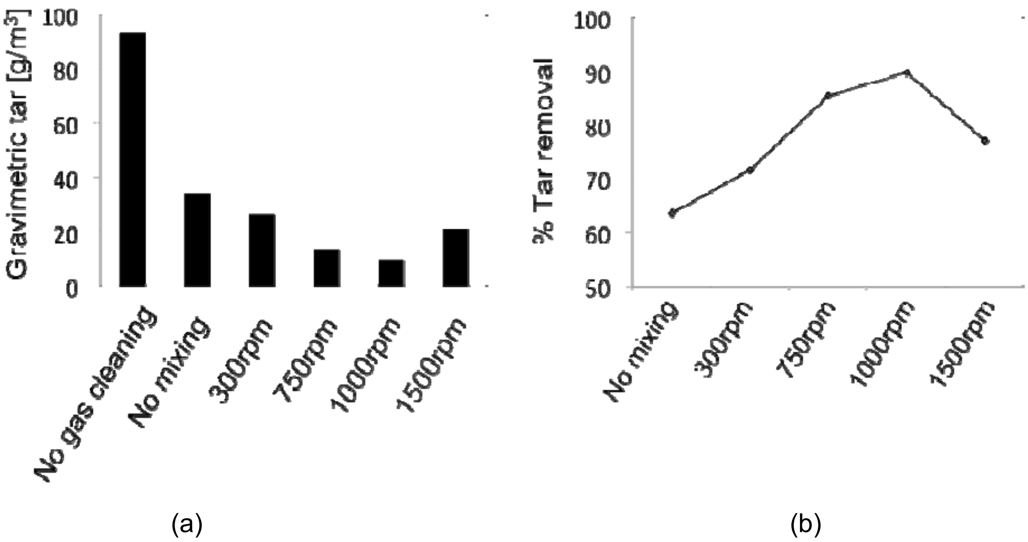


Fig. 6 Results of vegetable oil scrubber performance at each condition;

(a) Amount of gravimetric tar (b) % of gravimetric tar removal

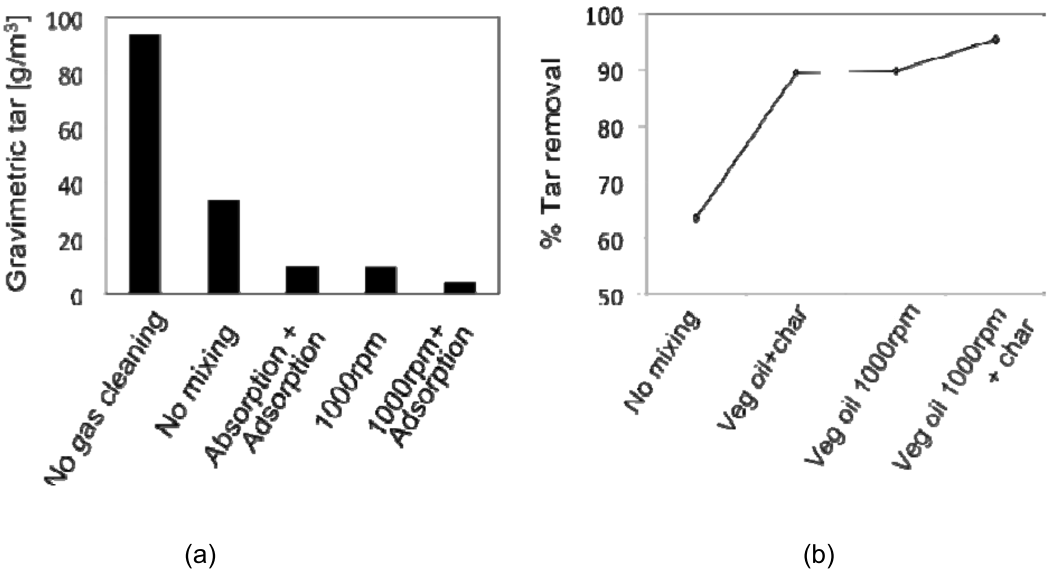


Fig. 7 Results of the combination of vegetable oil scrubber with rice husk char adsorption bed at each condition; (a) Amount of gravimetric tar (b) % of gravimetric tar removal#

while it decreased when the mixing speed was higher than 1000rpm. As a result, the best condition was given at 1000rpm mixing speed under which tar could be reduced to 9.6 g/m^3, corresponding to 89.8% gravimetric tar removal efficiency.

These results can be explained by two main factors of the turbulent effect, the bubble size and the contacting time between oil and tar molecule. As mixing speed increased, oil bubble was getting smaller, resulted in the increase of the surface area for absorption and that improved the tar absorption performance. At the same time, if the stirring speed was too high, the contacting time between tar and scrubbing medium decreased, and the bonding force between tar and oil molecule got weaker and less tar could be absorbed by the absorbent.

4.2 Combination of vegetable oil scrubber with rice husk char adsorption bed

The results of the combination of vegetable oil scrubber with the rice husk char adsorption bed are shown in Figs. 7a-7b. The combination of absorption with 1000rpm stirring speed and rice husk char adsorption gave 95.4% gravimetric tar removal efficiency. These results show an interesting fact that the rice husk char was a very good adsorbent because its pore can adsorb large amount of tar from the producer gas. According to the SEM observation, which showed that the surface of pores on rice husk char particles became increasingly rough compared to dried rice husk and the BET observation showed a high specific surface area. Therefore, the utilization of low-cost char produced in the gasification process as an effective carbon adsorbent has a bonus advantage from gasification system itself.

5. Conclusion

Vegetable oil was found to be effective for gravimetric tar removal. Turbulent mixing significantly improved the absorption efficiency by reducing the bubble size. In this research, 1000rpm was the optimum stirring speed. Rice husk char showed good performance in term of gravimetric tar adsorption due to its porous property. SEM and BET studies confirmed that rice husk char was a good material for tar adsorbent. Therefore, the combination of vegetable oil scrubber with rice husk char adsorbent could remove as high as 95.4% of gravimetric tar.

6. References

[1] Anis S. and Zainal Z.A., *Tar reduction in biomass producer gas via mechanical, catalytic and thermal methods: A review*, Renewable and Sustainable Energy Reviews 15(2011) 2355-2377.

[2] Good et al., Biomass Technology Group (2005).

[3] Lopamudra et al., *A review of the primary measures for tar elimination in biomass gasification processes*, Biomass and Bioenergy 24 (2003) 125–140.

[4] Phuphuakrat et al., *Absorptive removal of biomass tar using water and oily materials*, Bioresource Technology 102 (2011) 543–549.

[5] Phuphuakrat et al., *Tar removal from biomass pyrolysis gas in two-step function of decomposition and adsorption*, Applied Energy 87 (2010) 2203–2211.