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# Performance and chemical composition of waste palm cooking oil as scrubbing medium for tar removal from biomass producer gas

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ABSTRACT

Producer gas, a product of biomass gasification contains not only combustible gases but also tar which is an unwanted and detrimental substance to downstream applications. This paper presents a study on tar removal using laboratory prepared waste palm cooking oil (LWPCO), restaurant collected waste palm cooking oil (CWPCO), diesel oil and water as scrubbing mediums. The experiment succeeded in removing class 4 tar using diesel oil and CWPCO as scrubbing mediums. The unsaturated hydrocarbons (oleic and linoleic acids) present in the CWPCO resulted in the highest tar removal efficiency of 86% (excluding benzene). Besides utilizing unused residual material, application of CWPCO for tar removal can reduce operational cost. Combination of CWPCO with activated carbon provides a high quality producer gas with tar content of 0.022 $gm_n^{-3}$ and tar removal efficiency of 98%, which can be safely used in internal combustion engines (ICE).



## 1. Introduction

Growing demand for energy, depletion of fossil fuel resources and environmental issues are justifications for using renewable energy with biomass being the most potential amongst them. Biomass offers green technology with positive impact to the environment, economy and energy security. Gasification is a thermochemical process which converts biomass into low heating value gas commonly called producer gas which can be more conveniently utilized to generate electricity through internal combustion engines or gas turbines. However, the presence of tar in the producer gas hinders its exploitation in downstream applications by blocking pipes, tar deposition on the valves, wear in the engine cylinder and fouling of the gas turbine blades (Han and Kim, 2008).

Producer gas produced from an updraft gasifier contains about $100gm_n^{-3}$ of tar whilst only $0.5gm_n^{-3}$ is found in a downdraft gasifier (Milne et al., 1998; Rabou et al., 2009). Despite lower tar content obtained from downdraft gasification, tar removal system is still necessary for application in internal combustion engines or gas turbines because these devices are sensitive to tar and particulate. Tolerable tar content in internal combustion engine (ICE) and gas turbine (GT) are about $0.100gm_n^{-3}$ and $0.005gm_n^{-3}$, respectively (Milne et al., 1998).

Many studies show that tar properties and compositions are essential to enable researchers to design tar removal systems (Biziuk et al., 1996; Phuphuakrat et al., 2010a, 2010b, 2011; Anis et al., 2013). There are two main approaches of tar removal system: primary method that removes tar inside the gasifier and secondary method that occurs outside the gasifier. Secondary methods can be done either by chemical or physical means. Chemical method includes thermal and catalytic cracking whilst physical method consists of absorption (using spray tower, packed column scrubber, venturi scrubber, etc.), adsorption (using activated carbon, wood, silica gel, etc.), filtration (using ceramic filter, paper filter, sand bag filter, etc.), and cyclone separation (using cyclone and rotating particle separator) (Zainal et al., 2002; Anis and Zainal, 2011).

Physical tar removal methods from small scale pyrolysis process showed that the use of vegetable oil as a scrubbing medium resulted in the highest tar removal efficiency (Paethanom et al., 2012; Phuphuakrat et al., 2010a, 2011). The performance of scrubbing mediums can be ranked in the order of diesel oil > vegetable oil > biodiesel oil > engine oil > water. Water scrubbing has been widely used for removing tar and organic compounds, but its performance is limited by the hydrophobic properties of tar and needs additional cost for water treatment. Despite good performance of diesel and vegetable oils as scrubbing mediums, their relatively higher cost may not be the best choice to be used commercially.

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However, the use of waste cooking oil can reduce the cost and hopefully increase tar removal efficiency from the producer gas. Previous study found that waste cooking oil has high performance in removing tar (Paethanom et al., 2012). However, the study only concerned tar removal efficiency and tar composition without discussing the mechanism. The performance and chemical composition of waste cooking oil as scrubbing mediums are also another important factor affecting tar absorption ability.

Due to the high performance of waste cooking oil (residual-material from home/restaurant) as scrubbing medium, it provides a long-term alternative that can be reliable especially in removing tars (a product of biomass gasification) from biomass producer gas, which contains not only combustible gases but also tar which is an unwanted and detrimental substance to downstream applications (internal combustion engines and gas turbine). Yet, the mechanism of tar removal used waste cooking oil has been somehow neglected in the scientific literature. This work aims to study the tar removal from producer gas by physical means using absorption and the combination of absorption and adsorption methods whose data are scarcely found in the literature.

In this study, the scrubbing mediums used were water, diesel oil, laboratory prepared waste palm cooking oil (LWPCO), and restaurant collected waste palm cooking oil (CWPCO) to obtain high performance scrubbing medium in removing tar from biomass producer gas. The main objective of this work is to produce high quality biomass producer gas that will be expected to generate clean producer gas that is suitable for internal combustion engine (ICE) application. For this purpose, combination of absorption and adsorption method was used to enhance tar removal efficiency to maximum quality. The results of the scrubbing performance were analyzed and discussed in terms of tar content and compound before and after the tar removal system (TRS).

## 2. Methods

### 2.1. Materials

Off-cut rubber wood block from a furniture factory was used as biomass fuel in a throatless downdraft gasifier. The proximate and ultimate analyses of the biomass fuel are presented in Table 1. LWPCO was prepared under standard laboratory test for restaurant deep-fat frying of French-cut potatoes at continuous heating about 160 ± 15 °C for 5 min (Bezergianni and Kalogianni, 2009; Singhabhandhu and Tezuka, 2010). CWPCO was collected from restaurants nearby and rested for one day to separate the impurities present in the oil. Evaporation process was conducted at 70 °C to remove any water present. Commercial activated carbon was used in the adsorption method.

**Table 1**
Properties of rubber wood blocks.

| Proximate analysis (wt % dry basis) | |
|---|---|
| Fixed carbon | 11.4 |
| Volatile matter | 78.3 |
| Ash | 0.20 |
| Moisture | 10.1 |
| Elemental analysis (wt % dry ash-free basis) | |
| C | 44.80 |
| H | 12.19 |
| N | 0.45 |
| S | 0.88 |
| O (difference) | 41.68 |
| HHV (MJ $kg^{-1}$) | 20.6 |
| Bulk density (kg $m^{-3}$) | 450.8 |

### 2.2. Experimental setup

A schematic diagram of the experimental set up is presented in Fig. 1. The system consists of a throatless downdraft gasifier, tar removal system and tar sampling train. The gasifier with 1500 mm height, 150 mm inner diameter and 200 mm outer diameter is able to generate thermal power output of 10 kW thermal, corresponding to 6 $kgh^{-1}$ biomass feeding rate. Air as a gasifying medium was induced into the gasifier using a suction centrifugal fan. The temperature at the combustion zone was around 700 °C–1200 °C. Sampling of tar, particulates and gas products contained in the producer gas were done before and after the absorption process to determine the initial and final conditions of the products.

### 2.3. Tar removal system (TRS)

#### 2.3.1. Scrubbing method

The experiment was conducted in a 500 mL cylindrical glass chamber, filled with scrubbing medium of 300 mL agitated by a 750 rpm magnetic stirrer to obtain bubbles having high surface area to increase mass transfer. In each experimental run, the producer gas was passed from the top of the chamber to the immersed bottle to capture the tar as well as particulates. The producer gas flow rate through the TRS and tar sampling train was maintained at 5 $Lmin^{-1}$ for 10 min by means of an air driven vacuum pump as shown in Fig. 1.

#### 2.3.2. Combined of scrubbing medium with activated carbon

Fig. 2 shows the combination of scrubbing and adsorption method to remove tar from the producer gas. In this study, the optimum scrubbing medium was selected and combined with commercial activated carbon to remove the tar. A 500 mL cylindrical glass chamber, half filled with activated carbon was used for adsorption process. The comparison of physical properties of commercial activated carbon used in this experiment with previous study is shown in Table 2.

#### 2.3.3. Tar sampling train

The tar sampling train was made according to the guidelines for sampling and analysis of tar and particles in the producer gas by (Paasen et al., 2002). The tar sampling train consists of four impinger bottles placed in series. The first three bottles were half filled with isopropanol and the last was empty. All the bottles were placed in an ice bath at a temperature of about −22 °C which is able to condense light tar especially class 3 and 4 tar (Milne et al., 1998).

### 2.4. Tar and solvent analyzer

#### 2.4.1. Rotary evaporator

Tar content before and after the TRS were detected in the isopropanol solution collected in the tar sampling train. The isopropanol solution was then filtered through a pre-weighed qualitative filter paper (Whatman, 90 mm diameter) to separate the particle and the liquid solution. Then, the sample was put into a round bottom flask immersed in a water bath at 60 °C and evaporated using a rotary evaporator Buchi R205. The tar yield was then calculated by weighing the dry residue normalized by the volume of collected gas.

#### 2.4.2. Gas chromatography–mass spectrometry (GC–MS)

The chemical compounds of the oil-based scrubbing mediums and tar collected using the tar sampling train before and after the TRS were analyzed using Perkin Elmer 600T Gas Chromatography-Mass Spectrometer (GC–MS) analyzer equipped with NIST MS 2.0 software. A DB-5MS column used in the GC was 30 m long, 0.25 mm