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An Effect of Zeolite Size on Performance of Dry Scrubber in Tar Removal of Biomass Derived Syngas

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ABSTRACT

Increasing attention on the use of biomass derived syngas as internal combustion engine fuel, impacts on rising the demand of the scrubber for tar removal of the syngas. Wet scrubber is been used widely for this purpose. However, the liquid adsorbent containing tar may harmful when exposes to the environment. Thus to encounter the problem, the present work proposes the use of dry scrubber with zeolite as an adsorbent. The work aims to develop a simple and low cost zeolite scrubber and investigate and effect of zeolite size on performance of the scrubber for tar removal of syngas from biomass gasification. The result shows that zeolite size is proportional to specific area, heat transfer rate, and scrubber's effectiveness. The highest scrubber's effectiveness of 0.25 is obtained for the smallest zeolite size, i.e. 30 mm.

1. INTRODUCTION

In order to be used as a fuel of internal combustion engine, a syngas from biomass gasification has to be cleaned. The solid particle and tar content in the producer should be removed [1-3]. Tar content in the syngas should be less than 100 mg/Nm^3 [4] when the gas is intended for internal combustion engine application. Tar reduction can be performed either by primary method and/or secondary method. In the primary method, tar removal process occurs inside the gasifier. Meanwhile in secondary method, tar removal process takes place at downstream of the gasifier exit [5, 6]. Due to simplicity, mechanical technique is widely selected in secondary method, such as wet scrubber and dry scrubber. The scrubbing liquids have been used in wet scrubber are water [7, 8], waste palm oil [9], vegetable oil [7, 10] and diesel fuel, biodiesel fuel, and engine oil [10].

Generally, the after used liquid adsorbent, such as water, is required treatment before disposing to the environment. Tar is water soluble and create issues with waste water remediation in water [11]. The treatment of liquid adsorbent such as water need additional cost in producer gas clean-up process [12]. Thus, dry scrubber with solid adsorbent is developed and tested. Several materials have been used as dry adsorbent, such as bio-char [13] and a catalytic filter candle [14]. The concept of dry scrubber is similar to bed filter where solid material is used as filter bed. Bed filter is promising technology for hot gas clean-up which can be operated either in fixed bed, moving bed, or fluidized bed [15]. Due to low cost filter media and have constant pressure drop, granular bed filters are more attractive, especially when the filter is operated as a moving bed [16, 17].

Based on the concept of fixed bed filter, the process that occur in the fixed bed scrubber is illustrated by a schematic diagram in Figure 1. The scrubber is filled with solid adsorbent. The adsorbent acts as a coolant and an absorber of condensate tar. Syngas containing tar vapor (raw gas) enter the scrubber at high temperature (T_{in}). The syngas and tar vapor pass through the solid adsorbent whose temperature is lower than the gas temperature. Cooling of the gas occurs, heat from the gas is adsorbed by the adsorbent. The temperature of the syngas and tar vapor reduces, in some extend reaches tar condensation temperature. Tar vapor condenses into liquid tar which is adsorbed by the adsorbent. The syngas with less tar content (clean gas) exit the gasifier at low temperature (T_{out}). High temperature producer gas actually may impact the structure of the zeolite. However, this effect is not discussed in the present work, since the limitations of zeolite composition before and after used.

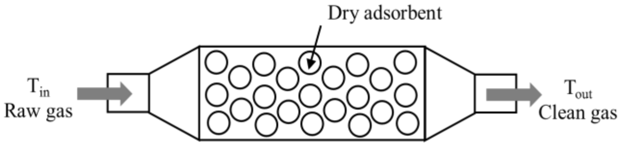

Figure 1. Schematic diagram of dry scrubber

Novelty statement:
The present work proposes a zeolite dry scrubber for tar removal of syngas from biomass gasification. The work aims to develop a low cost and an effective natural zeolite scrubber and to investigate and effect of zeolite diameter on performance of the scrubber. The innovation and novelty of the present work is the use of natural zeolite for tar removal of a producer gas from rice husk gasification. No previous works have been reported on the use of zeolite scrubber in the area of gasification so far.

2. METHOD

2.1 Data collection

Figure 2 presents the schematic diagram of the experimental setup in the present study. The zeolite scrubber is attached at downstream of the downdraft gasifier. The scrubber shell is made from PVC pipe. The tests are conducted by variation in zeolite diameter, i.e. 30, 40, and 50 mm. For each test, the mass of the zeolite filled to the scrubber is 2.3 kg. The temperature and pressure are measured at the inlet and the outlet of the scrubber. K-type thermocouples and u-tube manometers are used to measure the temperature and the pressure. Temperature data are logged into GraphTech 240 data logger. Meanwhile to figure out tar content before and after scrubbing, the impinging bottle method is adopted. The unit of the impinging bottle is shown in Figure 3. The gas is by-passed to the series of bottle filled with Isopropanol at inlet and outlet of the scrubber using a vacuum pump. The gas flow rate to the impinging bottles is measured using rotameter. The isopropanol containing tar is collected from the bottle and oven it at temperature of 50°C for 2 hours. Isopropanol evaporates and tar remains. The remaining tar is then weighted to obtain tar gravimetric. During the investigation, it is assumed no losses of the producer gas flow from the reactor exit to the impinging bottle.

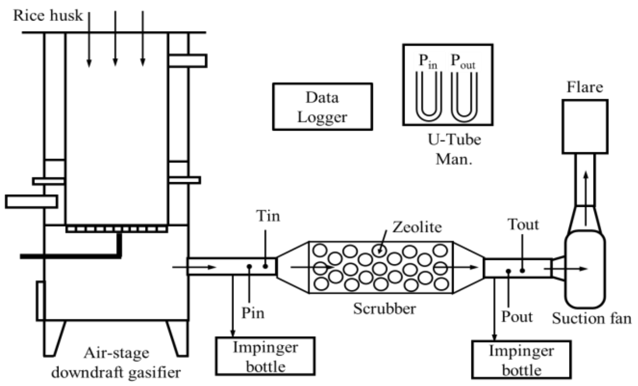

Figure 2. Schematic diagram of the experimental setup

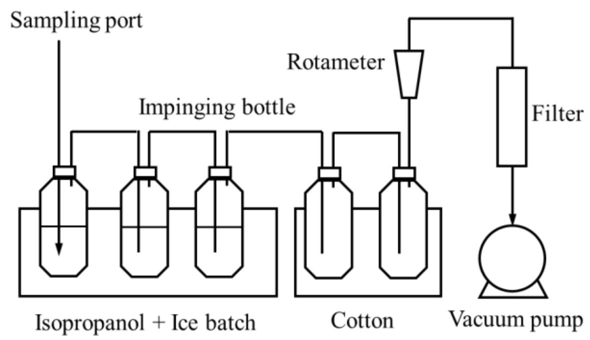

Figure 3. Tar sampling unit of the impinging bottle

2.2 Data analysis

Once data of temperatures, pressure, and tar gravimetric are obtained, the performance of the zeolite scrubber is analyzed in terms of heat transfer rate, pressure drop along the scrubber, tar content of the syngas, and effectiveness of the scrubber. Assuming no heat loss through the scrubber's shell, heat transfer rate from the syngas to the zeolite is calculated using Eq. (1):

$$Q = \frac{m \times c_{p,g} \times (T_{in} - T_{out})}{t} \qquad (1)$$

where, Q is the heat transfer rate from the syngas to the zeolite (kW), m is the mass of syngas (kg), $c_{p,g}$ is the specific heat of syngas (is assumed to be 4.18 kJ/kg.K), (T_{in}-T_{out}) is the temperature difference at inlet and outlet of the scrubber (°C), and t is the duration of the test (s). The mass of the syngas is estimated from the mass balance of the 3 kg rice husk gasification using air at equivalence ratio of 0.3 which is estimated to be 4.68 kg.

The pressure drop is obtained by the data of water level difference in the u-tube manometers at inlet an outlet of the scrubber and calculated using Eq. (2):

$$\Delta P = (mmH_2O)_{in} - (mmH_2O)_{out} \qquad (2)$$

Meanwhile, tar content before and after scrubbing and effectiveness of the scrubber are evaluated using Eq. (3) and Eq. (4), respectively.

$$TC = \frac{m_T}{\dot{V}_g \times t} \qquad (3)$$

$$\varepsilon = \frac{TC_{in} - TC_{out}}{TC_{in}} \qquad (4)$$

where, TC is tar content of the syngas (g tar/Nm^3 gas), m_T is the tar gravimetric (kg), $\dot{V}_g$ is the volume flow rate of the syngas to the impinging bottle (m^3/s), t is the test duration (s), ε is the scrubber's effectiveness, subscripts in and out refer before and after the scrubber.

3. RESULTS AND DISCUSSION

Figure 4 reveals temperature profile of the syngas entering and leaving the scrubber of 30, 40, and 50 mm zeolite diameter, respectively. The profile temperatures of the inlet and outlet syngas are similar for the scrubber with 30, 40, and 50 mm zeolite diameter. The temperatures increase as gasification proceeds longer. After passing the scrubber, the temperature of the syngas reduces, i.e. $T_{in} < T_{out}$. Heat transfer occurs from the syngas to the zeolite. Temperature of the syngas reduces and temperature of the zeolite steps-up. An average temperature difference (Delta T) of the syngas at inlet and outlet of the scrubber is given in Figure 5. The graph in Figure 5 shows the average temperature difference (Delta T) declines as zeolite diameter expands. Specific contact area of heat transfer between syngas and the zeolite reduces as increasing diameter of the zeolite, thus heat transfer rate also decreasing as increasing diameter of the zeolite as shown in Figure 5. The average temperature difference of the syngas at inlet and outlet of the scrubber are 23.7, 19.6, and 17.3°C for zeolite diameter of 30, 40, and 50 mm, accordingly. The temperature difference of the producer gas at inlet and exit of the scrubber is relatively small. This is due to the diameter of the zeolite investigated in the present work is relatively large. Thus, low heat transfer contact area between zeolite and producer gas, in turns low heat transfer rate. As can be seen in Figure 6, the values of heat transfer are 15.5, 13.6, and 12.5 kW.

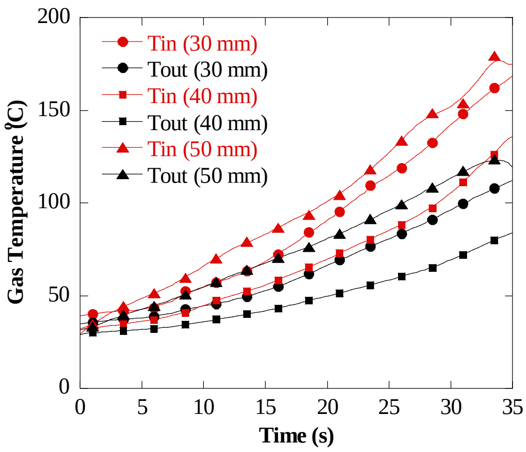

Figure 4. Temperature of the producer gas at inlet and outlet of the scrubber

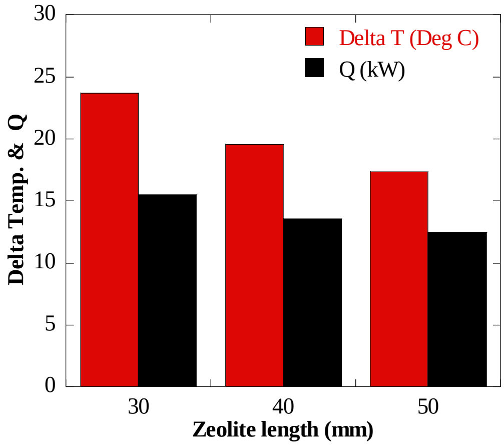

Figure 5. Temperature difference and heat rate

Meanwhile, Figure 6 displays an effect of zeolite diameter on tar content after scrubbing and effectiveness of the scrubber. Tar reduction after scrubbing can be observed by comparing tar content before scrubber (TC1) and after scrubber (TC2). It can be interpreted that the highest tar reduction is achieved at zeolite diameter of 30 mm. The difference between TC1 and TC2 is the largest for the use of 30 mm zeolite. The tar reduction decreases as zeolite diameter expands. This trend of decreasing tar reduction as increasing zeolite diameter impacts a similar trend on effectiveness of the scrubber. Regardless the effect of inlet temperature of the producer gas, the effectiveness of the scrubber declines significantly as diameter of the zeolite goes up from 30 mm to 50 mm. For the use of zeolite diameter of 30, 40, and 50 mm, the values of the effectiveness are 0.25, 0.17, and 0.13, respectively. However, more accurate result could be obtained by maintaining the same inlet temperatures of the producer gas for all zeolite diameter investigation. As diameter of the zeolite moves up, the heat transfer area between syngas and the zeolite reduces, in turns heat transfer rate from the syngas to the zeolite reduces (Figure 5). It means that cooling process becomes slower with larger zeolite diameter. This results in condensing rate of the tar is also slower, hence less tar vapor condenses when a larger zeolite is used. In order to increase effectiveness of the scrubber, additional filter layer could be attached in after scrubber outlet.

In the present work, very small pressure drop is noticed. The size of the zeolite observed in the present work is in order of mm which is relatively large compared than general granular bed filter. The resistance of syngas flow in the scrubber due to zeolite bed is very small, since the size of the zeolite is large. Thus, no significant pressure different between syngas inlet and syngas outlet occurs in the present study. Theoretically, the pressure drop increases as zeolite size reduces. The specific contact area steps-up as reducing zeolite size, hence affect in increasing flow resistance to the syngas, hence pressure drop increases. Particle size of the filter gave more affect to pressure drop than to its filtration efficiency [18].

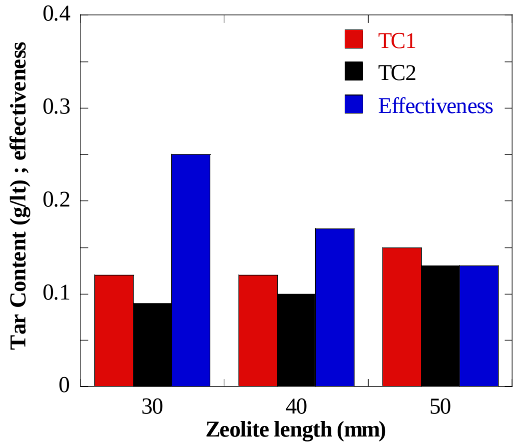

Figure 6. Tar content and effectiveness

The finding of the present work proves that diameter size for given mass of the zeolite adsorbent affects the specific contact area, heat transfer rate, and tar removal effectiveness of the scrubber. The size of the zeolite is proportional to specific area, heat transfer rate, and scrubber's effectiveness as shown in Figure 7. When the zeolite size coarser, its specific contact area become smaller, hence heat transfer rate decreases in which reduces the condensation rate of the tar vapor that leads decreasing tar removal effectiveness of the scrubber. Ma et al. [19] found that Ca/S molar ratio. It can be seen that SO_2 removal efficiency increases with decrease in particle size. When the sorbent is finer, its specific surface area becomes larger, which leads to higher contact efficiency.

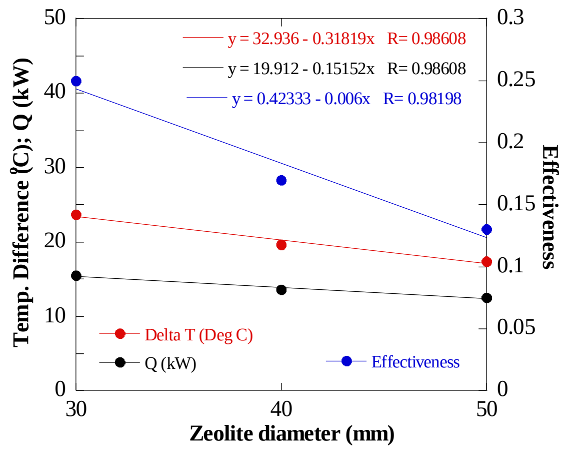

Figure 7. Relation between d_p, ΔT, Q, and ε

Meanwhile, Figure 8 displays photograph of the zeolite before and after being used. It is observed that zeolite surface color turns from white color before being used to brown color after being used. The tar condensate sticks to the surface of the zeolite, tar deposits on the zeolite surface and causes grey color of the zeolite after being used as adsorbent of the dry scrubber. From Figure 8, it can be stated cooling and scrubbing of the syngas occur less effective during the test. Several zeolite is still in white color after being used which indicated that cooling and scrubbing syngas is non-uniform in the scrubber. This may be caused by the syngas flows only over the top layer of the zeolite, thus the cooling and scrubbing occurs only on that layer. To overcome this phenomenon, the pressure of the syngas entering the scrubber should be increased, such "non-uniform" phenomenon shouldn't appear, it should be relatively uniform.

Figure 8. Photograph of the zeolite before and after being used

4. CONCLUSIONS

The zeolite scrubber is fabricated and attached at downstream of the downdraft gasifier. The scrubber performance of the scrubber is evaluated by varying diameter of the zeolite such that 30, 40, and 50 mm. It can be concluded that diameter size of the zeolite affect specific contact area, heat transfer rate, and effectiveness of the scrubber. The contact area, heat transfer rate, and effectiveness of the scrubber rise-up as zeolite size becomes smaller. The highest effectiveness of the scrubber of 0.25 for the use of 30 mm zeolite adsorbent. In the future work, more accurate result could be obtained by maintaining the same inlet temperatures of the producer gas for all zeolite diameter investigation.

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