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Design and Fabrication of A Cleaning Cum Cooling System for Downdraft Gasifier

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ABSTRACT

Biomass is the most abundant resources and available in all parts of Malaysia. It has the potential to be one of the best options for providing theon demand renewable fuel that can be utilized in various energy conversion technologies. The producer gas produced from biomass can be used to power electricity, thermal energy, or transportation fuels. However, the producer gas needs to be cleaned before being used. In the present paper the design and fabrication of cleaning cum cooling system is shown. The cleaning cum cooling system is used to filter the unwanted particle such as dust (particulate matter), tar and to absorb moisture produced by biomass gasification. The objectives are to design the cleaning cum cooling system by using SolidWorks 2016 software, to fabricate the mechanism by lab-scaled dimensions and to cool and clean the producer gas. The cleaning cum cooling system consists of three stages of filter (water scrubber, tar absorber and silica gel). Each filter has the same dimension size that is 110mm diameter and 400 mm height. The material used is Polyvinyl chloride (PVC) pipe. The results showed that temperature output of 30.9ºC is obtained at point after the cleaning cum cooling system. Other than that, 8.5 grams of particulate matter and 32 grams of concentrated tar were trapped in the water scrubber and tar absorber filters. For the moisture test, 40 grams of water was found in the silica gels. These show that the producer gas has been cleaned where a blue flame was lastly obtained. It showed the producer gas is in a good condition.

Keywords: *Biomass gasification; Gas cleaning; Tar separation; Particulate matter separation; Moisture absorber.*

1. INTRODUCTION

Gasification is the process of converting solid/liquid fuel into gaseous fuel. It involves the devolatilization and conversion of biomass in an atmosphere of steam and/or air to produce a medium or low calorific value gas. Gasification is a form of pyrolysis, carried out at high temperatures. The ratio of oxygen to biomass is typically around 0.3. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen. Biomass gasification is one of the upcoming biomass conversion technologies developed in order to produce a combustible gas mixture (called producer gas) using agro-residues. It can be effectively utilized for decentralized power generation and thermal applications.

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However, in order for the gas to be used as power generation applications it must be cleaned of tar, dust, moisture and be cooled. Cooling and cleaning of the gas is one of the most important processes in the whole gasification system. The failure or the success of producer gas units depends completely on their ability to provide a clean and cool gas to the engines. Thus, the importance of cleaning and cooling systems cannot be overemphasized. Hence, the present study is aimed to design and fabricate of cleaning cum cooling system. The objectives are to design system by using SolidWorks 2016 software, to fabricate the mechanism by lab-scaled dimensions and to cool and clean the producer gas by experiment.

2. LITERATURE REVIEWS

2.1 Biomass Gasification

Gasification is the process of converting a carbon-based fuel into a gaseous fuel with applying some heating value [1-3]. The thermal conversion process includes pyrolysis, gasification and combustion. For the gasification process, the primary product produced is gas which can be used for synthesis, gas turbine, engine, boiler to produce chemical, methanol, ammonia and electricity.

2.2 Producer Gas or Syngas

Producer gas is the mixture of combustible gases consisting the Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4) resulted from incomplete combustion from biomass gasification [4]. The producer gas also can be known as synthetic gas (syngas) which is a gas stream composed of only Hydrogen and Carbon monoxide that is derived from the steam and oxygen in the gasification process [5]. It is produced from a partial combustion of solid fuel from biomass in a 1000℃ temperature [6]. The feed material from biomass waste contains a combination of carbon, oxygen, hydrogen, sulphur, nitrogen and other traces of element which have all been ignored before due to their presence in small quantities.

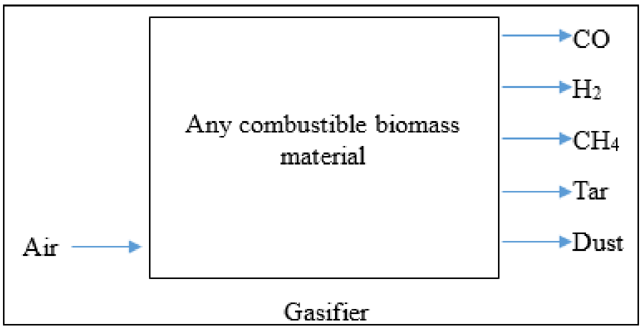

Figure 1: Product of gasification [4].

2.3 Tar

Brownish, typical smelling, high viscous and sticky in nature, tar is the organics produced under thermal or partial-oxidation regimes of any organic material and generally assumed to be largely aromatic [7]. It also can be defined as all contaminating organic compounds that have larger molecular weight than benzene [8]. In fact,tar is one of the most unwanted particles that is formed in the producer gas and tends to be deposited in the carburettor and intake valves causing sticking and troublesome operations. The most problematic issue in tar formation,is that they start to condense at low temperatures [4]. During gasification, tar is

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formed through a number of complex reactions and the condition of reactor can affect the types of tar formed. By increasing the temperature reaction, the amount of secondary reactions in the gaseous phase will increase and cause the conversion of oxygenated tar compounds and affect the maturity of tar. However, the maturation of tars form will depend on the gasification temperature used [9].

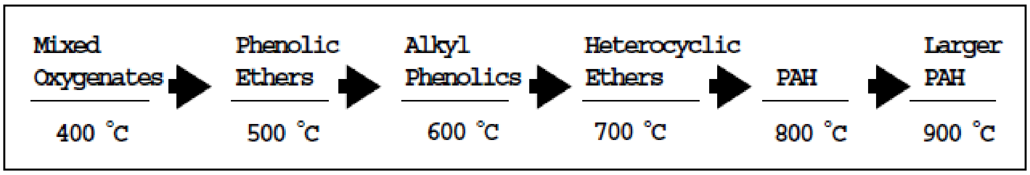

Figure 2: Maturation process of tars [10]

The dew point temperature of tar is between 150°C and 350°C, which far higher than a lowest process temperature (~30°C) [5]. The tar will start giving severe problems when it starts condensing if the level is not strongly reduced before the producer gas reaches the low temperature.

2.4 Particulate Matter (PM)

All the producer gas from gasifier produces dust or particulate matter [4]. The problematic issue arising from particulate matter in producer gas is it can clog the combustion engine and need to be removed. The allowable particulate matter in producer gas from the gasifier design should not produce more than 2-6 g/m^3. The total PM produced depends on the gas production from the gasifier, whereby the PM production increases as the total gas production increases.

2.5 Tar and Particle Removal

2.5.1 Water Scrubber

The water scrubber is one of the methods that can decrease the temperature of the producer gas and acts as a cooler [2,4]. In theory, all the heavy tar components will start condensing there. The operation in the water scrubber starts off by the liquid spraying the gas flow in a counter position before the gas encounters the throat or placed in the throat. Once the liquid spray has captured the tar and the particles, the particles will become heavier and separated with the gas flow [6].

2.5.2 Tar Absorber

The other method to improve the tar reduction technics is to use the tar absorption of high boiling tar component from the producer gas by using the carbonaceous materials such as lignite coke, activated carbon and charcoal. The absorption is widely used for purification process of gaseous impurities. The lignite coke and activated carbon have high absorption characteristics [11].

2.6 Moisture Content

Low moisture content is necessary of fuel because heat loss is due to its evaporation process before gasification takes place considerably and the heatbudget gasificationreaction is impaired. This is because the biomass materials exhibit a wide range of moisture content and

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its can affect the value of fuel source [6]. Normally, the desired moisture content in producer gas should be less than 20% [4].

2.7 Silica Gel

Silica gels have the ability to absorb or desorb the moisture and have an infinite life time span used as absorber. Its moisture absorbing properties are affected by the factor such as capillary pore size, the inclusion of hydroscopic salts, resulting in a wide range of performance in order to achieve the low moisture content in the gas [12].

2.8 Pressure in Device

The most important thing in designing the filter is to avoid the high-pressure drop in the filter. If the high-pressure drop occurs, it can cause the blockage in the filter and as such producing the syngas will be impossible. Calculations related to the designing the filter is shown in Eq 1 to 4 which is focused on the parameters such as flow-rate, bed height, velocity and the diameters of the pipe [13].

$$Q = v \times A \tag{1}$$

$$retention\ time = \frac{H}{v} \tag{2}$$

$$discharge = A \times v \tag{3}$$

$$Q = \frac{\pi}{4} \times D^2 \times v \tag{4}$$

Where,

Q=flow-rate (m^3/s), H=bed height (m), v=velocity (m/s) and D=Diameter (m).

2.9 Other Research

There are many devices that can be used to clean the producer gas reported by researchers. The electrostatic precipitators (ESPs) can capture particulate matter effectively from producer gas [14]. ESP is a filteration device that removes fine particles like dust and smoke from a flowing gas using the force of an induced electrostatic charge minimally impleading the flow of gases through the unit. It can handle very high temperature of up to 700-800^{o}C with collection efficiencies up to 99% for particles smaller than 10 nm.

The mechanisms such as filter, cyclone and ESP are also developed to trap particles [15]. They have reduced tar up to 10 mg/Nm^3. Hasler [16] also has developed venturi scrubber to purge the gases in the counter-current for rice husk gasifier. The efficiency from 51 to 91% for tar removal was achieved. Other than that, the wet scrubbing method was also done to remove PM. Venturi scrubber works on the principle of increasing gas velocity by reducing the flow area, spraying water into fine droplets.

A bag and cartridge filter were also used to clean the producer gas. Hindsgaul [17] has stated that a bag and cartridge filter has good cleaning efficiency from 96 to 99% by mass. The

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producer gas passes through this fibrous bag, which is enclosed inside the metal caged chamber. The dust particles are accumulated inside the bag. Once the dust cake is completely blocked the bag then it needs to be removed manually or to apply pressurized gas to its proper functions. It is an effective technique for particle removal from producer gas with low tar concentration. Figure 3 to 7 show the schematic diagram of the cleaning system developed by several authors.

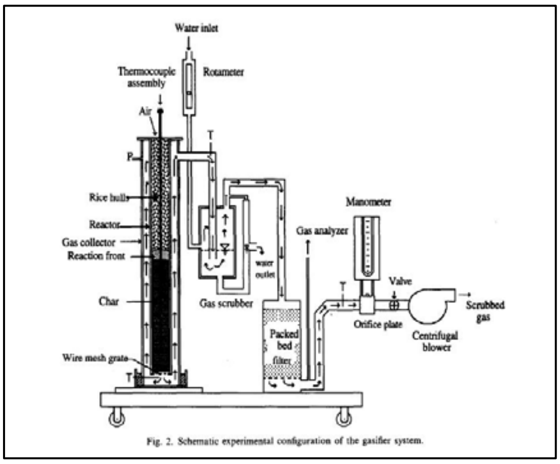


Figure 3: Schematic experimental configuration of the gasifier system [18]

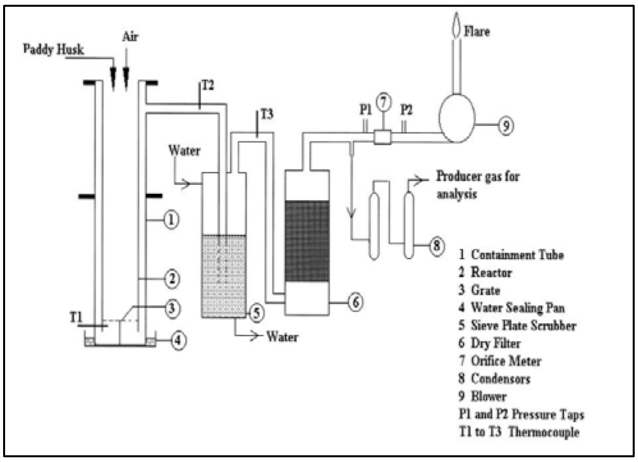
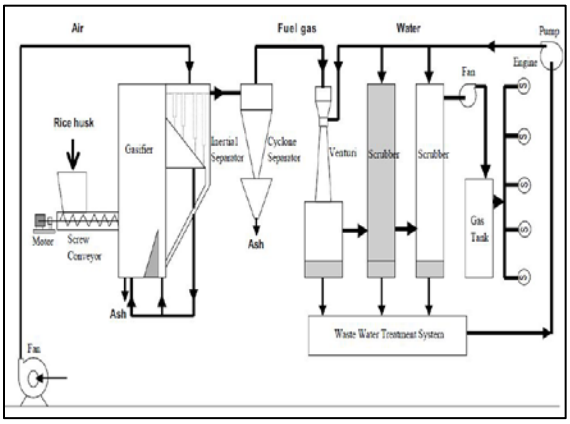


Figure 4: Experimental set-up of the gasifier unit [19]



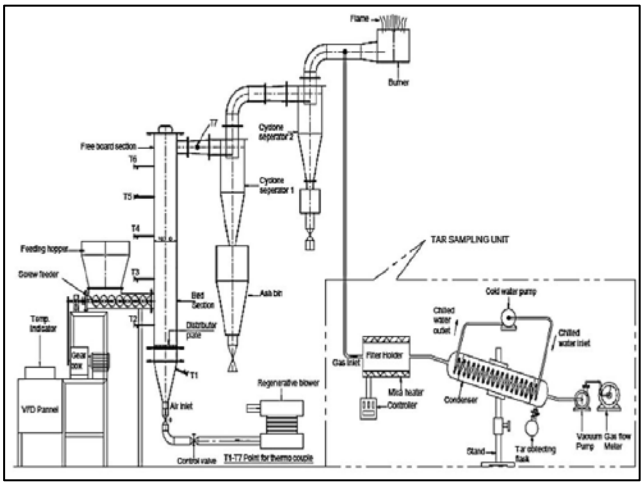


Figure 5: Schematic of 1MW rice husk gasification & power generation system [20]

Figure 6: Detailed setup of fluidized bed of rice husk gasification system [21]

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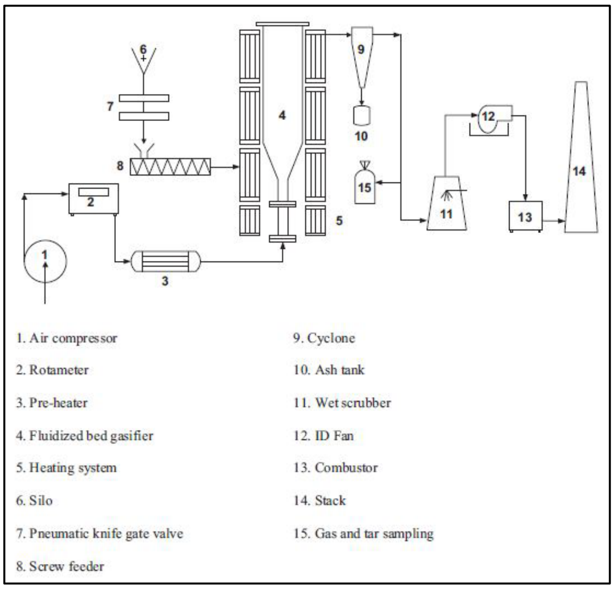

Figure 7: Diagram of flow of the fluidized bed gasification system [22]

Based on studies reviewed, it can be concluded that the use of water scrubber, tar absorber and silica gel as a cleaning cum cooling system have reduced the PM and tar contents. A good cleaning efficiency has been obtained from 96 to 99% by mass. Researchers also installed this cleaning and cooling system in their experiments as shown in Figures 3 to 7 for the purpose of obtaining good producer gas condition.

3. METHODOLOGY

The lab-scale dimension cleaning cum cooling system contains three filtration levels such as water scrubber, tar absorber and silica gel. Based on Equations 1 to 4, the diameter and height of three filters were determined. The cleaning cum cooling system was designed using SolidWorks 2016 software. Sketching was done first before going through a technical design process. Most of the parts were Polyvinyl chloride (PVC). PVC material was selected because the melting point of PVC is around 140^{o}C. Experimental data was taken in 3 sets. This is to ensure that the results are accurate. The experiment/test procedure was operated in the following steps:

1. The cleaning cum cooling system was properly connected to the heat exchanger system together with downdraft gasifier.
2. The rubber pipeline connection from the main water source was connected into the water scrubber filter. (The rubber tube must be locked tightly due to high pressure of water)
3. The charcoal and silica gels were weighed using digital weight for 300 grams and 200 grams respectively.
4. After being weighed, the charcoal and silica gels were inserted into the tar absorber and silica gel container.
5. Both filter bodies were closed tightly using a top cover.
6. Water is discharged into the water scrubber filter and the water out (excessive?) is weighed and subsequently recorded after 1 min.

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7. After 10 minutes operated, the weight of the water out from water scrubber, the inlet temperature and outlet temperature from cleaning cum cooling system were recorded for every 10 minutes and the colour of water was observed.
8. The weight of charcoal and silica gel were recorded after the downdraft gasifier combustion ended

4. RESULT AND DISCUSSION

The cleaning cum cooling system has a cylinder shape and the dimension is about 0.4 m height. Figure 8 shows the sketch of the system. By referring to equation 1 to 4, the diameter of the cleaning cum cooling system was calculated. Table 1 shows the calculated results. Figures 9 to 13 show the technical drawing proposed by using SolidWorks 2016 for Isometric, Front, Top and Side views. Meanwhile, Figures 14 and 15 show actual picture of cleaning cum cooling system and experimental set-up.

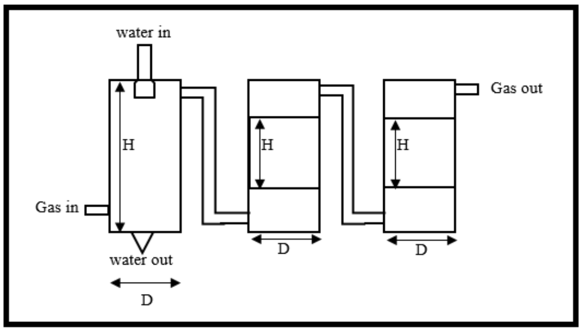

Figure 8: Sketch Cleaning cum cooling system

Table 1: Diameter of each filter

Type of filter	Diameter (m)
Water scrubber	0.10
Tar absorber	0.14
Silica gel	0.11

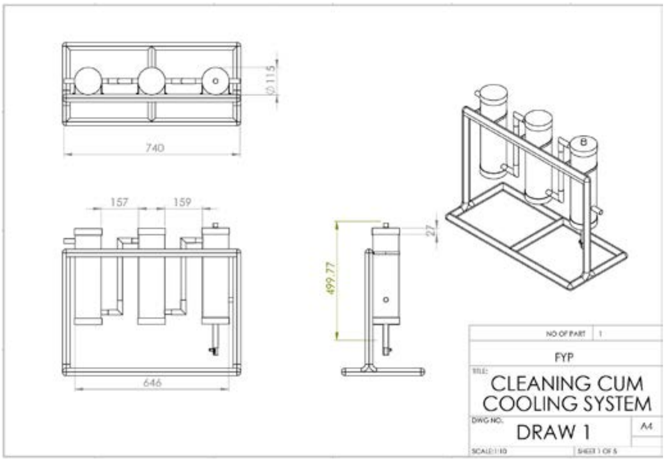

Figure 9: Cleaning cum cooling system

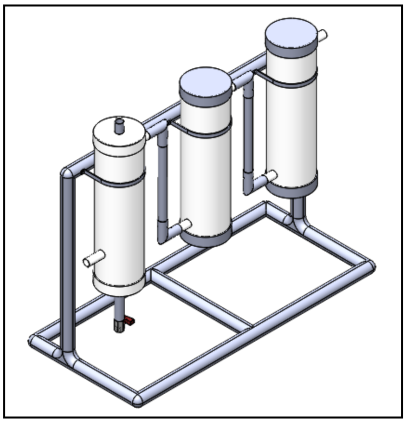
Figure 10: Isometric view

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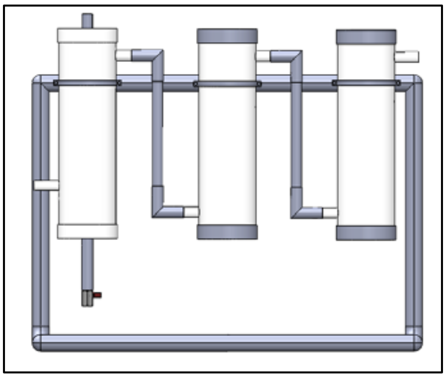
Figure 11: Front view

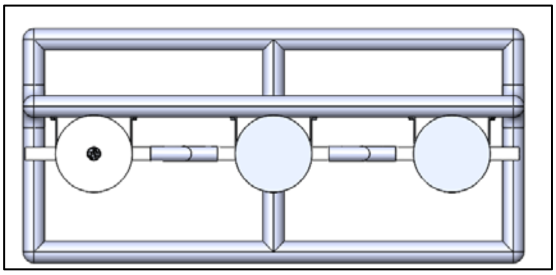
Figure 12: Top view

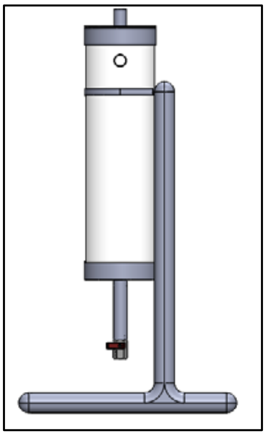
Figure 13: Side view

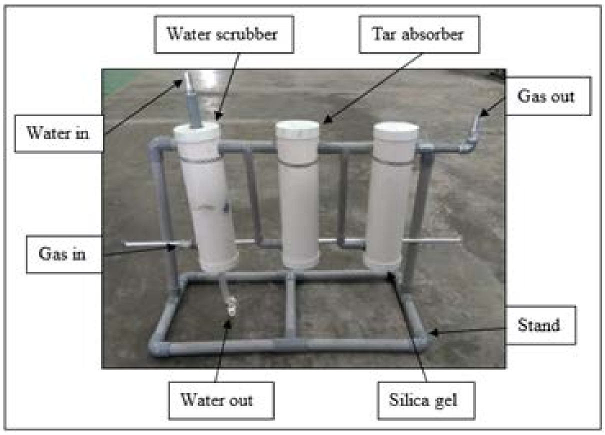

Figure 14: Actual Cleaning cum cooling system


Figure 15: Experiment Set Up

4.1 Temperature

Gas output temperature is one of the factors that influence the formation of tar in producer gas. Table 2 shows the temperature recorded before & after cleaning cum cooling system for three set of experiments every 10 minutes after combustion reaches stability within 10 minutes.

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Table 2: Temperature profile (T1 before, T2 after)

	Experiment 1		Experiment 2		Experiment 3	
Time (min)	**T1 (°C)**	**T2 (°C)**	**T1 (°C)**	**T2 (°C)**	**T1 (°C)**	**T2 (°C)**
10	40.7	32.2	35.9	31.9	36.3	31.7
20	38	31.9	34.3	30.9	35.4	31.4
30	36.5	31.5	35.1	31.3	36.3	31.6
40	36.3	31.4	34.8	31.2	36.5	32

It was observed that the highest producer gas temperature before entering system was (T1) 40.7°C and the lowest temperature is 34.3 °C. According to Marchin [15], tar dew point temperature is in a range of 150 to 350°C and it will start to condense below 150°C. It indicated that, before entering the cleaning system the tar has condensed itself and has been filtered. This will be discussed in the next section. Figure 16 shows the graph of producer gas temperature before passing through the system.

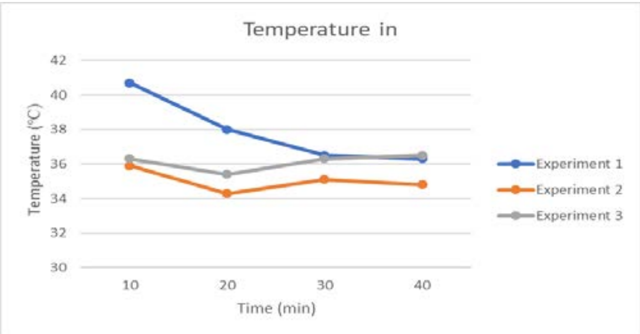

Figure 16: The graph of producer gas temperature before pass through the system.

Figure 17 shows the gas temperature after the system. The producer gas temperature obtained was only around 30.9 - 32.2°C. This indicated that the cleaning cum cooling system was good because the design and development of this system has succeeded in lowering the temperature to 30°C. The producer gas need to becooled in order to use in the power generator such as internal combustion engine [11].

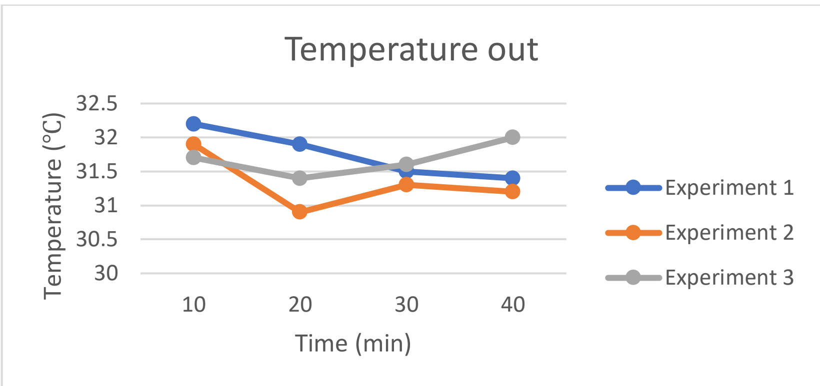

Figure 17: The graph of producer gas temperature after pass through the system.

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4.2 Tar and Particles

As mentioned earlier, water scrubber and tar absorber have been used to remove tar and particulate matter [2, 4, 6, 11]. Tables 3a and 3b show, the recorded data obtained during experiment in term of mass in water scrubber and tar absorber by using a digital weight device. W1 and W2 were before and after filter. The data was recorded for every 10 minutes after reaching a stable combustion in gasifier. Experiment was done in three times. By using data in Table 3a, the tar and particles in water scrubber versus time was plotted (Figure 18). It shows that the mass obtained were around 4 to 14 grams. The average of tar and dust for three experiments is calculated to be 8.5 grams for every minute.
Meanwhile, Figure 19 shows the tar and particulate trapped in the tar absorber. It is observed that the tar and particulate obtained in range of 25 to 32 grams and the average from three experiments was 28.67 grams. The Cleaning cum cooling system has received some amount of tar and particulate as mentioned because it already starts to condense before entering system. This also indicated that the system was in a good operation because the design and development was successful. The tar and particulate in the producer gas needed to be removed in order to be used in the power generator such as in the internal combustion engine [11].

Table 3a: Result collected from experiment for tar and particles (water scrubber)

	Experiment 1			Experiment 2			Experiment 3		
Time (min)	W1(g)	W2 (g)	Net (g)	W1 (g)	W2 (g)	Net (g)	W1 (g)	W2 (g)	Net (g)
10	175	189	14	178	184	6	176	188	12
20	175	182	7	178	187	9	176	184	8
30	175	180	5	178	182	4	176	184	8
40	175	184	9	178	188	10	176	186	10

Table 3b: Result collected from experiment for tar and particles (tar absorber).

	Dry Charcoal without impurity, A1 (gram)	Wet Charcoal with impurity, A2(gram)	Dry Charcoal with impurity, AC (gram)	tar and particles (gram)
Experiment 1	300	454	329	29
Experiment 2	300	432	325	25
Experiment 3	300	468	332	32

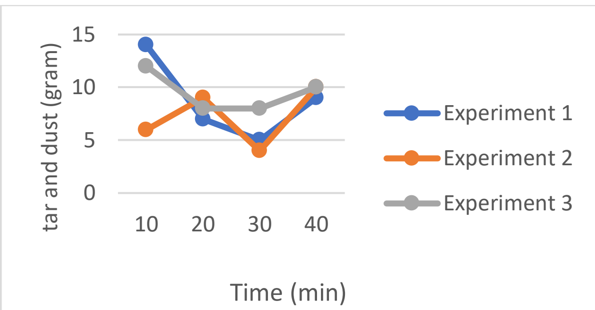

Figure 18: tar and particles (water scrubber)

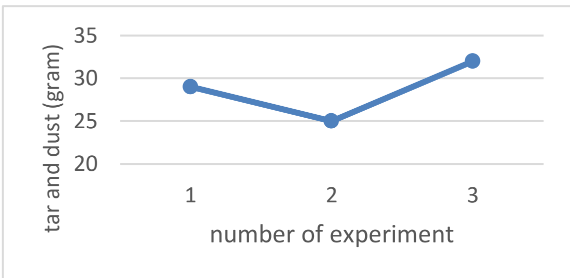

Figure 19: tar and particles (tar absorber)

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4.3 Gas Humidity

The moisture of producer gas needs to be removed in order to use in power generator. Silica gel was used to absorb moisture in producer gas. Table 4 shows the results of the humidity test.

Table 4: Result collected from experiment for weight of humidity.

	Dry silica gel (gram)	Wet silica gel (gram)	Net (gram)
Experiment 1	200	234	34
Experiment 2	200	232	32
Experiment 3	200	240	40

As seen in the Table 4, the initial weight of silica gel before it was run was 200 grams. It observed that the cleaning cum cooling system absorbed 32 to 40 grams of water that was together with the gas producer (Figure 20). As mentioned previously [6], low moisture content is necessary for fuel due to its heat loss based on its evaporation process before gasification taking place considerably and initiating the reaction of the heat budget gasification to be impaired. This is because the biomass materials exhibit a wide range of moisture content and itcan affect the value of fuel source.

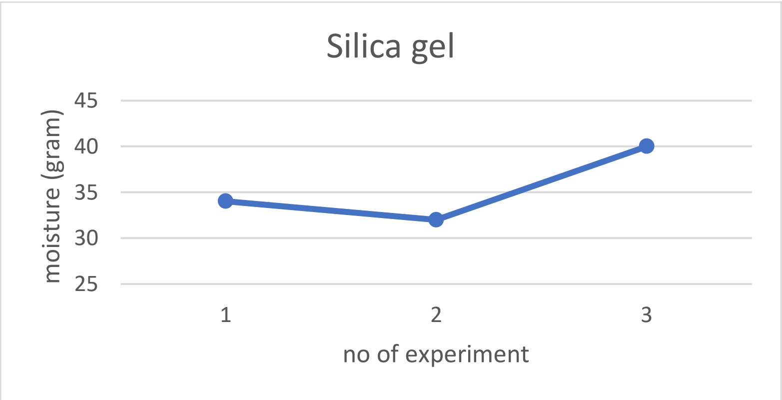

Figure 20: The graph of humidity

4.4 Producer gas flare Test

An indication of suitability of producer gas to beused in the power generator or IC engine was determined by a flare test. The producer gas was tested with a torch to check the presence of combustible gas. If the flame occurred, the gas would thus contain combustible gases such as carbon oxide, hydrogen and methane. Figure 21 are photographs of the flare test showing different flame quality at flare port 1 (before entering the system) and port 2 (after existing the system) during operation of the downdraft gasifier. It was observed that the producer gas flared with more to a blue flame without any smoke in flare port 2 as compared to orange/yellow flame before entering cleaning system in flare port 1. The main reason for the blue flame is because the producer gas does not contain any tar and particulates.

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Figure 21: The flame colour before and after cleaning cum cooling system.

5. CONCLUSION

The design and fabrication of cleaning cum cooling system for downdraft gasifier has been successfully done and developed. The objectives of this paper were successfully achieved. The cleaning cum cooling system consists of three filtration levels: water scrubber, tar absorber and silica gel have a cylinder shape size with dimension of 0.4 m in height, 0.1 m diameter (water scrubber), 0.14 m diameter (tar absorber) and 0.11m diameter (silica gel). This lab-scale cleaning system has proved to be successful in reducing the concentration of tar and particulate matter as shown and discussed in the preview section. Blue flame obtained shows that the system is operating properly. Therefore, the producer gas, which went through the cleaning process can therefore be directly connected to internal combustion engine as fuel.

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