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# A REVIEW ON GASIFIER MODIFICATION FOR TAR REDUCTION IN BIOMASS GASIFICATION

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## ABSTRACT

*This paper presents a review of gasifier modification for tar reduction in biomass gasification. Biomass gasification has been attracting high interest due to high conversion efficiency and low pollution. Utilization of biomass gasification process for energy and heat application greatly requires low tar content. The tar content in the producer gas will condense at low temperature and block engine parts. Tar content exceeding specified level will reduce the economic value of utilizing producer gas for power generation via internal combustion of engine applications. The reaction mechanisms of tar decomposition generally arise from chain cracking, steam reforming, dry reforming, carbon formation and partial combustion. Gasifier modification for tar reduction can be divided into several categories ie. the addition of air injection, recirculation of pyrolysis gas, combination of pyrolysis gas recirculation and addition of air injection, modification of gas outlet, modification of combustion zone position, separation process for pyrolysis and reduction at different chambers. Combination of several reaction mechanisms for tar reduction occurring with reactor modification will greatly reduce the amount of tar than if one reaction mechanism occurring in reactor modification because of gradual tar reduction occur through partial combustion and reforming or tar cracking in the reactor. Tar can be reduced to fulfill the specified requirement level for the internal combustion engines application through gasifier modification method.*

**Keywords :** Biomass, gasification, tar reduction, gasifiers, modification

## 1.0 INTRODUCTION

The depletion of world's fossil fuels and environmental problem (*global warming)* produced by combustion of fossil fuels have led to the search for alternative fuels. Biomass gasification has attracted high interest due to high conversion efficiency and low pollution but the producer gas produced unspecified high level of tar. On the basis of EU/EA/U meeting for protocol of tar measurement in Brussel 1998, tar is defined as whole organic contaminant by molecule weight greater than benzene ($C_6H_6$) [1]. Tar will condensed when temperature decreases below its dew point temperature. Tar can cause operational process line problems like blocking of gas cooling system, filter element and engine inlet systems [2].

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Application in internal combustion engines requires gas producer with the amount of tar around 10 – 50 $mg/Nm^3$ [3, 4]. Whereas, tar was produced at average conventional downdraft gasifiers of about 2 $g/Nm^3$ and conventional updraft gasifier of about 58 $g/Nm^3$ [5]. If the system applied gas cleaning equipments with high efficiencies, then the tar content will be reduced to about 20 - 40 $mg/Nm^3$ [4] and the tar content will be less than the specified level but it required high cost and large space installation [6]. Gas cleaning system also produced liquid waste including carcinogenic element and it needed extensive treatment before disposal [6].

There were two common methods carried out in reducing tar namely, primary and secondary methods. Primary method to reduce tar was carried out in the gasifier itself including to select proper operational parameter, to select proper fuel characteristics, the use of catalysts or additives in the bed, and the modification of gasifier. Secondary method is conventionally used as the treatment to producer gas after its going out gasifier including thermal cracking, catalytic cracking and mechanical treatments such as the use of cyclones, baffled filters, fabric filters, ceramic filters, rotating particle separators, electrostatic filters and scrubbers [7]. The reaction mechanism of tar decomposition generally arise from chain cracking, steam reforming, dry reforming, carbon formation and partial combustion [8, 9] as below;

- Chain cracking
  $pC_nH_x \rightarrow q\ C_mH_y + r\ H_2$
- Steam reforming
  $C_nH_x + nH_2O \rightarrow (n + x/2)H_2 + nCO$
- Dry reforming by gas $CO_2$
  $C_nH_x + nCO_2 \rightarrow (x/2)H_2 + 2n\ CO$
- Carbon formation
  $C_nH_x \rightarrow nC + (x/2)H_2$
- Partial Combustion
  $C_nH_x + (n/2 + x/4)\ O_2 \rightarrow n\ CO + x\ H_2O$

where $C_nH_x$ is tar, and $C_mH_y$ represents hydrocarbon with smaller carbon number than $C_nH_y$

This objective of this paper is to review gasifier modifications for tar reduction in biomass gasification which is applied to internal combustion engines and burners.

## 2.0 GASIFIER MODIFICATION METHOD

In the effort to reduce tar produced by biomass gasification process through gasifier modification, many researches have been carried out, among other is by Kaupp and Gross [10]. Kaupp and Gross reported that the DelaCotte tar-recycling gasifier expanded by gasification media $CO_2$ and $H_2O$ with temperature of 1000°C - 1100°C as shown in Figure 1. Pyrolysis gas came out from reactor entrained into burner by gasification air using an ejector. Then mixture of air and pyrolysis gas was combusted at the burner to produce $CO_2$, $H_2O$ and heat. Some combustion product moved to pyrolysis zone and the rest moved to reduction zone producing combustible gas through reaction of $CO_2$ and $H_2O$ with char (C). It produced combustible gas that was released at the lower part of reactor. This type of gasifier is claimed to produce low tar.

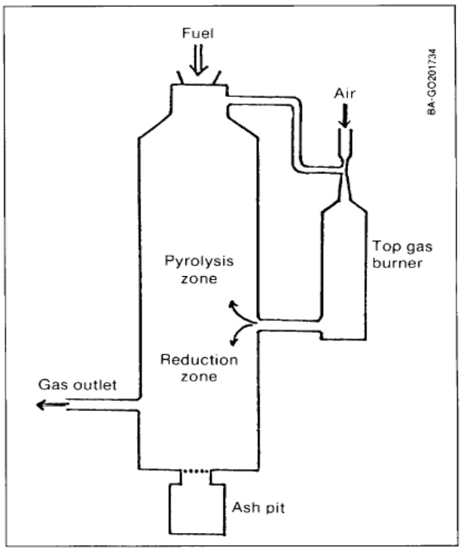


Figure 1. DeLacotte tar recycling gasifier [10]

Two stage gasifier was reported by Nowacki [11] as shown in Figure 2. This gasifier is an updraft gasifier that has one gas outlet above the drying zone and another one just at the top of the gasification zone where about half the gas produced by gasification is removed. The remainder flows upward through the devolatilization and drying zones. The temperatures attained in these two zones are considerably lower than the conventional updraft gasifier. Therefore, the incoming fuel is heated and the tar is evolved in a much slower manner. Thus, the problem in heavy tars, pitch and soot are avoided. This gasifier is meant for coal application but it could be used for biomass as input fuel.

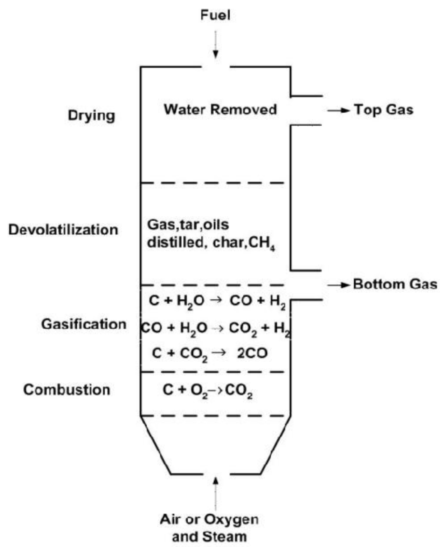


Figure 2. Two stage gasifier [11]

Updraft gasifier with direct combustion of the producer gas on the upper part of reactor was reported by Hobb *et. al.* [12] is shown in Figure 3. The heat of combustion could be utilized for boiler and dryer. Direct combustion of producer gas does not require tar cleaning system for indirect heating system.

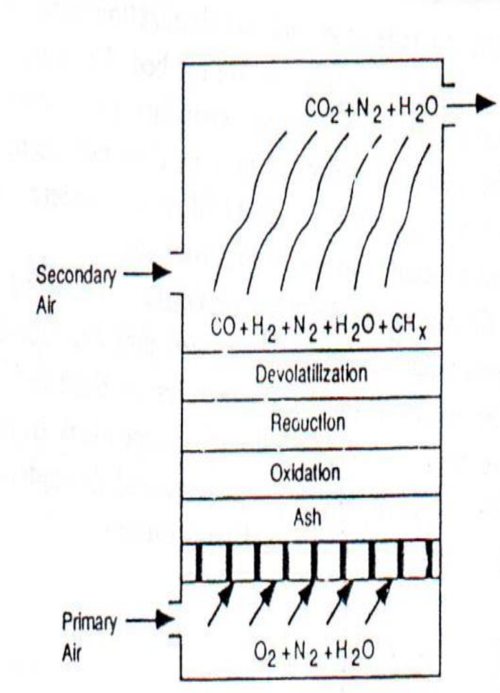


Figure 3. Up-draft gasifier [12]

Two stage throatless downdraft gasifier was developed by Bui *et.al* [5] at Asian Institute of Technology, Thailand as shown in Figure 4. This gasifier was different from the conventional type namely by adding secondary air inlet at the middle part of reactor. Its purpose is to increase the temperature at the reduction zone and then cause tar reduction by cracking at high temperature. By applying two air intakes, the temperature in the first stage would be decreased. Adding secondary air injection would help to combust the producer gas, released from the first stage, it caused an increase in temperature inside reactor as compared with the exertion of a single air injection. The maximum temperature inside the reactor could reach above 1000°C. Amount of tar product was 40 times smaller than single air. Amount of tar product was 90 mg/Nm$^3$ with 4150 kJ/m$^3$ of LHV and 69% of efficiency.

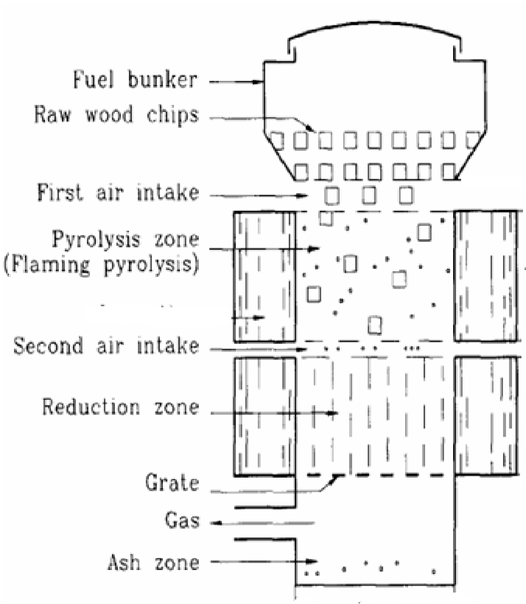


Figure 4. Two- stage gasification concept of Asian Institute of Technology [5]

Moving bed gasifier with internal gas recirculation was developed by Susanto and Beenacker [13] as shown in Figure 5. Basically, this gasifier was almost similar with DeLacotte tar recycling gasifier. But the burner for combustion process of pyrolysis gas was located in gasifier as to reduce the amount of heat loss to the environment. Pyrolysis gas was entrained into combustion chamber by using ejector then it was combusted by gasification air. Then flue gas from combustion chamber functioned as gasification agent. It was divided into two parts, namely: the first part was discharged to the reduction zone to react with char producing combustible gas and the second part was discharged to the pyrolysis zone to give heat for pyrolysis process. The exertion of internal recirculation would give great tar reduction compared to conventional downdraft gasifier with diameter of throat of 0.2 m. This gasifier produced about 0.350 g/m$^3$ of tar.

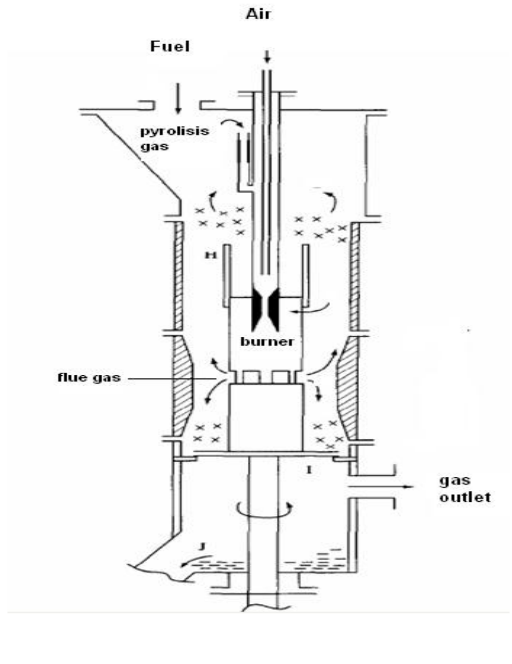


Figure 5. Moving bed gasifier by internal recirculation [13]

Two stage gasifier developed by Brandt *et. al*. [14] is shown in Figure 6. In the first stage, the screw driven pyrolysis reactor uses heat from the exhaust gas of internal combustion engine, to produce pyrolysis gas and char as they entered the second stage. The second stage was a downdraft reactor where pyrolysis gas was combusted partially at upper part of reactor using air or steam for tar reduction. The pyrolysis gas is then passed through a bed of char for further tar reduction process through cracking with char bed. Amount of tar produced after partial combustion process was 2940 to 3400 mg/kg of a dry wood, but after cracking process, the amount reduced to 40 to 6.4 mg/kg of a dry wood. The combining exertion of partial combustion and cracking on char bed enabled to obtain tar less than 15 mg/Nm$^3$.

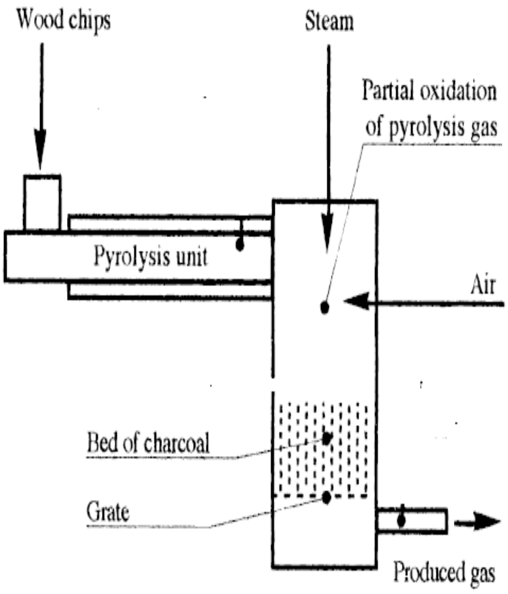


Figure 6. Two - stage gasifier, Technical University of Denmark [14]

Throatless downdraft gasifier with smaller size was developed by Barrio *et. al.* [15] is shown in Figure 7. This gasifier concept was not much different from the concept of two staged gasifier which was developed by Bui *et. al.* [5], but its size was smaller with greater variety of air inlet to the reactor. The total amount of air supply could be varied to obtain the best combination effect of producing higher LHV and lower tar content of producer gas. The minimum tar content produced was about 3 g/Nm$^3$. Due to the smaller reactor, it produces much heat loss.

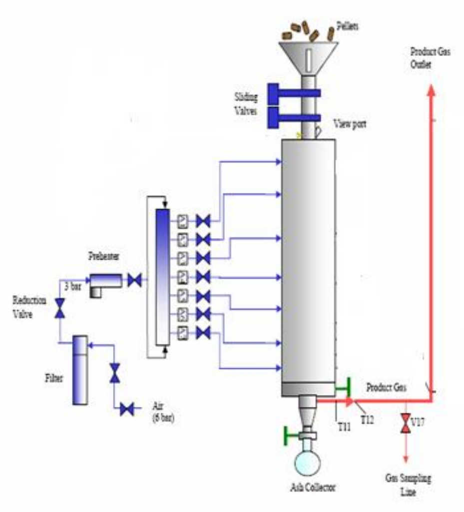


Figure 7. Stratified downdraft gasifier [15]

Three stage gasifier was developed by Koch [16] as shown in Figure 8. Basically, this gasifier was almost similar with the gasifier developed by Brandt *et. al.* [14]. In this pyrolysis process the reaction occured inside the updraft reactor using air as the gasification agent. Pyrolysis gas was combusted partially then it was passed through bed of char inside the downdraft reactor. Tar content in the producer gas is lower than the requirement for internal combustion engines which is of about 1-20 mg/Nm$^3$

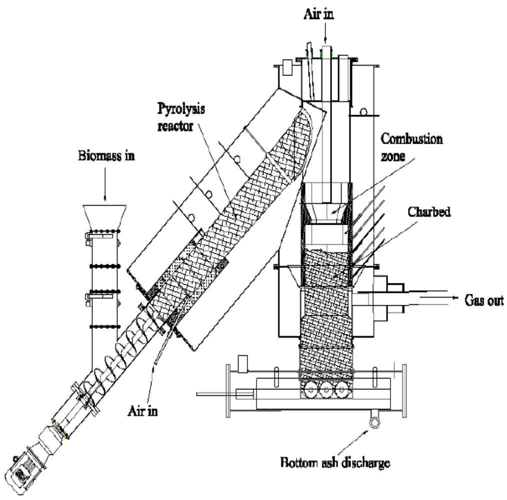


Figure 8. Three stage gasifier [16]

Two staged updraft gasifier was developed by Pino *et.al* [17] as shown in Figure 9. The first stage reactor was an updraft gasifier reactor using air and steam as the gasification agent. Second stage reactor was a fixed bed reforming reactor consisting char with nickel combines with alumina catalyst as a media of tar cracking and tar reforming.

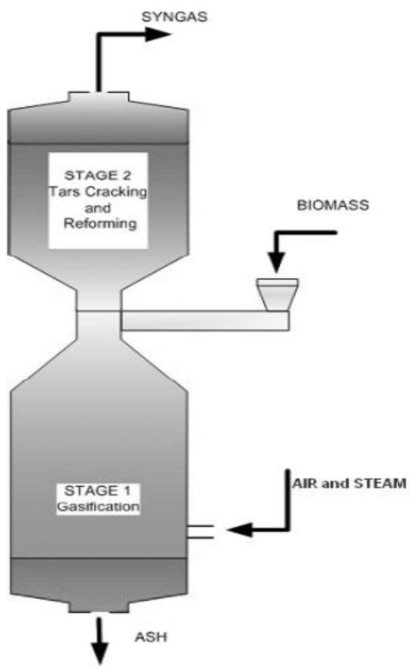


Figure 9. Two stage updraft gasifier [17]

Novel two staged biomass fluidized gasifier was developed by Cao *et. al*. [18] is shown in Figure 10. This gasifier was different from the conventional fluidized bed gasifier namely fueling at the top of reactor, injecting of secondary air and partly recirculating of combustible gas to the freeboard zone. The fuel inlet is situated at the top of reactor as to increase the pyrolysis process at the freeboard zone. Injection of secondary air and recirculating gas would induce combustion of mixed gas and air. Heat from combustion product would increase the temperature at freeboard zone then the tar decomposition by cracking at high char temperature becomes pronounced. The results showed that the increase of the lower reactor temperature from 651°C to 839°C with constant temperature at upper part 750°C could produce tar reduction from 1227 mg/Nm$^3$ to 338 mg/Nm$^3$. The increase of the upper part temperature from 750°C to 934°C with constant temperature at lower part 650°C could reduce tar to 12.34 Nm$^3$. Amount of tar could be reduced efficiently to 10 mg/Nm$^3$. LHV gas was produced about 5,000 kJ/Nm$^3$ and the efficiency about 56.9%.

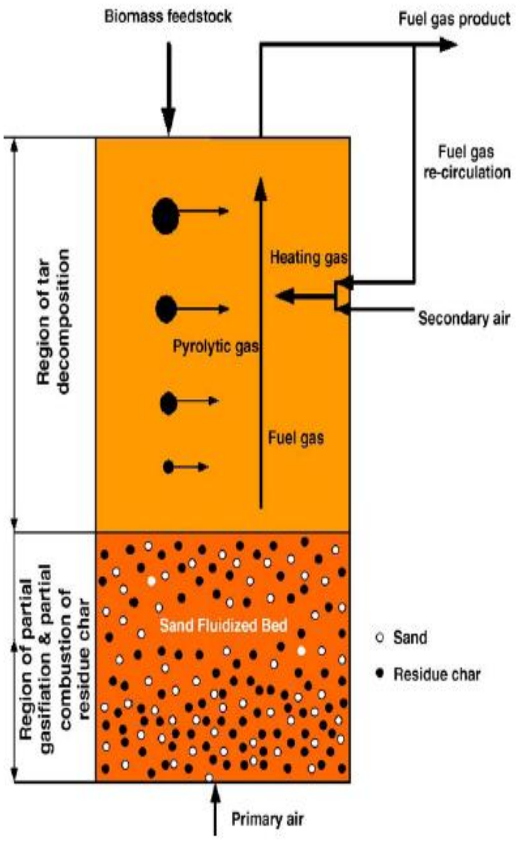


Figure 10. Novel two - stage fluidized bed biomass gasifier [18]

Updraft fixed bed gasifier with an embedded combustor was developed by Chyan [19] as shown in Figure 11. Basically, this reactor is the same as the one reported by Hobb *et. al.* [12]. Its burner was embedded at the lower part of the pyrolysis zone for the purpose of reducing the amount of water content in the gas and increasing the gas temperature. Combustor was applied to directly combust pyrolysis gas and the flue gas was utilized in the boiler producing steam and steering engine to produce energy. The purpose of direct combustion of gas inside the reactor was to reduce the utilization of tar cleaning equipment. The tar was not release out of reactor due to the direct combustion. LHV of the producer gas was of 5,012 kJ/Nm$^3$ .

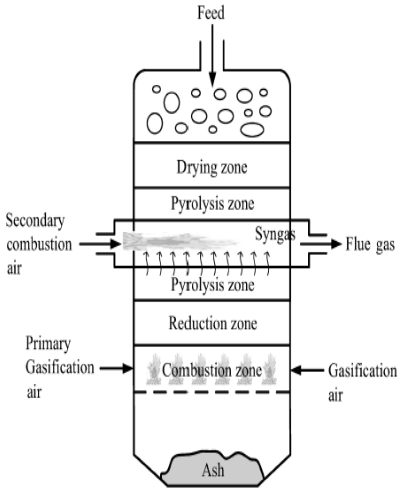


Figure 11. Updraft fixed bed gasifier with an embedded combustor [19]

Two stage gasification system developed by Wang et. al. [9] at Tokyo Institute of Technology, Japan is shown in Figure 12. This research was carried out by combining the updraft gasifier to produce combustible gas in the first stage. The second stage reactor was a reformer as to combust the gas produced by updraft gasifier partially using heated air and steam. The purpose of this partial combustion is to reduce the tar through its becoming combustible gas. Research result showed that the increase of air reforming ratio from 0.15 to 0.21 with the reformer temperature from 800°C to 850°C at gasification air ratio 0.21 that would reduce tar significantly from 5.79 $g/Nm^3$ to 1 $g/Nm^3$. The increase of air reforming ratio to 0.29 at temperature 950°C would reduce the tar content to 0.3 $g/Nm^3$, optimum condition was obtained at reformer air ratio 0.21. The increase of steam reforming ratio from 0.5 to 1.0 at gasification air ratio 0.21 and constant reformer temperature of 850°C could not reduce tar significantly. The tar content at optimum operation of reforming steam ratio was 0.7 $mg/Nm^3$. The alteration of air reforming ratio would give significant tar reduction compared with the alteration of steam reforming ratio. Optimum tar content was produced 1 $g/m^3$ with 3.9 $MJ/m^3$ LHV of gas and 66% efficiency of gasification.

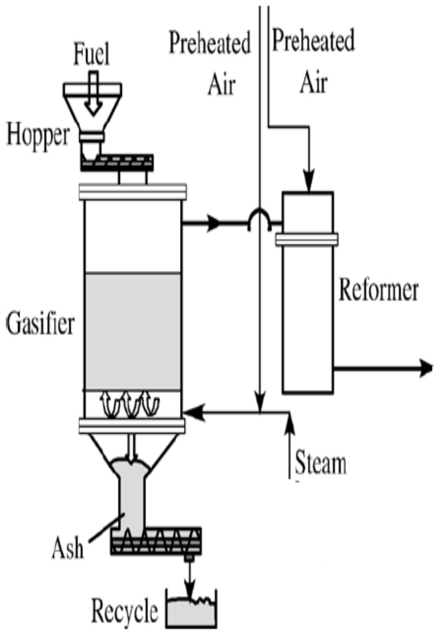


Figure 12. Two stage gasification Tokyo Institute of Technology [9]

Top lit updraft gasifier was developed by Saravanakumar et. al. [20] is shown in Figure 13. This gasifier had operational principle different from the conventional type of updraft gasifier where fuel was lit at the top of reactor then the position of combustion zone at the top part of reactor was different from the common combustion zone lower part of reactor. The purpose of modification is pyrolysis gas contained a lot of tar passing through high temperature of combustion zone. Then tar was decomposed through cracking at high temperature. The result showed tar content of approximately 1% to 5% from producer gas for top lit updraft gasifier and 10% to 30% from producer gas for conventional updraft gasifier. LHV and efficiency of the top lit updraft gasifier were 3500 kcal/Nm$^3$ and 65% to 84% respectively.

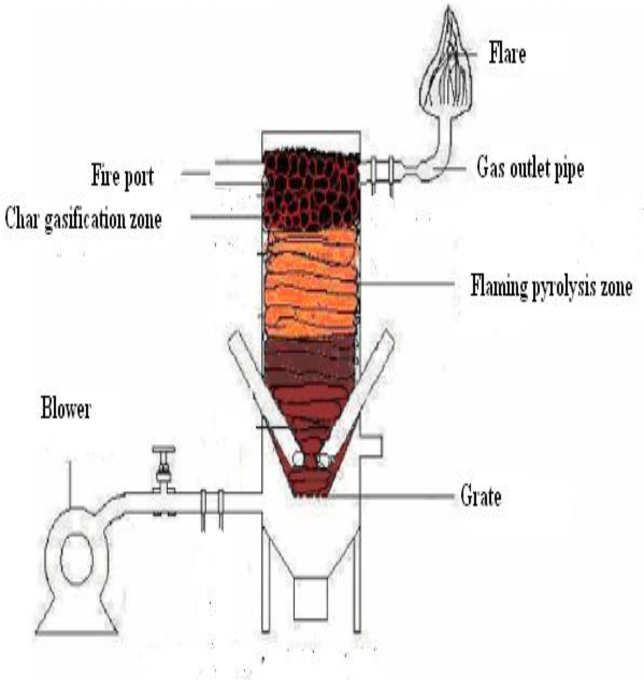


Figure 13. Top lit updraft gasifier [20]

Twin fired gasifier (downdraft gasifier with two combustion zone) was developed by Kramreiter et. al. [21] as shown in Figure 14. The concept of twin fired gasifier was the two combustion zone in the gasifier. The air inlet was located at the middle part of reactor for the combustion process. The secondary air inlet was positioned above the grate to increase the temperature of reduction zone, where combustion occurs. The result showed that the exertion of one combustion zone at the middle part of reactor (single air injection) where maximum temperature obtained at reduction zone about 800°C, addition of secondary air injection at lower part of reactor made the maximum temperature increase at reduction zone to about 950°C. This is the best process for tar reduction by cracking at high temperature. Tar content of 0.2 to 2 g/Nm$^3$ with an average gas heating value of 5.6 to 6.3 MJ/Nm$^3$.

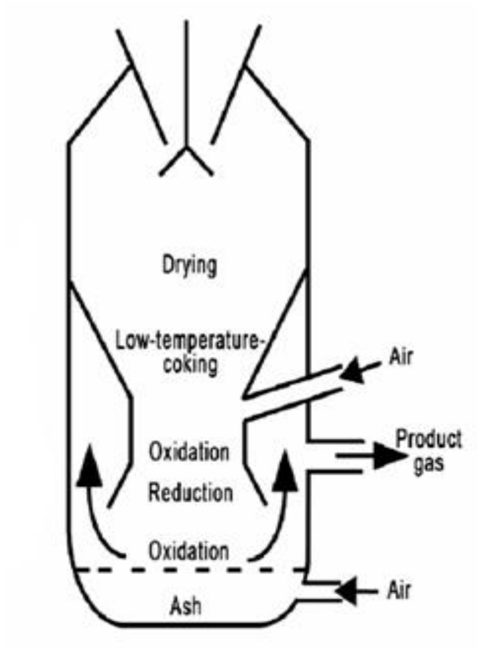


Figure 14. Twin fire gasifier [21]

Throatless downdraft gasifier with internal recirculation was modified by Gek [22] as shown in Figure 15. This gasifier was different from common throatless downdraft gasifier where there were many recirculation of pyrolysis gas to combustion zone using ejector and conduit. Main problem in downdraft gasifier without throat zone was a lot of tar passing out from high temperature of combustion zone due unconcentrated combustion zone. To overcome this problem, pyrolysis gas was inhaled from the pyrolysis zone using sideways in the reactor by ejector into the combustion zone. The presence of initial mixing between pyrolysis gas and air before the combustion make the partial combustion process of tar and cracking at high temperature close to perfect.

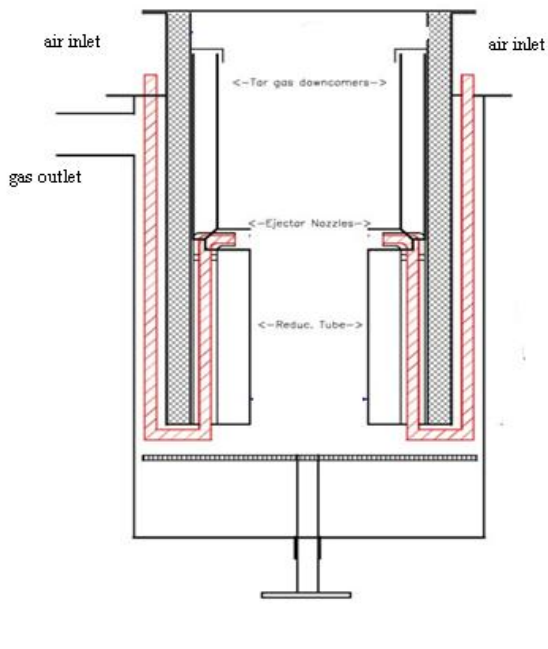


Figure 15. Throatless downdraft gasifier with internal recirculation ejector [22]

Low-tar big Gasifier was developed by Anderson *et. al.* [23] as shown in Figure 16. Basically, the gasification process in low–tar big gasifier was done separately in the pyrolysis and gasification chambers. The pyrolysis process occurs in the bubbling fluid bed utilized steam. Product gas of pyrolysis was entrained into combustion chamber by an ejector which to be combusted partially to reduce tar contained in the pyrolysis gas. Char from pyrolysis process go down into gasification reactor (bubbling fluid bed gasifier) for gasificaton process using steam as the gasification agent. Result gas of pyrolysis process and gasification process mixed into freeboard zone as the final product of gasification. This gasifier could gasify biomass of water content around 65 to 70 wt %.

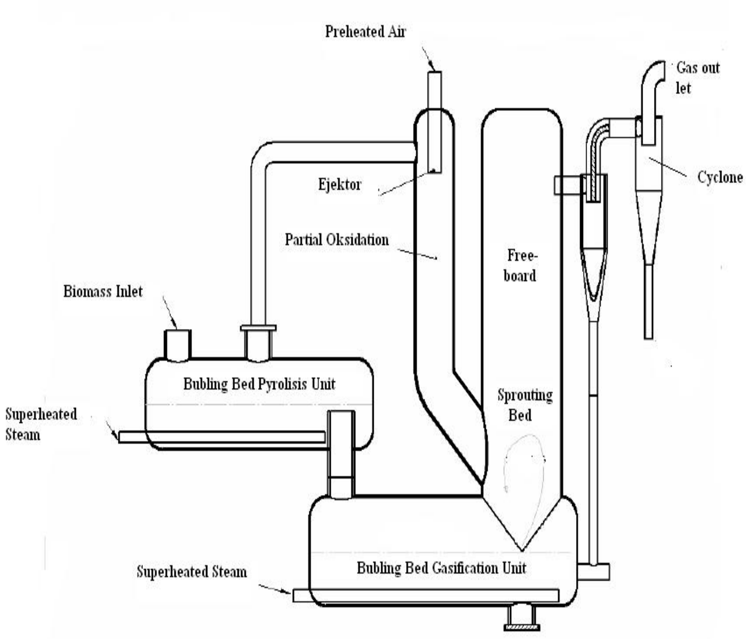


Figure 16. Low–tar big gasifier [23]

## 3.0 DISCUSSIONS

From the review study, gasifier modification for tar reduction can be divided into 7 categories ie. the addition of air injection carried out by Bui et. al. [5], Barrio et. al. [15], Kremeiter et. al. [20], Hobb et. al. [12]; recirculation of pyrolysis gas reported by Kaupp and Gross [10], Susanto and Beenackers [13], Gek [22]; combination of pyrolysis gas recirculation and addition of air injection carried out by Cao et. al. [18]; modification of gas outlets reported by Chyan [19] and Nowacki [11]; modification of position of combustion zone by Saravanakumar et. al. [20]; application of catalytic bed by Pino et. al. [17] and separation process of pyrolysis and reduction using different chambers as reported by Brand [14], Koch et. al. [16], Wang et. al. [9] and Anderseen et. al. [23].

The addition of air injection are carried out to increase temperature inside the reactor, particularly at reduction and combustion zone so that tar cracking occur at high temperature, the amount of tar produced is about 90 mg/Nm$^3$ for throatless downdraft gasifier. Recirculation of pyrolysis gas is carried out to combust the pyrolysis gas in the gas burner before it reticulated to the reduction zone or to drive the pyrolysis gas to the combustion zone, amount of tar produced is about 0.350 g/Nm$^3$. Combination of pyrolysis gas recirculation and addition of air injection are intended to occur partial combustion of pyrolysis gas recirculation and increase temperature inside reactor for tar cracking, amount of tar produced is about 10 mg/Nm$^3$ at fluidized bed gasifier. The application of catalytic is carried out by passing through pyrolysis gas at catalyst bed for tar cracking and tar reforming. Modification of outlet gas is carried out particularly to release reduction gas from reduction process that contains fewer tars than pyrolysis gas from pyrolysis process. Modification of combustion zone position is carried out by passing the pyrolysis gases at high temperature zone (combustion zone) then the tar cracking process occurs. In the separation process of pyrolysis and reduction at different chamber, it is intended to initially burn the pyrolysis gas partially by using air or steam to reduce tar content then it is passed through on hot char bed for cracking and reforming process, amount of tar produced is about 1-15 mg/Nm$^3$.

Combination of several reaction mechanism for tar reduction occurring in reactor modification will produce amount of tar reduction better than if one reaction mechanism occurring at reactor modification because of occurring gradual tar reduction through partial combustion and reforming or cracking at reactor

## 4.0 CONCLUSION

i. Gasifier modification for tar reduction can be divided into : the addition of air injection, recirculation of pyrolysis gas, combination of pyrolysis gas recirculation and addition of air injection, modification of outlet gas, modification of combustion zone position, separation process of pyrolysis and reduction at different chamber
ii. Tar reduction through gasifier modification could occur due to the reaction mechanism namely: cracking, steam reforming, dry reforming, carbon formation and partial combustion.
iii. Combination of several reaction mechanism for tar reduction occurring in an reactor modification will produce lesser amount of tar reduction better
iv. Tar can be reduced to fulfil the specified requirement level for the internal combustion engines application through gasifier modification method.

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