Pre-feasibility study on the effect of the gas temperature to the ash separation of sawdust gasification in cyclone gasifier

M.A. Miskam, M.Y.Idroas, Z.A.Z. Alauddin, K.F. Mustafa

School of Mechanical Engineering, USM Engineering Campus,
Sri Ampangan, 14300 Nibong Tebal,
Pulau Pinang, Malaysia.

Abstract

About 303 tons of sawdust produced per day in Malaysia from sawmills and wood-based industries and the sawdust are dumped at landfill as a waste. With the existing gasification technology, sawdust can be used as a source of energy but the presence of inorganic material in the fuel however limited the use of sawdust for operation of gas turbines. Corrosion, erosion and deposition from fuel gases derived from sawdust can cause damage to gas turbine components. However, the latest cyclone gasification concept can rectify the problem and make a full use of sawdust for power generation. The main advantage of the cyclone gasification is the capability of achieving as well as maintaining the temperature of the fuel at a level where ash melting or ash vaporization will not occur. So, the corrosive ashes would then remain solid in the char particles, which could be separated from the product gas in the cyclone. In this paper, a review of experimental and theoretical studies are adopted in order to comprehend the effects of temperature to the amount of alkali compounds generated in producer gas throughout the cyclone gasification process. The objective is to understand the thermal distribution in the cyclone chamber and to characterize the temperature in order to produce minimal impact of alkali compounds to the damage of gas turbine.

Keywords: Cyclone Gasification, Sawdust, Thermal Distribution, alkali compounds

1.0 Introduction

In the future, our energy systems will need to be renewable and sustainable, efficient and cost-effective, convenient and safe [1]. Biomass is seen as an interesting energy source for several reasons. The main reason is that bioenergy can contribute to sustainable development. Resources are often locally available and conversion into secondary energy carriers is feasible without high capital investments. Furthermore, the importance of biomass as fuel has increased during the last decades for two main reasons. The first one is the oil crises and the second is the efforts to control the greenhouse effect cause by the emissions of CO_2 increases [2]. There are several ways to reduce the CO_2 emissions and the use of biomass as fuel is one of them.

One of the options is to utilize sawdust since there are great amount of produced everyday. Thousands of sawmills and wood-based industries in Malaysia are face with a problem of what to do with almost endless truckloads of sawdust waste. Malaysia's total round-wood production is 20.7 million cubic meters in 2002 [3]. From this amount of logs, about 303 tons of sawdust produced per day in Malaysia from these industries and because of wood waste disposal is difficult and expensive, these sawdust are easily dumped at landfill areas. When this waste is unmanaged correctly, it can be a very dangerous threat to the environment. The major effects on soils are reducing their nitrogen content, increasing their acidity and polluting with phenol compounds. These effects will reduce soil productivity. Sawdust also affects the waters either by direct commutation of lakes and rivers or by their impurity, which has negative impact on the living ecosystems. In addition, the sawdust becomes a potential health problem when sawdust particles become airborne or contact with skin such as respiratory disease, cancer and skin disorders.

Biomass is widely considered to be a major potential fuel and renewable resource for the future. So, the use of biomass for power generation is expected to increase in the world [4]. There is a wide range of processes available available for converting biomass into more valuable fuels. The thermal processes to make heat, gaseous fuels from which wide variety products, including electricity can be produced [2]. Different cogeneration options for utilization of biomass fuels have therefore been studied. Biomass fuelled gasification have been found to be the one of the promising technologies for electric power generation. In gasification process, biomass subjected to partial pyrolysis under stoichiometric condition, where the air quantity limited to suitable kg of air per kg of biomass. The resultant mixture of gases generated during the gasification process is call producer gas, contains CO and H_2 and is combustible. Normally, conventional gasifiers are base on gasification of biomass in size of 10mm to 100mm. Those gasifiers include fixed bed gasifiers such as up-drought, down-drought, cross-drought and devolatilisation. Although fluidized bed gasifier can gasify 1mm to 10mm biomass particles, the producer's gas should be clean after the combustion.

For a few decades, cyclones were studied to be an alternative gasifier to gasify smaller particle of biomass fuels such as sawdust. The use of sawdust for operation of gas turbines is however limited by problems caused by the inorganic material in the fuel. The presence of these materials may lead to erosion of the turbine blades caused by particles carried by the gas stream and deposition of potassium and sodium compounds on turbine surfaces. The deposition may cause flow blockage, vibrations and possibly corrosion. However, the latest cyclone gasification concept can rectify the problem and make a full use of sawdust for power generation. The main advantage of the cyclone gasification is the capability of achieving as well as maintaining the temperature of the fuel at a level where ash melting or ash vaporization will not occur. So, the corrosive ashes would then remain solid in the char particles, which could be separated from the product gas in the cyclone.

In this paper, the principles of operation, a design basis for cyclone gasifier, the operating parameters for successful cyclone gasification and important parameters affecting the product gas composition, product gas temperature and separation of particles and alkali metals from a sawdust fuelled cyclone gasifier are reviewed. The objective is to understand the thermal distribution in the cyclone chamber and to characterize the temperature in order to produce minimal impact of alkali compounds to the damage of gas turbine.

2.0 Principles Of Operation

Cyclones are one of the most widely used separators, which rely on centrifugal forces to separate particles from gas stream. The uses of the cyclone is basically for pollution control [6] where high efficiencies are required to meet stringent regulation and particulate size classifiers where aerodynamic classification of particle size plays a vital role in the production process.

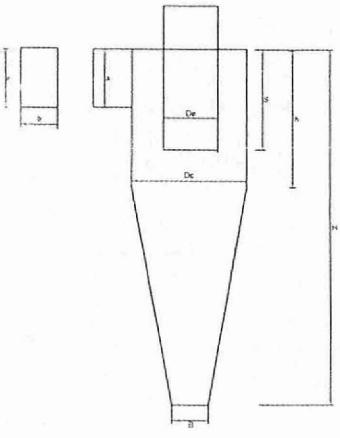

Figure 1. Schematic diagram of cyclone illustrate geometrical dimensions

Cyclone is used because inexpensive to construct, cost effective to operate and adaptable to a wide range of operating condition such as high temperatures and pressures [7]. Cyclones can typically achieve moderate to high efficiencies for particles larger than about 5 μm in diameter and can operate at very high loading.

A cyclone is a mechanism that used to separate solid materials from gases or liquids [6]. All cyclone separators based on centrifugal separation of particles in an induced vortex within the gas flow [8]. When the fluid, with the dispersed particles in suspension injected tangentially through the inlet pipe into the cyclone, then due to the specially designed geometrical feature of the cyclone, the fluid acquires a spiraling motion [9], which first descends along an outer spiral and then ascends through an inner spiral. When the vertical motion, spiraling reached the conical section, the centrifugal forces can be several times greater than gravity contributing to particle separation [10]. The dispersed particles, which have a different density to their carrying fluid drive by the centripetal acceleration to move relative to the fluid motion. The relatively larger particles possess a larger inertia and therefore acquire a stronger centripetal acceleration. When the centripetal acceleration is sufficiently large, then the particles drift towards the sidewall and finally they separated through the apex of the cyclone. The geometrical dimension of the most common cyclone design with tangential inlet [11] are shown in figure 1 where Dc = body diameter; D_e = gas outlet diameter; a = inlet height; b = inlet width; H = cyclone height; h = cylinder height; S = gas outlet duct length and B = cone bottom opening.

3.0 Design Basis For Cyclone Gasifier

The flow pattern in a cyclone is very complex [12]. The complexity of the flow pattern inside the chamber is due to high turbulence level, strong anisotropy, three-dimensionality and possible non-stationary features typical of highly swirling motions. In cyclone the gas stream enters the cyclone inlet tangentially with suitable velocity so that the swirl motion will occurs along the inside space of the cyclone. It observed that, the gas flow is more spiraling downward from the inlet close to the wall of the cyclone until it reaches the bottom of the cyclone. At the bottom, the gas spiral changes direction and spirals upwards, towards the outlet, in the centre of the cyclone [13]. The rotating flow maintained by the tangentially directed inlet flow. The gas velocity is however well inside the turbulent flow region and will lead to a transfer of gas between the outer and inner flow [14]. The conical shield often built into the bottom of the tapered body of the cyclone prevents already collected material from being re-entrained. The particles that are not collected carried inward by the gas flow and removed through the exit duct.

The separation process that occurs inside a cyclone thought to be drive by the centrifugal force acting radial outward due to the curve path and the drag forces caused by the inward radial flow. The centrifugal force developed inside the cyclone accelerates the settling rate of the particles, thereby separating them according to specific gravity in the medium. Thus, the more dense material flung to the outer wall of the cyclone where the settling velocity is at its lowest and progresses downwards along the cyclone wall in a spiral flow pattern until it exits at the bottom cone. For small particles, the drag force maybe sufficient to move the particle towards the center of the cyclone. If the inward drag force is strong enough, and particles reach the central flow region where the flow is ascending, they will most likely to escape together with the outgoing gas. However, the centrifugal force will increase, as the particle is moving towards the radius of the outlet pipe due to the increased tangential velocity. Thus, the force on a particle may balance at some radius where the particle theoretically stops its radial movement and rotates in an orbit with a constant radius. In practice, the radial velocity is not constant in the tangential direction and the particle will consequently move. The particle can also change path caused by secondary effect such as turbulent eddies or collisions with other particles [13]. At the bottom cone, a reverse vortex begins to form creating a low-pressure zone (generally referred to as the air core) flowing upwards along the axis of the cyclone, through the vortex finder and exits at the overflow.

Pressure drop over the cyclone is an important variable when evaluating performance of a cyclone. It is a measure of the amount of work that is required to operate the cyclone at the given condition, which is important for operational and economical reasons. Pressure drop defined as the difference in mean total pressure at the inlet and the outlet. The total pressure drop over a cyclone consists of losses at the inlet, outlet and within the cyclone body. The wall friction and the contraction of the inner vortex on entering the vortex finder cause the pressure drop in a cyclone. Accordingly, the total pressure drop is composed of two contributions. The first part is the pressure loss in the separation zone, cause by the friction of gas/surface or gas/solids/surface. Secondly, the pressure drops in the vortex finder and determined by the relationship between the tangential velocity, the radius and the mean axial velocity in the vortex finder.

Influence of temperature as parameter on separation efficiency and pressure drop should be investigate since the cyclone in this study is design to operate at high temperature. Results from experiments [15] show that the separation efficiency is significant influenced by temperature and the separation efficiency had shown to decrease with increasing temperature. Oppositely, the pressure drop will decrease with increase in temperature. These effects explained by the decreased density, increased wall friction and increased viscosity due to the increased temperature. All three variables have the effect of lowering the tangential velocity that accordingly lowers the pressure drop and separation efficiency. All these results based on conditions where the inlet velocity was constant between the different experiments [Fredriksson, 1999].

4.0 Gasification Process In Cyclone Gasifier

A schematic diagram of the atmospheric cyclone gasifier is shown in Figure 2 [16]. The system consists of fuel feeding bin with screw feeders, downcomers and cyclone. The fuel is partially combusted in the cyclone with air or air/steam mixture to produce a combustible gas. The fuel is supplied to the cyclone inlets from the feeding bin via screw feeders and two downcomers. The fuel is injected into the cyclone by two tangentially directed air driven injectors in to the cyclone gasifier. Gasification air was supplied to the cyclone together with the fuel via the downcomers and from the injectors. The injectors directed the fuel/air mixture to enter the cyclone in a tangential direction, which generates a swirl flow in the cyclone. The swirl will force the incoming sawdust particles to follow a trajectory close to the cyclone wall, where the main part of reactions takes place. The product gas leaves through the top outlet of the cyclone, while ungasified char particles fall downwards toward the bottom outlet, where they can be collected.

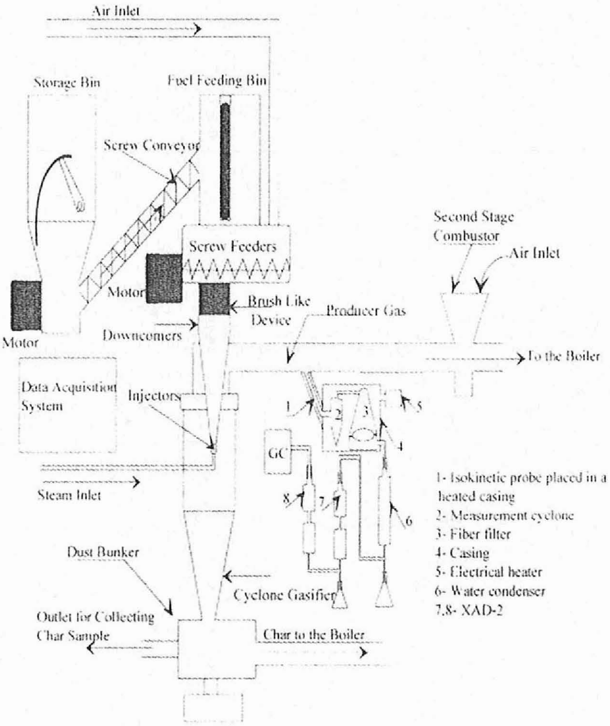

Figure 2. Schematic diagram of cyclone gasification system.

In the cyclone gasifier, the experiments were started by pre-heating the cyclone with a propane burner before injection of the fuel [17]. The fuel injection was started when the wall temperature was about 850°C, after which the heat necessary for the reactions to proceed will be generated from the reactions themselves. The producer gas was generated after a few minutes from the injection of fuel and it leaves through the top outlet of the cyclone.
When the cyclone was running at steady state conditions with stable temperature and at a specific equivalence ratio, a char sample was collected from the bottom residue.

4.0 Effect Of Thermal Distribution And Gas Temperature To The Separation Of Particles And Alkali Metal

The volatile and non-volatile are the fraction of solid fuel combustible. The overall rate of sawdust gasification depends on individual rates of the processes involved such as drying, release of the combustible volatiles, mixing of the volatiles vapour and the oxidant, combustion of the volatiles and the gasification of non-volatile combustibles. While, the rates of these individual processes depend on the size of a fuel particle, the heat transfers with surroundings and the gas composition in the vicinity of the particle. A residence time also effect the amounts of fuel gasified [18]. The devolatilisation start when sawdust particle enter the hot cyclone chamber. The particles are dries and pyrolysed the self-sustaining exothermic reaction takes place. When volatile combustibles mixed with air, the combustibles and the oxygen form a flammable mixture. Little oxygen can penetrate through the flame into the fuel particle. During this process, the density of particle decreased but the size is only slightly reducing. Gas mixture composed primarily of carbon dioxide, carbon monoxide, hydrogen, water vapour, nitrogen and pyrolysis products including tar, hydrocarbons and residual solid (char) are the final product. The char, tar and hydrocarbons are then gasified by reactions with the carbon dioxide and water vapour when the oxygen around the particle is consumed and the volatile flame is extinguished, to produce gas composed mainly of CO, H_2, CH_4, C_2H_4 and C_2H_2.

The equivalence ratio, the geometry of the cyclone gasifier and the residence time are the main factors to contribute the complete reactions of all tars, hydrocarbons and char with the gasification air. During the gasification process, a fraction of the ash forming elements may be volatilised and released. These volatiles may react on the surfaces of the char and carryover particles contents in the producer gas. As a result the surface composition and size of them are changed. It is depends on the ash composition of the fuel, the particle size, the particle temperature and the gasification pressure.

5.0 Several Key Of Operation Condition

The fuel particles should be heated in sufficient high temperature after entering the cyclone to initiate volatiles and gasification reaction. So, the cyclone wall temperature is very important for this heating process. For stable process of gasification the experience shows that the wall temperature exceeds 600°C – 950°C and the equivalence ratio could be varied between 0.18 and 0.25 [19]. As a result, a gas temperature ranging from 800°C to 850°C and the gasification process is running smoothly. When calculating the difference between input alkali with the sawdust fuel and alkali separated with char collected from the cyclone, the amount of alkali carried with the producer gas at cyclone outlet can be determined.

Gabra et al. [16] in the present work had run the experiment in a cyclone gasifier and fluidized bed using bagasse to evaluate the actual potential of alkali separation during gasification process. The process was performed with crushed bagasse and cane trash. The size distributions determined by sieving are shown in Table 1. Table 2 shows the experiment results of the ash forming elements in bagasse fuel and gasification residue samples from bagasse gasification in cyclone gasifier in g/kg (fuel). The results showed that alkali separation for bagasse in cyclone gasifier is about 70% of the input alkali with the fuel. The operation conditions for this experiment are follows. The cyclone wall temperature limits for stable gasification temperature were found to be in the range of 650–950°C. The equivalence ratios ranging from 0.25 to 0.21 and the gas temperature is on an average of 850°C. While, the feeding rate of bagasse is 39 kg/h. The system reached stable conditions after a few minutes and a char sample was collected from the bottom residue.

Table 1. Size distribution of bagasse

	Size distribution	
Particle size (mm)	Crushed bagasse	Ground bagasse pellets
> 2.0	0%	1%
1.0–2.0	2%	23%
0.5–1.0	23%	23%
0.25–0.5	50%	25%
0.125–0.25	11%	16%
0.1–0.125	6%	2%
0.071–0.1	3%	2%
0.04–0.071	3%	5%
< 0–0.04	3%	3%
Bulk density (kg/m^3)	128	485

Wood powder gasified in cyclone gasifier and separator was studied by Fredriksson [20]. A commercially produced wood powder was used and the fuel was produced by grinding the raw material, pine and fir in rotary cutter. Table 3 shows the size distribution of wood powder. Figure 3 shows amount of alkali (K+Na) in product gas from cyclone gasifier of wood powder measured by sampling. It was found that alkali retention in collected ash was

40-60%. This experiment was used steam and air as injection medium to test the performance of the cyclone. Different operating conditions were achieved showed in table 4. From these experiments, it also has been found that pre-heating of the walls to about 950°C is necessary to ensure stable transition to wood powder gasification.

Deposition occurs when particles with molten ash or condensed liquid phase impacts on surfaces and remains there because of their high sticking coefficient. Alkali metals such as potassium (K) and sodium (Na) are generally form compounds with a relatively low melting point. The melting point of potassium carbonate and sodium carbonate is 891°C and 851°C respectively. Pure potassium sulphate melts at 1069°C which is drastically reduced in combination with other potassium compounds such as potassium chloride, which has a melting point of 770°C. Deposition can be a problem even if the ash content in the fuel is low, as the flow rate is very high in gas turbine and thus the resulting amount of material could be considerable.

According to Misra et al. [21] the corrosive alkali compounds are supposed to vaporise at temperature ranging from 800°C to 900°C. Despite a gas temperature at cyclone outlet in the range of 850–800°C, it was found that the elemental compositions of the ash in bagasse fuel, char and fly ash collected after combustion are almost the same. So, this show that these elements do not vaporise and therefore they do not significantly go into gas phase. One possible explanation is that even if the gas temperature is above the temperature of vaporisation for the ash forming elements, the residence time in the cyclone is too short for the large particles to reach a temperature where the alkali compounds vaporise. The particles containing char and ash are separated from the flow when they reached the lower outlet.

Figure 3. Amount of alkali (K+Na) in product gas from cyclone gasification of wood powder

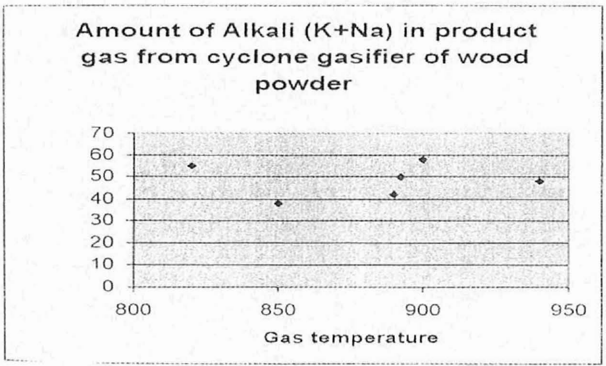

Table 2. Ash forming elements in bagasse fuel and gasification residue samples from bagasse gasification in cyclone gasifier in g/kg (fuel)

Fuel rate (kg/h)		39	39	1.66	1.71
Total run time (h)		6	6	1.37	12.5
Bed te[illegible]		850	850	850	850
Air flo[illegible]		47	47	2.85	2.85
Equiva[illegible] (ER)		0.25	0.25	0.34	0.34
		Gasification residues			
		Replication 1	*Replication 2*	*Experiment 1*	*Experiment 2*
Ash forming elements (g/kg) (fuel)	*Fuel*	*CG*	*CG*	*FBG*	*FBG*
Si	23.83	14.50	14.18	4.32	15.26
Al	1.46	1.03	1.01	0.21	0.06
Ca	1.84	1.29	1.26	0.22	0.09
Fe	1.33	0.96	0.93	0.30	0.15
K	1.04	0.80	0.79	0.19	0.05
Mg	0.95	0.61	0.63	0.12	0.04
Mn	0.58	0.04	0.04	0.06	0.01
Na	0.27	0.13	0.13	0.00	0.00
P	0.13	0.09	0.09	0.02	0.01
Ti	0.26	0.15	0.15	0.24	0.01
Cl	0.28	0.03	0.03	0.06	0.10
K + Na separated with char as % of K + Na input with fuel		71%	70%	12%	3.6%
K + Na in gas, mg/kg wet gas		154	156	265	285

Table 3. Size distribution of wood powder

Size (mm)	*Weight %*
s>1	0.45
0.5-1.0	21.89
0.250-0.5	38.50
0.125-0.250	22.41
0.100-0.125	4.12
0.074-0.100	4.95
0.063-0.074	4.62
0.040-0.063	2.95
s<0.040	0.12
Sum	100.0
Mean value	0.368

Table 4. Experimental parameter ranges

Parameter	Specification/Range
Fuel feed rate	26 and 34 kg/h
Thermal input	137 kW
Injection media	Air or Air/Steam
Equivalence ratio	
- Air injection	0.16-0.32
- Air/Steam injection	0.30-0.40
Steam/Fuel ratio	0.5 and 0.8 kg steam/kg fuel
Cyclone pressure	Atmospheric
Gas temperature	
- Air injection	800-950°C
- Air/Steam injection	900-1000°C

6.0 Conclusion

The objective of this paper was to develop the understanding of the thermal distribution in the cyclone gasifier using sawdust and to characterize the temperature in order to produce minimal impact of alkali compounds to the damage of gas turbine. From the discussion presented in this paper, the following conclusions can be drawn:

- Since, sawdust produced in Malaysia as a fuel in this gasification process, so we must know the characteristics of this fuel. The size distribution of the fuel particles is important for the particles flow in downcomers. Injectors and cyclone. The size distribution also determines the time required for gasification and the carry-over of particles with the product gas.
- The cyclone wall temperature limits for stable gasification temperature were found to be in the range of 650–950°C. This interval of the allowable operation temperature of the cyclone gives equivalence ratios ranging from 0.25 to 0.21. The desired equivalence ratios were produced by adjustment of the air flow. A cyclone gasifier that is operated to generate a producer gas and char residue at a gas temperature of about 850°C will achieve significant separation of the Na and K supplied with the fuel.
- The observations from the cyclone gasifier also indicate that at least the alkali carried with the char particles that were separated in the cyclone was not gasified to a significant extent. This confirms conclusions drawn by others those equilibrium calculations overestimate the formation of gaseous and liquid phases of biomass ashes in gasifiers.
- In the cyclone gasifier, char is continuously separated and removed. The ash included in this char carries significant amounts of K and Na which are not going with the product gas flow. The reactions during the

gasification process also may not reach equilibrium conditions because of short residence time. The short residence time may therefore keep the alkali elements in a solid form and the volatilisation of these elements will not occur.

The alkali that left the cyclone with product gas appear to be in solid or melted phase in the unseparated char particles and consequently not vaporised during gasification.

As the Na and K were assumed to remain within the particles during gasification, it was concluded that to reduce the amount of alkali metals in the product gas it would be necessary to improve the particle separation efficiency.

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