Recent Decisions in Technologies for Sustainable Development

Selected, peer reviewed papers from the
3rd International Conference on
Sustainable Technology Development
(ICSTD 2014),
October 30-31, 2014, Bali, Indonesia

Edited by

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Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland
http://www.ttp.net

Volume 776 of
Applied Mechanics and Materials
ISSN print 1660-9336
ISSN cd 1660-9336
ISSN web 1662-7482

Full text available online at *http://www.scientific.net*

***Distributed** worldwide by*

Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland

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Preface

This volume was selected from papers presented at the 3rd International Conference on Sustainable Technology Development (ICSTD Bali 2014), which have been held in Udayana University Bali during October 30-31, 2014. The conference was organized by Faculty of Engineering, University of Udayana Bali Indonesia. This conference covered wide range of engineering issues toward the achievement of sustainablility.

In order to meet high standard of Applied Mechanics and Materials, the organization committee has made their efforts to do the following things. Firstly, all submitted papers have been reviewed by 2 anonymous expert reviewers, poor quality papers have been rejected after reviewing. Secondly, periodically review meetings have been held around the reviewers about three times for exchanging reviewing suggestions. Finally, the conference organization had several preliminary sessions before the conference. Through efforts of the scientific committee and Editors team, the volume will be the best collected papers.

We would like to thank the Faculty of Engineering, University of Udayana, the member of organizing and scientific committees, and also to TTP publisher.

Editors

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Applied Mechanics and Materials Vol 776 (2015) pp 300-306
Submitted: 2015-02-19
Accepted: 2015-04-10

doi:10.4028/www.scientific.net/AMM.776.300

Design of Fluidized Bed Co-Gasifier of Coal and Wastes Fuels

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Keywords: fluidized bed, co-gasifier, biomass, waste

Abstract. The solid waste produced from urban area is an urgent issue to be addressed. A fluidized bed (FB) gasification technology has been widely applied and proven effective to convert waste into clean energy and environmentally friendly. Co-gasification is a technique of mixing two or more fuels that aims to improve calorific value of the gas production. A FB gasifier reactor is designed using some previous experiments and available literature as well as from the internal experience of the research group. The gasification reactor pilot plant scale using data input of waste and biomass fuels has been fabricated with diameter of 0.7 m and a height of 1.5 m. The Tests have been performed showing that the FB gasifier is very feasible to be developed.

Introduction

The increased efforts of the need to reduce CO_2 emission to prevent global warming from power generation systems have led to an interest in biomass and wastes as fuel sources. As a potentially energy renewable resource, biomass and wastes are gaining more attention worldwide. The use of fluidized bed (FB) technology for waste and biomass fuels has expanded since the twentieth century either for energy recovery or wastes disposal. This technology is well known for its excellent gas-solid mixing and favorable emission characteristics. Pre-processing of biomass/wastes feeds to acceptable particle size and moisture content, usually necessary for conventional technologies, can then be minimized in fluidized bed operations, as long as it could be conveniently fed into the bed. FB technology is usually indicated to be the best choice, or sometimes the only choice, to convert alternative fuels to energy due to its fuel flexibility and the possibility to achieve an efficient and clean operation. It is also found that a high recovery of heat can be achieved, this is mainly due to the heat transfer coefficient in fluidized bed combustors is much greater than that of conventional combustion systems.

Looking at the future potential of urban waste, the high energy content within the waste is very urgent to utilize. Technology must find a feasible process which allows wastes to be converted as energy in an environmental way. Fluidized bed gasification is a promising technology that can convert energy from the low rank calorific solid fuel such as biomass and wastes into a combustible gas whose composition and heating value are greatly dictated by the type of gasifying agents. Because of the lower calorific values of waste fuels accompanied by flame stability problems, co-gasification currently holds more appeal than any of the sole source technologies including more advanced conversion options such as integrated gasification combined cycles. It is anticipated that co-gasification of waste fuels with coal will reduce flame stability problems, as well as minimize corrosion effects. The co-gasification of coal and wastes has the potential to reduce CO_2 emissions and the amount of pollutants as NOx and SOx. Co-gasification process has been widely studied using mixtures of several kind of feedstock such as waste fuels with other materials like coal and biomass even plastic waste [1,2].

The purpose of this study is to design a pilot plant of fluidized bed co-gasifier using coal and waste/biomass fuels and to investigate its performance.

Methodology

Pilot plant fluidized bed gasifier system was designed based on literature references available with innovations according to the fuel used. The calculation involves determining the dimensions of the reactor, fluidization velocity, distributor system, fuel feeder and other accessories complement the gasifier .

Reactor dimensions. A fluidizing reactor unit is developed as a place for reaction of a fuel with the medium gas gasification. Based on the reference of previous studies [3-5], the calculation steps to determine the dimensions of the gasifier reactor is based on the calculation of hydrodynamic parameters .

The first step is to determine the fraction of empty space (voidage) which is calculated as follows:

$$\varepsilon_{mf} = \left(1 - \frac{\rho_b}{\rho_p}\right) \tag{1}$$

where ε_{mf} , ρ_b, ρ_p is a voidage value at minimum fluidization, density of gasification agent and density of solid particles respectively.

The Archimedes Number (Ar) is then calculated by using the following equation:

$$Ar = \frac{g \times d_p^3 \times \rho_g \times (\rho_p - \rho_g)}{(\varphi)^2} \tag{2}$$

where g is gravity force, d_p is average diameter quartz sand, μ is viscosity of the gasification agent and φ is sphericity factor of bed material.

This research uses quartz sand as a bed material with solid density of 2180 kg/m^3 and specific heat of 0.20 kcal/kg^{o}C, which is well known to store heat during gasification process. The measuremet of sphericity and mean diameter of quartz sand using macro photo and Image-J software of 0,727 dan 492 μm respectively.

As Archimedes number is known, the *Reynold* (Re_{mf}) can be determined using *Ergun* equation as:

$$Ar = 150\frac{(1-\varepsilon_{mf})}{\varphi^2 \varepsilon_{mf}{}^3}\mathrm{Re}_{mf} + \frac{1{,}75}{\varphi\, \varepsilon_{mf}^3}\mathrm{Re}_{mf}^2 \tag{3}$$

Then, the minimum fluidization velocity can be simply calculated as:

$$U_{mf} = \frac{\mathrm{Re}_{mf} \times \mu}{\rho_g \times d_p} \tag{4}$$

Distributor plate. A distributor plate plays an important component to enhance a stable fluidization process. To ensure uniform fluidization, the type of distributor cap bubble tuyere consisted of 40 pieces points is equipped with two nozzles. To avoid an agglomeration on the distributor plate because of ash fuel melting, the plate was designed to rotate at speed of about 1 cm/s. The plate distributor arrangement and its component can be seen in Fig. 1.

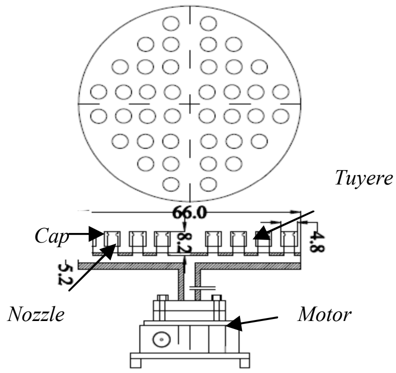

Fig. 1. Plate distributor and its component (size *in cm*)

Start-Up System. For the start-up system, an oil burner connected to the entrance of the plenum was selected. Preheating is set to the average temperature cross the bed on the overall of 600ºC quartz sand which is capable to generate auto ignition temperature of combustion and gasification.

Fuel Feeding. Fluidized bed gasification system is designed to gasify of waste/biomass fuels and coal so that the screw feeder assembly is selected to ensure the inclusion of the constant fuel mass flow rate of 30 kg/h. Fuel feeding subsystem as shown in Fig. 2 below along with air flow line to push fuel into the reactor at the same time ensuring the absence of back pressure.

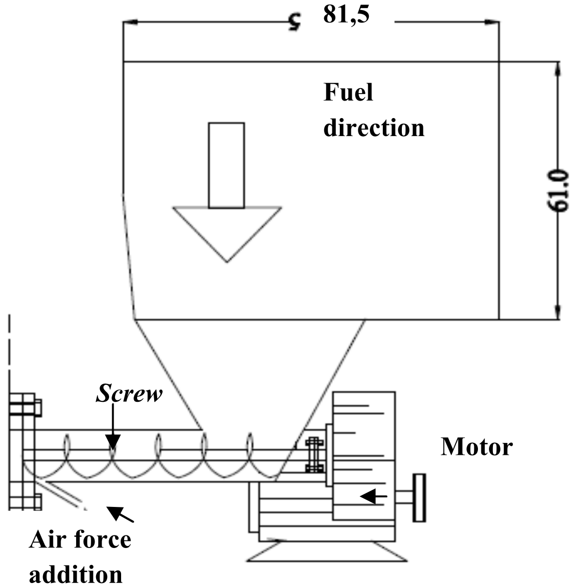

Fig. 2. Fuel Feeding Systems and Components (size in cm)

Cyclone. A Cyclone is a primary tool to separate between gas and fine particles in which the larger particles fall into the water reservoir. The produced gas goes to a cyclone dust collector connected to a water tank that also serves to prevent back pressure or explosion. Gas out of the cyclone associated with a heat exchanger system in which cold water continuously fed at a constant flow rate of 16.5 m^3/hr. Test data indicate that the gas cooling system is able to reduce the heat to 400 percent. The dimension and the size of cyclone and safety chamber subsystem are seen in Fig. 3

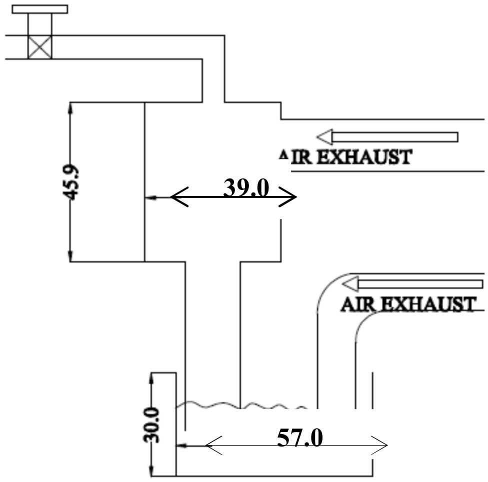

Fig. 3. Cyclone Systems and Components (size in cm)

Characterization of fuel. A characteristic of urban waste generated from city residents about 70 percent of the composition is organic waste, the rest is non-organic waste consists of plastic and tin cans. Demographic aspects such as socio-economic (tourism, shops, markets, household) be the biggest factor affecting the characteristics of the waste. Besides cultural factors, customs, and the local believe also plays an important role in the rate of waste production. Unlike fossil fuels, waste and biomass have the physical and chemical properties which are more difficult to process because of their physic and chemical content. Each type of biomass has its own content which affects the performance when used as fuel for combustion or gasification processes. To determine the parameter of each biomass and waste, the series tests including proximate, ultimate analysis and calorific value measurements of the fuel was done as seen in Table 1.

Tabel 1. Proximate and Ultimate Analysis

Parameter	Urban waste	Rice husk	Coal
Moisture (%)	12,59	11,92	4,5
Volatile (%)	81,65	72.16	23,1
Ash (%)	18,35	27.84	33,5
Carbon (%)	64,46	37,65	86,14
Hydrogen (%)	6,25	11,05	0,75
Nitrogen (%)	0,52	0,97	1,12
Sulfur (%)	0,05	0,06	0,56
Oxygen(%)	18,03	39,43	1,54
Calorie (kJ/kg)	16083	12569	20242

Result and Discussion

The result of calculation and modeling is used to design and fabricate of *pilot plant co-gasifier fluidized bed* of coal and wastes/biomass fuels. A fluidized bed gasifier unit as seen in the Fig. 4, is generally divided into two main parts, namely a reactor and supporting accessories. The reactor has a cylindrical shape with a diameter of 0.7 m and a height of 1.5 m, operated at fluidized bubbling bed mode with an atmospheric pressure. In this study, air is used as a gasification agent which distribution port is divided in two main points. Primary air is inserted from the bottom of the reactor through a distributor plate, while secondary air is added through the fuel channel feeder and oil burner port. Four thermocouples are mounted on the wall in the reactor to determine the temperature profile along the reactor and gasification processes. The reactor walls lined with refractory bricks to reduce heat loss to the environment. A sample of the fuel which is a mixture between coal and waste/biomass at the same time inserted continuously through the fuel screw feeder having a diameter feeding of 5 cm with volume of 0.3 m^3. To avoid thermal pyrolysis along the feeder line into the reactor an additional air channeled was added.

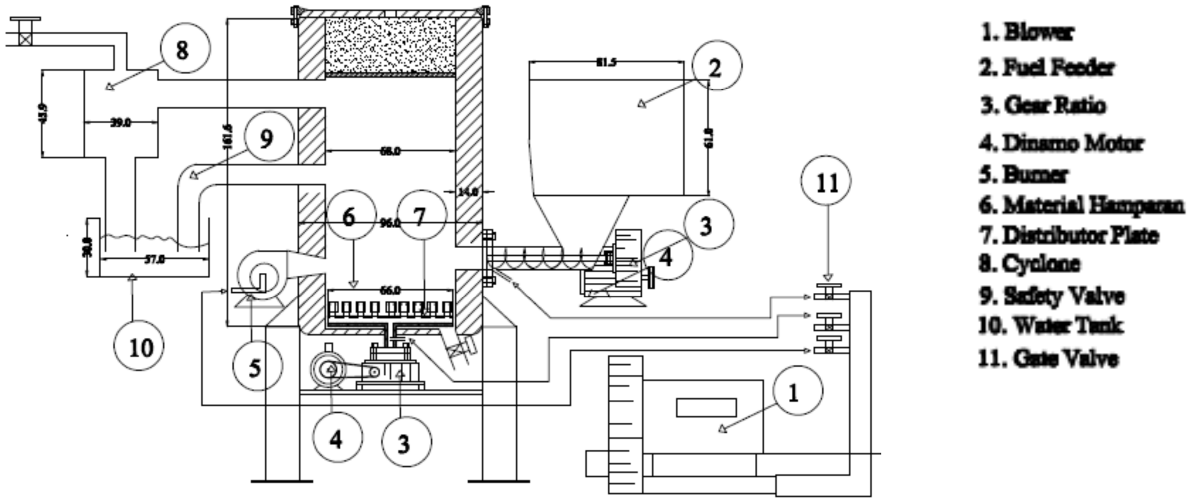

Fig. 4. Schematic of fluidized bed gasification system

Reactor temperature profile. During the operation, the reactor was heated up using oil burner until uniform temperature of 600ºC according to a design condition. The profile temperature was measured using 4-thermocouple from the bottom of the bed pointed from T_1 until T_4. The obtained temperatures of T_3 and T_4 (Fig. 5A) are relatively similar during start-up compared to the one for co-gasification of coal and rice husk (Fig. 5B). This is mainly due to the high volatile content of the waste and biomass fuels cause some gas lifted quickly by fluidization gas and burn that results in a rise in temperature.

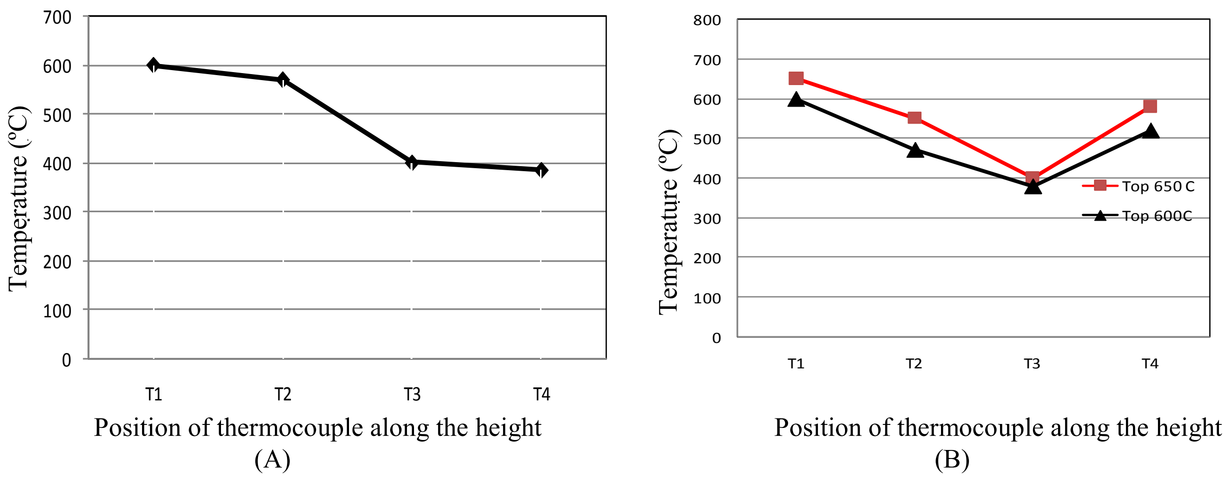

Fig. 5. Temperature distribution along vertical bed height at (A) *start-up* and (B) co-gasification of coal and rice husk

Equivalence Ratio. It is well recognized that the performance of gasifier depends mainly on the equivalence ratio range being used. This indicates that the minimal amount of air required oxidizing the fuel and generating enough heat to maintain the gasification endothermic process. The equivalence ratio on gasification process is the most important factors to justify the condition of operation. The value (ξ) is defined as:

$$\xi = \frac{(R_{A/C})_r}{(R_{A/C})_a} \qquad (6)$$

where $(R_{A/C})_r$ and $(R_{A/C})_a$ are the air fuel ratio stoichiometric and actual respectively.

The air-fuel stoichiometric relation was calculated from the expression belows [5]:

$$(R_{A/C})_s = 8{,}89.(\%C + 0{,}375\%S) + 26.5.\%H - 3.3.\%C \quad (7)$$

From the calculation model above the equivalence ratio of 0.35 was obtained.

FCR and AFR. To determine fuel composition rate (FCR) and air fuel ratio (AFR), the wellknown published model were used for calculation in which the increase amount of wastes and rice husk composition used an increase number of fuel feed and fuel was obtained as seen in Table 2. However, the length operation and flame time is contrary for both fuel combinations. This is mainly caused by the high content of volatile in the wastes/biomass fuels resulted in more easily to ignite and burn.

Table 2. Experimental data of operation and flame time, FCR and AFR

No.	Fuel	Mass Composition (%)	Fuel (kg)		Time (s)		FCR (kg/hr)	AFR (m^3/hr)
			Feeding	Ash	Operation	Flame		
1	Wastes + Coal	50 - 50	20	5	1875	1635	28.8	87.89
		60 - 40	20	4	1665	1470	34.59	105.57
		70 - 30	20	3.5	960	795	61.88	188.82
2	Rice Husk + Coal	50 - 50	20	5	1860	1605	29.03	88.59
		60 - 40	20	4.25	1680	1425	33.75	102.99
		70 - 30	20	2.85	1380	1320	44.74	136.53

Sampling. The experimental works were carried out under standard operating procedures for gasification. Fuel was inserted through the screw feeder with a capacity rate of 25 kg/hr. The fluidization velocity was set up at 0.253 m/s using adjustable valve. The sampling point is located just after the gas passing the heat exchanger unit. Gas samples collected and analyzed for major gas components by gas chromatography test. Parameters of a fluidized bed gasifier reactor design and composition of producer gas can be seen in Table 3. The increase in the bed temperature the amount of CO and H_2 concentrations was obtained to increase slightly.

Tabel 3. Design parameter and producer gas concentrations

No.	Reactor parameter	Fuel: Wastes, Biomass and Coal	
1.	Diameter (m)	0,7	
2.	Height (m)	1,5	
3.	Bed volume (m^3)	0,04	
4.	Bed height (m)	0,1	
5.	Bed weight (kg)	100	
6.	Gasification agent	Air	
7.	Bed temperatur (ºC)	600	650
8.	Equivalency Ratio	0,35	0,35
9.	CO (%)	7	10
10.	H_2 (%)	4	5
11.	CH_4 (%)	2,2	2,0
12.	N_2 (%)	50	48

Summary

Through a simple mathematical model calculations and practical basis, the design and size of the pilot plant of fluidized bed co-gasifier system can be developed. Initial performance test of the gasifier unit by increasing the concentration of wastes/biomass the FCR and AFR increased. The increase in the bed temperature the amount of syngas concentrations was obtained slightly increased.

Acknowledgement: This study was kindly supported by Indonesia's Ministry of Research and Technology through *Insentif Riset Sinas,* Contract No.: 60/SEK/INSINAS/CO/I/2013

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