EXPERIMENTAL AND COMPUTATIONAL STUDIES ON BUBBLING BED GASIFIER USING BIOMASS AS FEEDSTOCK FOR GREEN HYDROGEN PRODUCTION

A Proposal for Funding under

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Submitted to

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1. Project Title

Experimental and Computational studies on Bubbling Bed Gasifier using Biomass as Feedstock for Green Hydrogen Production

2. Project Proponents

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3. Introduction

All over the world most of the energy requirements are being met by burning fossil fuels. The energy consumption of fossil fuels and their derivatives has become a yardstick to determine whether the nation is a developed or a developing country in the world. Sustainable development can be achieved through energy conservation methods or renewable energy sources. Also, the greenhouse gas (GHG) emission reduction and carbon-trading through clean development mechanism (CDM) have gained significant prominence as a part of steps toward combating climate change (Ramaswamy 2016). Among the various renewable energy sources, the utilization of biomass could be a viable option for agriculture-dependent economy countries like India.

Many of the problems in wood gasification are related to the properties of the fuel. Although wood is a clean fuel with low nitrogen, low sulphur, and ash content, it is thermally unstable, which may lead to the formation of condensable tars in gasifiers resulting in problems such as choking and blockage of piping in its end-use (Devi et al. 2002).

Direct use of biomass suffers from disadvantages such as the low energy density of wood, typically 18 MJ/kg, in combination with its high moisture content as a result of its hygroscopic character, typically around 10 wt% even after drying. Higher gasification efficiencies can be achieved for fuels with low O/C ratios, such as coal, than for fuels with high O/C ratios, such as wood (Alganash et al. 2015). Firstly, it is due to the high chemical exergy of wood, which is not fully utilized when the wood is gasified. Secondly, the optimum temperature for wood gasification is rather low, below 700ºC, but higher gasification temperatures are required in practice, so that wood becomes over-oxidized in the gasifier. Therefore, highly oxygenated biomasses are not ideal fuels for gasifiers from an exergetic point of view.

4. Background and Motivation

A wide variety of conversion technologies is available for the production of fuels from biomass. Biomass conversion technology can be basically grouped into three categories as follows:
(1) Direct combustion
(2) Thermo-chemical conversion
(3) Biochemical conversion.

In direct combustion, air/oxygen supplied is generally higher than that of the stoichiometric limit. In the thermo-chemical conversion method, the biomass is raised to high temperature and depending on the quantity of oxygen supplied the process such as pyrolysis or gasification takes place. The biochemical conversion process is a low energy process and relies upon the action of bacteria which degrade complex molecules of biomass into simpler ones. Production of biogas (mixture of CH_4 and CO_2) from animal dung by anaerobic digestion is a good example of biochemical process.

Pyrolysis: The pyrolysis process includes the heating of biomass at temperatures of 500–900ºC in a closed chamber or reactor in the absence of oxygen. It is an irreversible chemical change, which is due to heat supplied in the absence of oxygen. This process yield mainly liquid fuel. In the absence of oxygen, the energy splits the chemical bonds and leaves the energy which is stored in biomass. As the temperature rises the cellulose and lignin break down to simpler substances that are driven off leaving a char residue behind.

Hydrogenation: It is a chemical reaction between hydrogen molecule (H_2) and another compound or element, ordinarily in the presence of a catalyst (Zainal et al. 2001). Typical hydrogenation reactions include the reaction of hydrogen and carbon monoxide to form methanol or hydrocarbons, depending on the choice of catalyst.

Anaerobic digestion: This method involves the microbial digestion of biomass. Anaerobic is a micro-organism that can live and grow in the absence of air or oxygen. The process takes place at a temperature of about 65ºC and requires moisture content of at least 80%. This produces gas that contains mostly CO_2 and CH_4 with minimum impurities.

Fermentation: Fermentation is a breakdown of complex molecules in organic compound under the influence of ferment such as yeast, bacteria, enzymes etc. It is a widely used technology for the conversion of grains and sugar crops into ethanol (ethyl alcohol) (Lin and Tanaka 2006) It can be mixed with gasoline to produce gasohol which is the mixture of 90% gasoline and 10% alcohol.

Gasification is a thermochemical process by which biomass/coal is converted into a mixture of combustible in presence of sub-stoichiometric air. Combustible products include CO, H_2, and other hydrocarbons. Gasification usually involves various reaction processes like drying, pyrolysis, oxidation, and reduction wherein drying stage moisture content is reduced up to 10% at temperatures of 100°C to 200°C (Susastriawan et al. 2017). In the pyrolysis stage thermal breakdown of biomass occurs without oxygen to release volatile matter to release carbon monoxide, carbon dioxide, methane, and hydrogen, and finally, solid carbon is obtained. Heterogeneous reactions involve the oxidation of solid carbon and release of carbon dioxide and water releasing an enormous amount of energy which is absorbed during pyrolysis and drying zone.

Further, the gasification systems are classified based on the gasifying agents, pressure, heat source, and reactor design which is depicted as shown in figure 1.1.

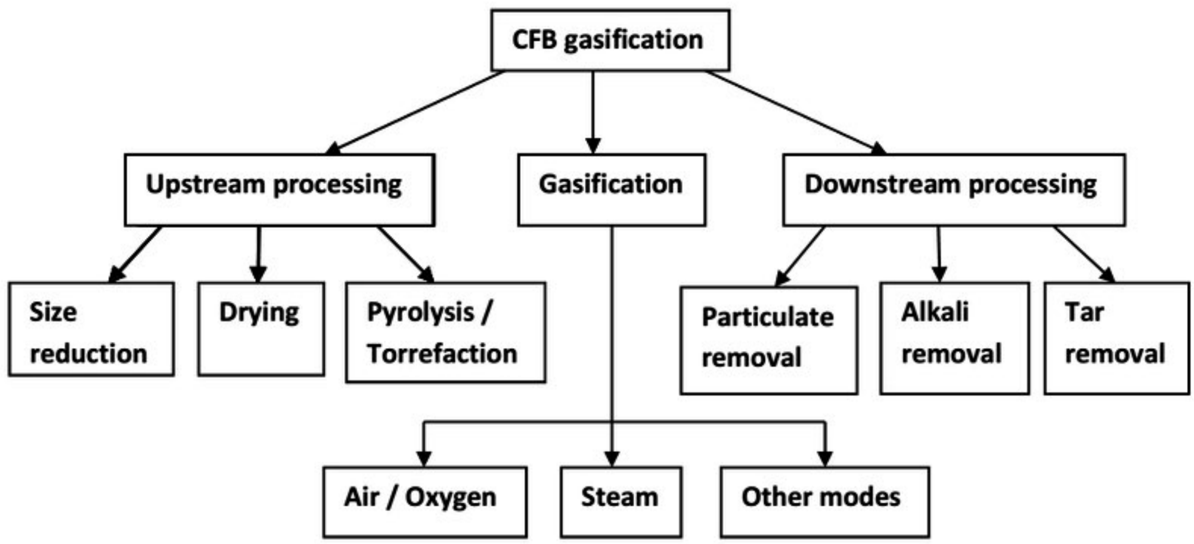

Figure 1: *Classification of Gasification system*

Depending upon whether the bed is movable or immovable, the reactors are classified into downdraft, updraft, cross draft, fluidized bed reactors. They have a very good characteristic like high-quality producer gas and low tar content but they have a severe drawback like blocking of gratings (Susastriawan et al. 2017). In downdraft gasifier biomass feedstock is subjected to drying in the first stage followed by pyrolysis, oxidation, and finally reduction process. Quality of producer gas depends directly on many factors like biomass characteristics, gasifier design, and biomass characteristics like size, density, elemental composition, fixed carbon, moisture content, volatile matter, and ash content which are obtained from the ultimate and proximate analysis. Most favourable property of the producer gas achieved at biomass pellet size of 1-2cm (Yin et al. 2012). Smaller the size of biomass, higher is the efficiency of gasification. Larger size leads to the reduction in reactivity of biomass and causes bridging and starting problem(Patel et al. 2014). Biomass with moisture content greater than 30% reduces the calorific value of Syngas**.** Depending upon pressure on the reactor, gasifiers are classified as pressurized and non-pressurized gasifiers. Finally, if the reactor is heated by external source then they are known as allothermal and if heat is provided by combustion itself it is called auto thermal reactors (Sheth and Babu 2009).

The major problems associated with the biomass is its moisture content, bulk density, bulk and low calorific value when compared to fossil fuels. Handling, storage and transportation of biomass become costlier than biomass fuel itself. To use the bio-waste very efficiently it is justified to elevate its calorific value by converting it into liquid form. Biomass gasification is the most promising way that can handle a wide variety of biomass extensively. It is the complex chemical process involving more chemical reactions, heat, and mass transfer fluid and has interactions with gasifying agents like air oxygen steam etc.

Summary of Literature review: Biomass gasification is an important technology component for expanding the use of renewable resource as a feed stock for power generations and generation of producer gas which has application in fuel cells etc. Wood, forest residue, rice husk, agro residue, high ash coals are abundantly found in India which can be used for decentralization of power for rural and hilly regions. Raw producer gas can be produced by gasification of biomass using different gasifying agents that has different applications.

The literature survey reveals that all the fluidized bed gasifier which was surveyed was a large scale fluidized bed gasifiers ranging anywhere between 20 to 80 MW per hour, handling such type of gasifier is a difficult task, it creates more pollution, preparation of pellets needed for such type of gasifiers requires larger time, heating of such gasifiers also takes a larger time so small scale fluidized bed will be built which can operate at the ranges from 1–2 kg per hour. Such kind of reactors can also be commercialized for home and small scale food industry.

The literature survey reveals that gasifying agents like air has larger concentration of nitrogen in its output gas and lesser concentration of hydrogen. Similarly, pure steam gasification has larger concentration of hydrogen in its output gas. Gasifying with CO_2 has larger concentration of Carbon monoxide. So depending the application of the product gas the gasifier agents can be set. Using Carbon dioxide as a gasifying agent for Co-gasification of high ash Indian coal has not been performed by any researchers, using CO_2 as a gasifying agents in fluidized bed gasification is very limited as it requires external heat as reactions inside the reactor are endothermic, so air can be mixed to make reaction slightly exothermic.

According the authors knowledge validation of the CFD model of the above experiment was performed by limited researchers in India. Cold flow and hot flow studies are performed extensively with many drag models, User defined function for heterogeneous reactions are used to get accurate results of the above performed experimental data. Based on the literature review following objectives were finalized. The details of the objectives are presented in following sub-sections.

1. Development of small scale fluidized bubbling bed gasifier for gasification with AIR CO_2 gasifying agent with cold flow analysis
2. Developing CFD model for cold flow for bubbling fluidized bed gasifier using barracuda virtual reactor
3. Experimentation on gasification of and biomass with validation
4. Experimentation on co-gasification of high ash Indian biomass
5. Development of modified Red-mud Catalyst

6. Project Abstract

Production of hydrogen using Biomass gasification is an important technology for expanding the use of renewable resource as a feed stock for power generations. The aim of this study was to develop a catalyst from red mud for the removal of tar and hydrogen enhancement and characterization of red mud before and after treatment like surface area, and pore size distribution.

Main draw backs of catalytic gasification process are the cost of the catalyst and its regeneration and disposal. The red mud is a waste by product of alumina production process is used as a catalyst for the upgradation. The catalysts is an excellent tool to be used for tracking of tars and converting them into lighter gases, and a lot of researches have investigated a various types of catalysts based on metals like Ni, Pd, Pt etc. However, the catalysts based on these metals are expensive which make the process unaffordable/expensive in larger scale production. The novelty of this project is based on

the application of modified red mud (MRM) supported Fe, ZSM-5 to be used as cheapest catalyst for cracking of formed tars within co-gasification process and transforming them into lighter gases. As well as, the expected results from this project will move forward the utilization of red mud waste as industrial honeycomb catalyst, and facilitate its further pilot test of MRM based catalyst in the conversion of tars into an additional energy sources.

Development of pilot scale fluidized bed gasifier for co-gasification with Air s gasifying agent.

Development of lab scale fluidized bed system operating on Co-gasification will be designed which can operate between 10 to 30 kg/ hour. Design of reactors and sub system was based on mass flow rate of biomass. Stoichiometric modeling will be developed to determine product gas variation with air factor, which is the key parameter in designing fluidized bed gasifiers. Based on the composition of product gas the density of product gas, higher heating value of the product gas, amount of air required for gasification, product gas volumetric flow rate, mass and energy balance, determination of retention time of product gases, reactor volume, average flow rate of gases, gasifier internal diameter , minimum fluidization velocity, Superficial velocity, terminal velocity, operational velocity, drag coefficient on particles, Reynolds number

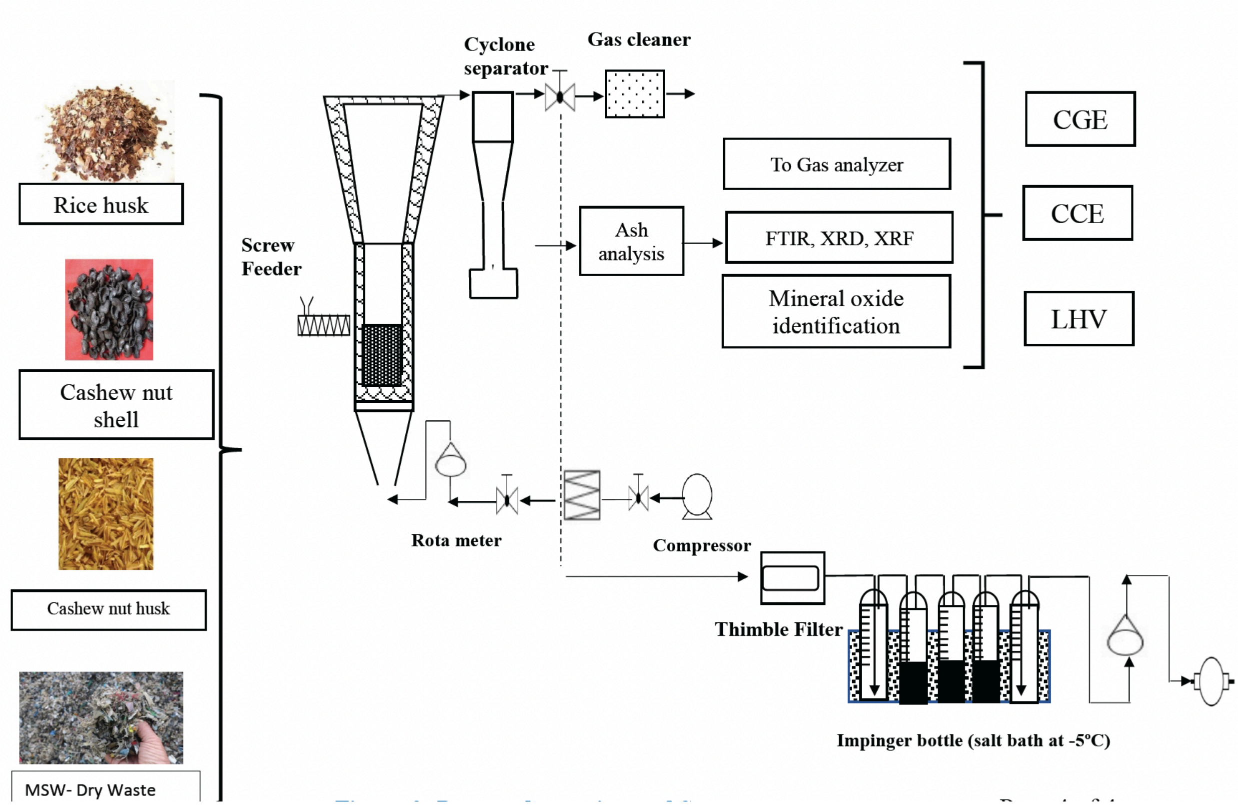

Figure 2: *Flow diagram of bubbling bed gasifier*

of flow, sand diameter, bubble diameter, determination of free board height and bed height, design of distributor plate, Calculation of the minimum pressure drop over the distributor, Reynolds number for the total flow approaching the distributor, velocity of the gas through the orifices, Number of Orifices needed, total pressure drop and compressor sizing was calculated and verified.

7. Contact Details

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8. Why this Project?

The application and the utilization of the proposed bench-scale fluidized bed gasification unit is to perform the gasification of a variety of carbonaceous feedstock like biomass, plastic, waste material etc. for the production of synthetic gas (syngas) or producer gas having major constituents as CO, CO2, H2 gases. The product syngas could further be utilized for the production of value-added chemicals such as Methanol, Di Methyl Ether etc. The proposed gasification unit would also comprise of a gas analyzer/detection system for the quantitative analysis of product gas.

9. Objectives

The details of the objectives are presented in following sub-sections.

1. *Development of small scale fluidized bubbling bed gasifier for gasification with AIR CO_2 gasifying agent with cold flow analysis:* Development of lab scale fluidized bed system gasifier will be designed which can operate between 1 to 2kg/ hour. Design of reactors and sub system was based on mass flow rate of biomass
2. *Developing CFD model for cold flow for bubbling fluidized bed gasifier using barracuda virtual reactor:* The developed models need to be validated so in-depth cold flow analysis is carried out using different drag models like Syamlal-O-Brien,

Gidaspow, Mckeen, Representative Unit Cell for determining some of the parameters which will indicate the efficiency of fluidized bed.

3. *Experimentation on gasification of biomass with validation:* Experimental investigations are conducted for gasification of biomass using air and CO_2 as a gasifying agent. Effects of equivalence ratio, temperature, biomass particle size on molar gas concentration of product gases are studied. Numerical validations for the above experiment are carried out.
4. *Experimentation on co-gasification of high ash Indian biomass:* Experimental investigations are conducted for Co-gasification of rice stubble using air and CO_2 as a gasifying agent. Effects of equivalence ratio, temperature, and biomass particle size, gasification performance on different blends of coal and biomass ratio and its impact on molar gas concentration of product gases are studied.
5. *Development of modified Red-mud Catalyst*

9. Expected outcomes and benefits from the project

1	Viable and low cost green hydrogen production technology
2	Cheap Novel red-mud catalyst for utilisation in biomass gasification
3	Steam production from syngas for Par boiling in rice mills
4	Sustainability and reducing the global air pollution level
5	Waste to energy with Minimum environmental effect

10. Resource Requirements

1st Year/Phase-I		
	List of Non-recurring expenditure	**Amount (Rs. in lakhs)**
1	Solid feeding and measuring unit	1.5
2	Gas Injection System	1.0
3	Steam Injector & preheater/mixing system	1.5
4	Integrated continuous Gasification system	2.0
5	Product separation, collection & measurement section	1.0

6	Necessary fixtures and accessories to operate the gasification unit continuously	1.0
	Total	8
	List of Recurring expenditure	**Amount (Rs. in lakhs)**
1	Chemicals, Glassware , Plastic Ware & Biological Specimen	0.6
2	Electrical & Electronics spare parts/any other related items	0.075
3	Mechanical Spare parts / any other related items	0.075
4	Contingency	0.6
5	Books & Journal	0.05
	Total	1.4
	2nd Year/Phase-II	
	List of Non-recurring expenditure	**Amount (Rs. in lakhs)**
1	CPFD's Barracuda Virtual Reactor	5.0
2	Gas chromatography	24.0
	Total	29.0
	List of Recurring expenditure	**Amount (Rs. in lakhs)**
1	Chemicals, Glassware , Plastic Ware & Biological Specimen	0.6
2	Electrical & Electronics spare parts/any other related items	0.075
3	Mechanical Spare parts / any other related items	0.075
4	Contingency	0.6
5	Books & Journal	0.05
	Total	1.4
	Grand Total (1st Year & 2nd Year)	**39.8**

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