PROJECT REPORT ON

DEVELOPMENT OF GASIFIER SUITABLE FOR NON-WOODY BIORESIDUES FOR ELECTRIC POWER GENERATION

Submitted to

Department of Science, Technology and Environment, Govt. of Puducherry

Prepared by

L. Kumararaja
Senior Lecturer

Department of Mechanical Engineering

PONDICHERRY ENGINEERING COLLEGE

(Sponsored by Govt. of Puducherry and affiliated to Pondicherry University)

Puducherry – 605 014.

Ph. Nos: 0413-2655281-287 Website: www.pec.edu
Fax No : 0413-2655101

DEVELOPMENT OF GASIFIER SUITABLE FOR NON-WOODY BIORESIDUES FOR ELECTRIC POWER GENERATION

ACKNOWLEDGEMENTS

The project titled "Development of gasifier suitable for non-woody bioresidues for electric power generation" has analyzed the possibility of using loose bioresidues through gasification in a better way.

At the outset, I thank **Dr. K. Subbarayudu,** Head of Department of Mechanical Engineering, Pondicherry Engineering College, for his support in the execution of the project and also for allowing me to use the facilities available in the department.

I am grateful to **Dr. T. G. Palanivelu**, former Principal and **Dr. V. Prithviraj**, Principal, Pondicherry Engineering College, for their help in the procurement of equipments pertaining to the project. I gratefully acknowledge the support of B.Tech (Mechanical) and M.Tech (Energy Tech.) students who did their project works related to this developmental project. It is my duty to thank all those who are in one way or other connected with the project.

This project was executed with the financial grant from Department of Science, Technology and Environment (DSTE), Government of Puducherry. I express my deep gratitude to DSTE for funding the project.

L. KUMARARAJA

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The availability of bioresidues from various agricultural activities has been estimated to be around 300 million tones per year in India. A considerable portion of this quantity is getting wasted. The problems associated with bioresidues are their undesirable characteristics, irregular availability, etc. Several methods have been developed to utilize them for meeting our energy requirements. One such method is the thermo-chemical conversion called gasification. Most of the existing biomass gasification plants have packed bed type of gasifiers consuming wood pieces or bioresidues in briquetted form. When loose bioresidues are used in packed bed gasifiers, certain operational problems arise. This is due to the distinct characteristics of loose bioresidues vis-à-vis that of wood pieces or briquettes. The distinct physical characteristics of loose bioresidues which influence the operation of gasifier are shape, size, voidage, bulk density, apparent particle density, etc. The distinct chemical characteristics of such bioresidues are moisture content, ash content, ash fusion temperature, ash deformation temperature, etc. These characteristics control the design and operation of gasifiers. As part of this project, a versatile gasifier with a feeding rate of about 4-6 kg/h of bioresidues depending upon their type, was designed and fabricated. First, the properties of certain loose biomass were determined. Bulk density, apparent particle density, bed voidage, superficial air velocity and surface area of bed per unit volume were determined for certain non-woody loose bioresidues. Second, the pressure distribution along the gasifier axis was determined for each type of biomass namely, wood pieces, wood shavings, saw dust, coir pith, groundnut shells and charcoal when gasification air was passed through the packed bed of biomass maintained in the gasifier. Third, non-woody bioresidues like coir pith, groundnut shells and charcoal were gasified and the results were compared with that of wood pieces. Groundnut shells could be gasified easily when compared to coir pith. There was absolutely no problem with charcoal gasification and it was much better than wood pieces gasification.

Chapter 1

INTRODUCTION

1.1 Biomass

India being a developing nation, sustainable development is more important. Energy is an important factor for any developing country. Ever increasing consumption of fossil fuels and rapid depletion of known reserves are matters of serious concern in the country. The utilization of renewable energy sources is an effective approach towards alleviating these constraints. In this context, biomass stands out as a promising source of energy. The term - biomass - generally refers to all the products of photosynthesis. However, in Energy Engineering parlance the term - biomass - is used only to the portion of plant matter from which thermal energy or mechanical energy is derived. After extracting various benefits from all types of flora, the resulting biomass is called bioresidues. These bioresidues / biomass are utilized to produce thermal energy or mechanical energy. The utilization of biomass for energy generation can also play an important role in reduction of green house gases, reclamation of wastelands and socio-economic development of rural people.

1.2 Gasification

There are several techniques available for biomass-to-energy conversion. They are broadly classified as (i) thermo-chemical conversion methods and (ii) bio-chemical conversion methods. Under the first category, (i) combustion, (ii) gasification, and (iii) pyrolysis are the methods. In this project, the aim is to utilize bioresidues to produce thermal energy or mechanical energy by gasification. In this method, solid biomass is converted to a gaseous fuel which is then burnt to produce thermal energy or mechanical energy. The gaseous fuel is called as producer gas. When it is burnt in a gas burner it produces thermal energy which can be utilized for any heating application. On the otherhand, if the gas is burnt in an internal combustion engine, it produces mechanical energy which can be utilized in any work absorbing device like electrical generator, pump, compressor etc.

1.3 Issues in large scale usage

Biomass usage necessitates a good knowledge about them and their availability. Careful local surveys of biomass availability and the seasonal variations of quantities and costs are essential for the selection of the conversion technology, equipment, plant design and plant rating. For power plants which require large quantities of biomass every day, careful planning, organization and management of the biomass chain become critical. Some of the possible problems related to biomass management and over use should be clearly recognized when planning and implementing such projects. These include possible deprivation of cooking fuel for poorer sections, deprivation of soil organic matter to the surrounding land, and over capacity of planned power plants compared to the availability of the biomass in the neighborhood. Agro forestry and energy plantations should be carefully planned and integrated in the local demographic and climatic conditions. Local uses of biomass for other purposes will also compete.

Chapter 2

LITERATURE REVIEW

2.1 Review of articles

Before beginning the project, an extensive literature survey was done. Many articles published in scientific journals relating to the title of the project were collected and studied. The abstracts of few such papers are presented below:

2.1.1

E. M. H. Khater *et al*., [1] in their paper on '*Gasification of rice hulls',* have discussed the behaviour of a downdraft gasifier of 30 cm diameter and 140 cm height using rice hulls as a fuel. Feeding rates of 1.3-5.1 kg h^{-1} and airflow rates of 2-4.44 m^3 h^{-1}, which corresponds to 26- 55 % of the stoichiometric amount needed for complete combustion, were used. The maximum temperature attained was found to lie between 570ºC and 820ºC. At an air to fuel ratio of 55 % of that of stoichiometric case, the maximum yield of combustible constitutents in the producer gas was attained. The obtained gas had a composition including 13.67% CO, 5.13% H_2 and 2.42 % CH_4.

2.1.2

Valentino M. Tiangco *et al*., [2] in their paper on *'Optimum specific gasification rate for static bed rice hull gasifiers',* have explained the experimental determination of the optimum specific gasification rate for static bed rice hull gas producers which was conducted for reactor diameters of 16-30 cm. All experiments were performed with reactors under suction from a throttled centrifugal blower. Cold-gas efficiency was observed to increase as specific gasification rate increased from 100 to 200 kg/h m^{-2}, and then begin to decline as gasification rate was increased further. The decline in efficiency at higher gasification rates was due to decreasing gas heating value which could not be compensated by increasing gas flow.

2.1.3

Anil Kr Jain *et al*., [3] have published a paper titled *'Determination of reactor scaling factors for throatless rice husk gasifier'*. Four open core throatless batch fed rice husk gasifier reactors having internal diameters of 15.2, 20.3, 24.4 and 34.3 cm were designed and fabricated. Each reactor connected with gas cleaning unit was tested for its performance characteristics. Gas quality, gas production rate, gasification efficiency, specific gasification rate and equivalence ratio were determined for every run on each of the four reactors. It was found that for each reactor the gasifier performance was the best at a specific gasification rate of around 192.5 kg/h-m^2.

2.1.4

M. Dogru *et al*., [4] have described *'Gasification of hazelnut shells in a downdraft gasifier'*. A pilot scale downdraft gasifier was used to investigate gasification potential of hazelnut shells. A full mass balance has been reported including the tar production rate as well as the composition of the produced gas as a function of feed rate. Additionally, the effect of feed rate on calorific value, composition of the product gas and associated variations of gasifier zone temperatures were determined with temperatures recorded throughout the main zones of the gasifier and also at the gasifier outlet and gas cleaning zones. Pressure drops were also measured across the gasifier and gas cleaning system because the produced gas might be used in conjunction with a power production engine. It is important to have low pressure drop in the system.

2.1.5

Jae Ik Na *et al*., [5] have explained about waste gasification in their paper on *'Characteristics of oxygen-blown gasification for combustible waste in a fixed-bed gasifier'*. With increasing environmental considerations and stricter regulations, gasification of waste is considered to be a more attractive technology than conventional incineration for energy recovery as well as material recycling. The experiment for combustible waste mixed with plastic and cellulosic materials was performed in a fixed-bed gasifier to investigate the gasification behaviour with the operating conditions. Waste pelletized to a diameter of 2-3 cm and 5 cm length, was gasified in the temperature range 1100-1450ºC. The composition of H_2 was in the range 30-40 % and CO 15-30 % depending upon the oxygen/waste ratio. From the experimental results, the cold gas efficiency was around 61 % and the heating values of product gases were in the range of 2800-3200 kcal/Nm^3.

2.1.6

R. N. Singh *et al.,* [6] in their paper on *'Feasibility study of cashew nut shells as an open core gasifier feedstock'* have presented the results of investigation carried out in studying the fuel properties of cashew nut shell and its gasification feasibility in open core down draft gasifier. Cashew nut shell was converted to producer gas in an open core down-draft gasifier whose performance was evaluated in terms of fuel consumption rate, calorifc value of producer gas and gasification efficiency at different gas flow rates. It was found that producer gas calorific value and volumetric percentage of its combustible constituents, along with gasification efficiency, in general, increased with the increase in gas flow rate.

Chapter 3

BIOMASS AND THEIR PROPERTIES

3.1 Biomass resource base

The broad biomass resource base is comprised of agricultural crop residues, feedstock produced on energy farms, manure from confined livestock and poultry operations, wood and bark mill residues from primary wood product manufacturing plants, bark residues from the wood pulp industry, logging residues from timber harvesting operations, non-commercial components of standing forests and the organic fraction of municipal solid wastes. Overall, it appears that there is a resource base of significant size and that this base will in all probability be expanded in future as harvests increase and as energy farming needs and technologies develop. The overall biomass resources can be broadly categorized into (i) woody biomass and (ii) non-woody biomass.

3.1.1 Woody biomass

Woody biomass is characterized by high bulk density, less voidage, low ash content, low moisture content, high calorific value. Because of the multitude of advantages of woody biomass its cost is higher, but supply is limited. Woody biomass is a preferred fuel in any biomass-to-energy conversion device; however its usage is disturbed by its availability and cost.

3.1.2 Non-woody biomass

The various agricultural crop residues resulting after harvest, organic fraction of municipal solid wastes, manure from confined livestock and poultry operations constitute non-woody biomass. Non-woody biomass is characterized by lower bulk density, higher voidage, higher ash content, higher moisture content, and lower calorific value. Because of the various associated drawbacks, their costs are lesser and sometimes even negative.

3.2 Biomass properties relevant to gasification

An understanding of the structure and properties of biomass materials is necessary in order to evaluate their utility as chemical feedstocks. Chemical analysis, heats of combustion and formation, physical structure, heat capacities and transport properties of biomass feedstocks and chars are more relevant in the gasification of any biomass.

3.2.1 Bulk Chemical Analysis

In evaluating gasification feedstocks, it is generally useful to have proximate and ultimate analyses, heats of combustion and sometimes ash analyses. These provide information on volatility of the feedstock, elemental composition and heat content. The elemental analysis is particularly important in evaluating the feedstock in terms of potential pollution. The low energy density of biomass makes them less preferred by the people when compared to fossil fuels like gas, oil and coal.

3.2.2 Physical properties

The major physical data necessary for predicting the thermal response of biomass materials under pyrolysis, gasification and combustion reactions are shape, size, voidage, thermal conductivity, heat capacity, diffusion coefficient and densities viz. bulk density, apparent particle density and true density. The values of these properties are different for different biomass especially in the case of loose biomass. The methods of determination of some of these properties of biomass are explained in the chapter titled 'Experiments'; their values are listed in the chapter titled 'Results and Discussion'.

Chapter 4

BIOMASS GASIFICATION

4.1 Gasification

Gasification is the thermo-chemical conversion of a solid or liquid fuel into a gaseous fuel. The conversion of biomass into a gaseous energy carrier by means of partial oxidation is carried out at high temperatures. The product gas thus formed is called producer gas. It consists of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen.

The gasification of biomass is accomplished by supplying sub-stoichiometric quantity of air in an air sealed, closed chamber under slight negative or positive pressure. It is a complex reaction mechanism. It consists of four steps namely, drying, devolatilization, oxidation and reduction carried out one after another in a downdraft gasifier. Splitting of the gasifier into strictly separate zones is not realistic, but nevertheless conceptually essential.

4.2 Stages in Gasification

4.2.1 Drying

Biomass consist of moisture ranging from 5 to 35%. At temperatures above 100°C, water is evaporated. While drying, biomass do not experience any kind of decomposition.

4.2.2 Devolatilization

Devolatilization involves the release of three kinds of products: solid, liquid and gases. The ratio of products is influenced by the chemical composition of biomass and the operating conditions. The heating value of gas produced during this process is 3.5 – 8.9 MJ/m^3. The gas contains high molecular weight condensable hydrocarbons. In an open top downdraft gasifier, because of the downward passage of air through the bed, these hydrocarbon gases react with air stream thus undergoing combustion.

4.2.3 Oxidation

Oxygen present in air is partially consumed in the combustion of hydrocarbon gases while the rest is consumed in the heterogeneous reaction with char produced after devolatilization. Oxidation takes place at a high temperature of 700-1400°C.

$C + O_2 \leftrightarrow CO_2 + 393.8$ MJ/kgmol

Hydrogen in fuel reacts with oxygen in the air, producing steam.

$H_2 + \frac{1}{2} O_2 \leftrightarrow H_2O + 239$ MJ/kgmol

4.2.4 Reduction

In the reduction zone, a number of high temperature chemical readtions take place in the absence of oxygen. The principal reactions that take place in reduction zone are mentioned below:

Boudouard reaction: $CO_2 + C \leftrightarrow 2CO - 172.6$ MJ/kgmol

Water- gas reaction: $C + H_2O \leftrightarrow CO + H_2 - 131.4$ MJ/kgmol

Water shift reaction: $CO + H_2O \leftrightarrow CO_2 + H_2 + 41.2$ MJ/kgmol

Methane production reaction: $C + 2H_2 \leftrightarrow CH_4 + 75$ MJ/kgmol

Main reactions show that heat is required during the reduction process. Hence, the temperature of gas goes down during this stage. If complete gasification takes place, no carbon is left over; only ash is formed. The schematic of a downdraft gasifier is shown in fig. 4.1.

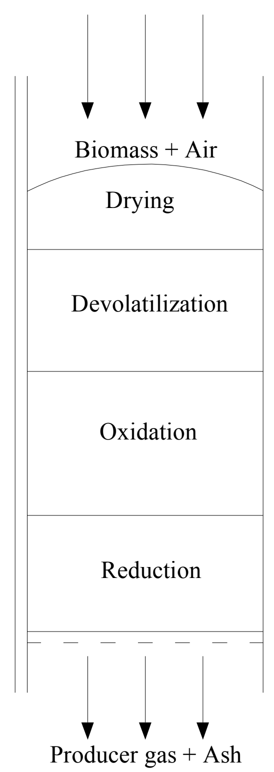

Fig 4.1 Sequence of reactions in downdraft gasifier

4.3 Gasifier

Gasifier is a chemical reactor where various complex physical changes and chemical reactions take place. Any variety of biomass like wood, agricultural wastes, roots of various crops, maize cobs, etc. can be gasified in the gasifier. Biomass gets dried, devolatilized, oxidized and reduced, as it flows through the gasifier. The exit producer gas has a heating value of about 4000-5500 kJ/m^3.

4.4 Types of Gasifiers

The gasifiers are classified in many ways. One type of classification is based on the gas flow direction in the gasifier. Accordingly the gasifiers are classified as:

- Updraft gasifier
- Downdraft gasifier
- Twin-fire gasifier
- Cross draft gasifier
- Other types of gasifiers

4.4.1 Updraft gasifier

Air is introduced at the bottom and flows upwards against the fuel movement. An updraft gasifier otherwise called as counter-current gasifier (fig. 4.2) has clearly defined zones for partial combustion, reduction, devolatilization / pyrolysis and drying. The producer gas is drawn at the top of the gasifier. The updraft gasifier achieves higher efficiency, since the hot producer gas passes upwards through raw biomass bed, thus preheating it before leaving the gasifier. The sensible heat of gas is used to preheat and dry the fuel. The disadvantages of updraft gas producer are excessive amount of tar in raw gas and poor loading capability. Hence it is not suitable for running internal combustion engines.

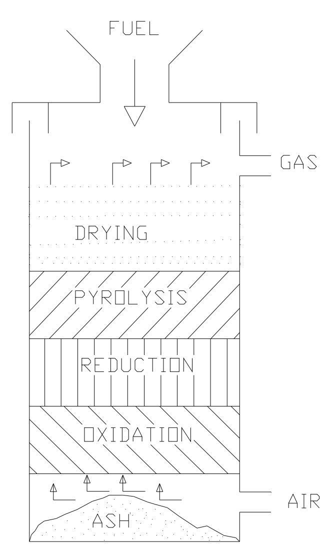

Fig 4.2 Updraft gasifier

4.4.2 Downdraft gasifier

In the updraft gasifier, producer gas leaves the gasifier with high tar content which may seriously affect the operation of internal combustion engines. This problem is minimized in downdraft gasifier also called as co-current gasifier (fig. 4.3). In this type, air is introduced at a higher level; flows downwards through the biomass bed and producer gas is drawn out at the bottom. A lower efficiency and difficulties in handling higher moisture content and ash content biomass are common problems in small downdraft gasifiers. The time needed to ignite and bring the plant to working condition generating good quality gas is shorter than that required for updraft gasifier. This gasifier is preferred to updraft gasifier for running internal combustion engines.

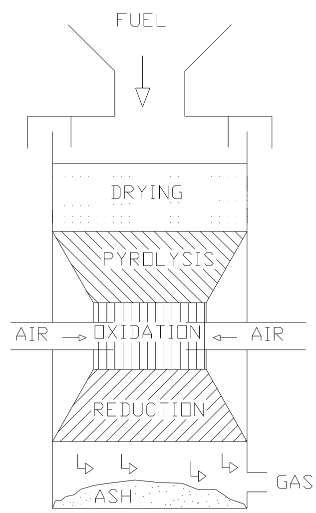

Fig 4.3 Downdraft gasifier

4.4.3 Twin-fire gasifier

The advantages of co-current and counter-current gasifiers are combined in twin-fire gasifier (fig. 4.4). It consists of two well defined reaction zones. Drying, low-temperature carbonization and cracking of gases occur in the upper zone, while permanent gasification of charcoal takes place in the lower zone. The gas temperature lies between 460 to 520 ºC. Twin-fire gasifier produces fairly clean gas.

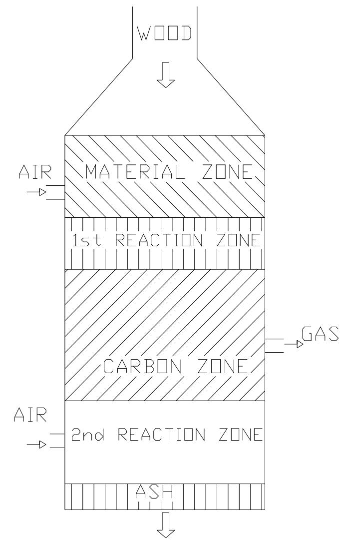

Fig 4.4 Twin-fire gasifier

4.4.4 Cross draft gasifier

Although cross draft gas producers have certain advantages over updraft and downdraft gasifiers, they are not ideal. The disadvantages such as high exit gas temperature, poor CO_2 reduction and high gas velocity are the consequences of the design. Unlike downdraft and updraft gasifiers, the ash bin, fire and reduction zones in cross draft gasifiers are separate. These design characteristics limit the type of fuel usage restricted to only low ash fuels such as wood, charcoal and coke (fig. 4.5). The load following ability of cross draft gasifier is quite good due to concentrated zones which operate at temperatures up to 1200ºC. Start up time (5 - 10 minutes) is much faster than that of downdraft and updraft units. The relatively higher temperature in cross draft gas producer has an obvious effect on exit gas composition such as high carbon monoxide, and low hydrogen and methane content when dry fuel such as charcoal is used. Cross draft gasifier operates well on dry air blast and dry fuel.

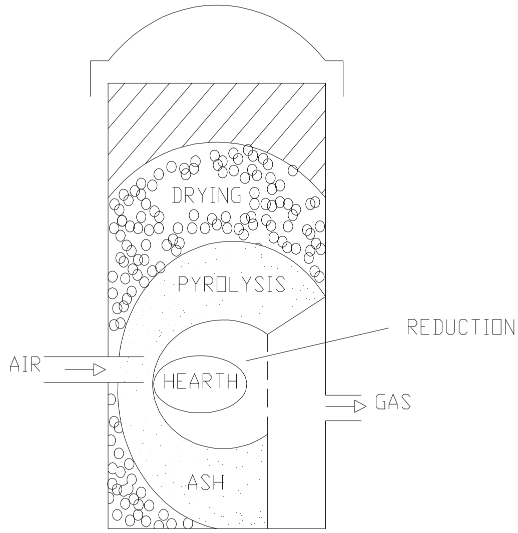

Fig 4.5 Cross draft gasifier

4.4.5 Other types of gasifiers

Although updraft, downdraft or cross draft gas producers have been the most commonly built types, there is a wide variety of gasifiers which do not really fit into any of these categories and are classified as other gas producers. Some units are built to combine the advantages of cross draft with downdraft or updraft gas producers.

4.5 Producer gas and its constituents

Producer gas is a mixture of combustible and non-combustible gases. The heating value of producer gas varies from 4.5 to 6 MJ/m³ depending upon the proportion of its constituents. When atmospheric air is used as gasification agent, the producer gas consists of mainly carbon monoxide, hydrogen, carbon dioxide and nitrogen. The general composition of producer gas obtained by wood gasification is given in table 4.1 on volumetric basis.

Table 4.1 General composition of producer gas

Carbon monoxide	18-22 %
Hydrogen	13-19 %
Methane	1-5 %
Heavier hydrocarbons	0.2-0.4 %
Carbon dioxide	9-12 %
Nitrogen	45-55 %
Water vapour	4 %

Carbon monoxide is produced from the reduction of carbon dioxide and its quantity varies from 18 to 22 % on volume basis. Although carbon monoxide possesses higher octane number of 106, its burning velocity is low. As it is toxic in nature, operator needs to be careful while handling the gas.

Hydrogen is also a product of reduction process in the gasifier. Hydrogen possesses an octane number of 60-66 and it increases the burning velocity of producer gas. Methane and hydrogen are responsible for higher heating value of producer gas. Carbon dioxide and nitrogen are non-combustible gases present in the producer gas. Higher percentage of carbon dioxide indicates incomplete reduction. The presence of water vapour in producer gas is due to the moisture content in air introduced during oxidation, the injection of steam in gasifier or the moisture content of biomass.

Chapter 5

DEVELOPMENT OF GASIFICATION SYSTEM

5.1 Gasification system

The complete gasification system for electric power generation consists of (i) biomass gasifier, (ii) a number of equipments for gas cooling and cleaning and (iii) internal combustion engine + electrical generator. Refer fig. 5.1. The gas cooling and cleaning are basically unit operations which are carried out in different types of devices namely cyclone separator, dust filter, gas cooler, etc. The flow of producer gas through the system is caused by engine suction augmented by a blower. The project

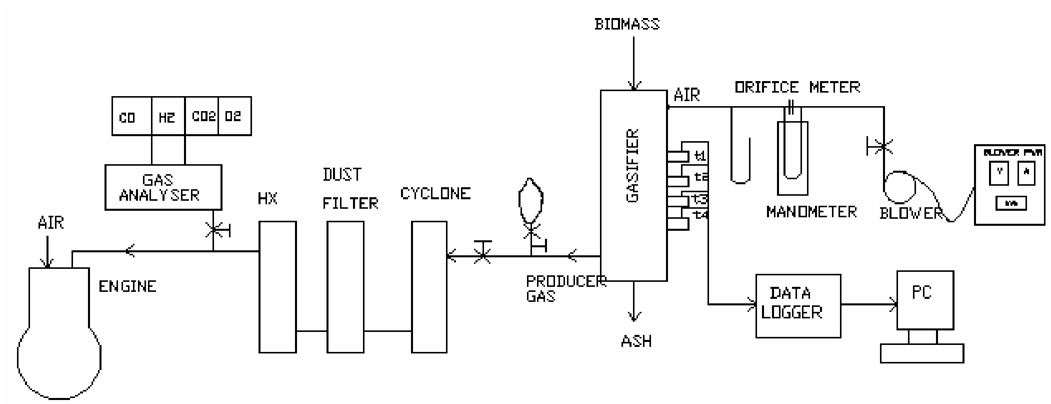

Fig: 5.1 Schematic of biomass gasification system

was initially contemplated to include all these essential elements in the gasification system. But with the available fund, only the most essential components of the gasification system have been fabricated and tested so far. It is shown in fig.5.2.

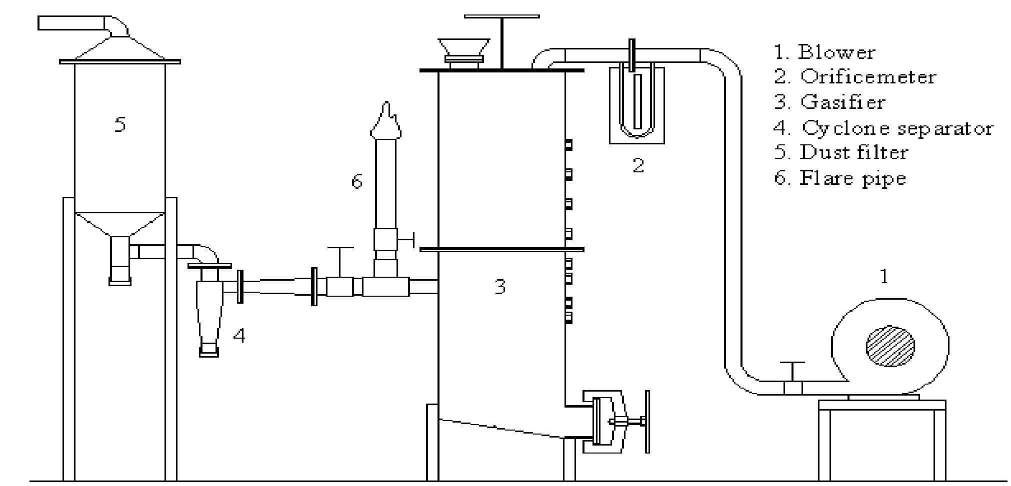

Fig. 5.2 Experimental gasification system

5.2 Downdraft gasifier for wood and briquettes

Most of the biomass gasification plants have packed bed type of gasifiers consuming wood pieces or briquettes. With this background information, a versatile downdraft biomass gasifier of feeding rate 4-6 kg/h was designed and fabricated. It was developed in such a way that it can generate producer gas sufficient to drive a 5 h.p engine.

The experimental system consists of blower, gasifier, cyclone separator, dust filter and a flare pipe. The motorized blower supplies air to the gasifier. The gasifier is a packed bed reactor of variable configuration type i.e., it can be used as downdraft, updraft, throat type or throat less type gasifier. It can be operated by blowing air from the air blower or by sucking air through the gasifier by means of the blower or an i.c. engine. Depending upon the requirements, any particular configuration can be chosen and used for any type of biomass to conduct the experiment. The air supply from the motorized blower is regulated by a valve. The air flow adjustment is important for uninterrupted and successful operation of gasifier. The air flow rate is measured by an orifice meter made of stainless steel. Air enters the gasifier through an air inlet pipe at the top. The biomass is fed through a feeding port, which is also provided at the top of gasifier. The biomass feeding port is kept closed during operation of gasifier and opened only during feeding. The gasifier is a cylindrical shell with provisions for pressure and temperature measurements. Tappings are provided along the cylindrical shell of the gasifier at regular intervals. The gasifier is lined inside with refractory cement to withstand high temperature. The ash accumulated in the ash chamber due to continuous operation of the gasifier is removed through an ash port. Refer fig. 5.3.

The producer gas exiting the gasifier is passed to a cyclone separator to remove larger dust particles. Then it is sent to a dust filter for hot gas cleaning. In this filter, the gas passes through filter elements fabricated of SS sieve (No. 100). There is also a provision to flare the gas directly after the gasifier without passing through any downstream equipment. A torch is used initially to ignite the producer gas emanating from the flare pipe.

Fig. 5.3 Gasifier for wood and briquettes

5.3 Downdraft gasifier for loose bioresidues

When loose biomass were used in the gasifier originally developed for wood and briquettes, certain operational problems arose. This is due to the distinct characteristics of loose biomass vis-à-vis that of wood pieces or briquettes. Firstly, because of the fluffiness of loose bioresidues, it was difficult to be fed through the hopper of the gasifier. No such difficulty was faced in the case of wood pieces. Secondly, the air supply was not uniform in the gasifier. Gasification of loose bioresidues was done in the gasifier after doing certain modifications and improvements in its design. They are explained in the following sections.

5.3.1. Biomass feeding attachment

The feeding attachment consists of a hopper and two open/close type lids. This provision ensures smooth feeding of the loose biomass into the reactor. The top and bottom lids never open simultaneously. Refer fig. 5.4. Initially loose biomass is fed into the hopper by opening the top lid. Then the bottom lid is opened using shutter and lever mechanism. This arrangement helps in feeding the fuel without stopping the blower and it also ensures continuous running of the gasifier. Because of this lock hopper type arrangement, escapement of gases through the feed port during feeding of biomass was also avoided. The feeding area has been increased by about 60 % which facilitates free flowing of loose biomass into the gasifier.

Fig. 5.4 Biomass feeding attachment

5.3.2 Central air supply pipe

In the initial design originally developed for wood pieces, air was supplied from a blower directly into the gasifier through the top cover. This resulted in improper distribution of air inside the gasifier and hence reaction zones were not stratified. To ensure proper air entry into the gasifier and its uniform distribution inside the gasifier, an improved design of air supply pipe was incorporated in the gasifier. In the improved design, an annular distributor pipe is used to supply air into the gasifier.

5.3.3. Bed agitating rod

An agitating rod passing through the centre of the reactor maintains the top surface of biomass bed even. This provision aids in achieving better stratification of reaction zones.

5.3.4 Sight glass

A provision has been made on the top cover of the reactor to fit a sight glass. The sight glass is used to see the inside of the reactor during operation and helps to maintain the biomass bed level as per the requirement.

Chapter 6

EXPERIMENTS

6.1 Determination of some physical properties

First, some properties of certain loose biomass were determined. Bulk density, apparent particle density and voidage are the physical properties which were determined for certain biomass in the lab by following brief procedures.

6.1.1 Bulk density (ρ)

It is the mass of biomass particles per unit volume of the biomass particles including voids between the particles and pores within the particles. Bulk density is not an intrinsic property of a loose biomass; it can change depending on how the biomass is handled. It is a measure of the "fluffiness" of loose biomass in its natural form.

It was determined by taking biomass in a 1000 ml measuring jar and placing it on a digital weighing balance (1 g accuracy) and measuring the total weight as M1. The weight of empty jar is then measured as M2.

Bulk density $\rho = (M1 - M2)/V$

where M1 = total weight of (biomass + jar)

M2 = weight of jar

V = volume of jar (1000 ml)

6.1.2 Apparent particle density (ρ_s)

It is the mass of a biomass particle divided by its volume including pores which are inherently present in it. A single biomass particle was weighed (M) in a digital weighing balance of 0.001 g accuracy. Its volume (V) was then measured by a suitable method.

Apparent particle density $\rho_s = M/V$

6.1.3 Voidage (e)

It is the fraction of volume of the vessel not occupied by solid biomass particles.

6.2 Determination of operational parameters

Some of the operational parameters of the gasifier like superficial air velocity, residence time of air and surface area of bed per unit volume of the gasifier were determined for different air flow rates for each biomass. Carman-Kozeny equation was used to determine the surface area of the bed per unit volume for each biomass.

6.3 Tests for pressure drop measurement

Tests for pressure drop measurement along the depth of biomass bed were carried out under forced, downdraft mode with throat, in the unfired condition of gasifier. Refer fig.6.1. The bottom opening of the diverging portion below the throat of gasifier was closed with a wire mesh. A known quantity of wood pieces was charged into the gasifier up to the level of topmost pressure tapping. The top surface of biomass bed is taken as the reference for describing the position of pressure measurement. Manometers were connected to all the pressure tappings. A manometer was also connected across the orifice meter to measure air flow rate. The blower was started and delivery valve was kept fully open. Under this condition, the static pressure readings along the depth of biomass bed and orificemeter reading were noted. The air flow was then reduced in equal steps by regulating the blower valve. For each valve opening, all the static pressure readings along the depth of biomass bed and orificemeter reading were noted. The same experimental procedure was followed for different biomass like wood shavings, saw dust, coir pith, groundnut shells and charcoal.

Fig 6.1 Pressure drop measurement

6.4 Gasification tests

During gasification, generally there will be temperature stratification inside the gasifier at different depths. The actual temperature field was sensed by thermocouples inserted through the temperature tappings. Trials were conducted using wood pieces and groundnut shells separately. In each case, the gasifier was initially charged with 1 kg charcoal and ignited. The centrifugal blower supplied air for gasification and its flow rate was measured by orifice meter. The gasifier was operated in forced, downdraft mode. Refer fig.6.2. Once sufficient temperature was attained, biomass was fed in batches of 0.5 - 1 kg at a rate such that a desired bed height was reached. After reaching the desired bed height, the biomass feed rate was maintained at a value such that the bed height remained constant atleast for an hour during gasification trial. Biomass feed quantity was measured by a weighing balance of 1 g resolution. Temperature distribution along the depth of biomass bed was measured using 'K' type thermocouples inserted through eight tappings along the gasifier axis. The producer gas was flared at the opening of outlet pipe.

To finish the experiment, biomass feeding was stopped and air supply was continued for some more time. Because of biomass consumption due to gasification, its level gradually decreased inside the reactor. Once the level reached the initial level of charcoal taken, air supply was cut off and the reactions were stopped. The quantity of final residue was weighed.

Fig. 6.2 Gasifier in operation

Chapter 7

RESULTS AND DISCUSSION

7.1 Measured values of some physical properties

The measured values of the some physical properties are shown in Table 7.1 for certain biomass.

Table 7.1 Some physical properties of certain biomass

Sl. No.	Biomass	Apparent Particle Density ρ_s (kg/m^3)	Bulk Density ρ_b (kg/m^3)	Fractional Voidage e
1	Cashew nut shell	1152.5	295	0.68
2	Ground nut shell	366.66	89	0.76
3	Cashew nut shell char	368.96	123	0.74
4	Ground nut shell char	185.7	57	0.84
5	Charcoal	336	188	0.59

It is evident that charification reduces apparent particle density, bulk density but increases voidage of biomass.

7.2 Operational parameters

The operational parameters of the gasifier like superficial air velocity, residence time of air and surface area of bed per unit volume of the gasifier were determined for different air flow rates for each biomass. Table 7.2 gives the results for groundnut shells (biomass) and charcoal (biochar) only. These are the values obtained when gasification air passed through the packed bed biomass gasifier.

Table 7.2 Superficial air velocity, Residence time and Surface area of bed per unit volume for certain biomass

Sl. No.	Biofuel	Superficial air velocity (m/s)	Residence Time (s)	Surface of bed per unit volume (m^2/m^3)
1	Groundnut shells	0.115	3.56	3563
2	Charcoal			3335

The results indicate that dissimilar physical properties of biomass tend to control the chemical reactions differently.

7.3 Pressure drop in biomass beds

7.3.1 Wood pieces

The pressure drop along the depth of a bed of wood pieces is shown in fig. 7.1, for ten different air flow rates. The maximum possible air flow rate in the case of wood pieces is 0.0114 m^3/s. It is evident that the total pressure drop across the bed depth is only 4 mm of water column. Due to this, the air blower power requirement for wood pieces gasification will be the minimum.

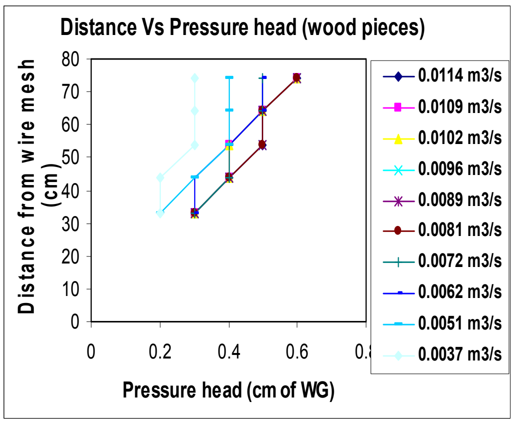

Fig. 7.1 Pressure drop for wood pieces

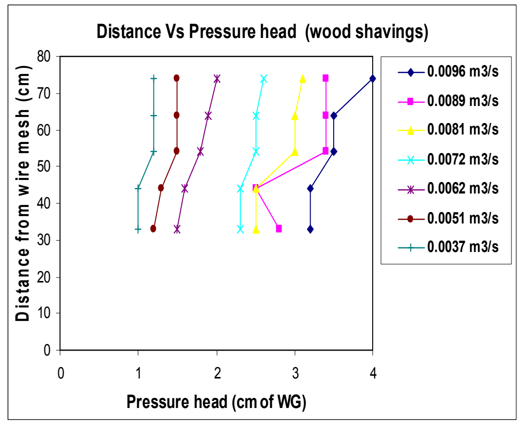

Fig. 7.2 Pressure drop for wood shavings

7.3.2 Wood shavings

The pressure drop along the depth of a bed of wood shavings is shown in fig. 7.2, for seven different air flow rates. The maximum possible air flow rate in the case of wood shavings is 0.0096 m^3/s. It is clear that the total pressure drop across the bed depth is about 8 mm of water column. Due to this, the air blower power requirement will be greater than that for wood pieces gasification.

7.3.3 Saw dust

The pressure drop along the depth of a bed of saw dust is shown in fig. 7.3, for only one air flow rate which is the maximum possible i.e., 0.0024 m^3/s. As the maximum possible air flow rate itself was very less, trials for still lower air flow rates could not be conducted. From fig. 7.3, it can be seen that the total pressure drop across saw dust bed is about 60 mm of water column which is the largest among all biomass. Due to this, the air blower power requirement for saw dust gasification will be the maximum.

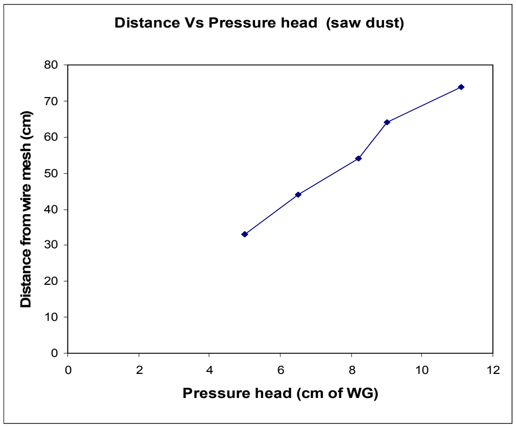

Fig. 7.3 Pressure drop for saw dust

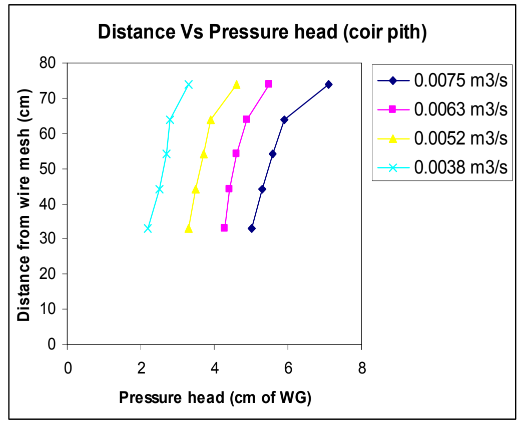

Fig. 7.4 Pressure drop for coir pith

7.3.4 Coir pith

The pressure drop along the depth of a bed of coir pith is shown in fig.7.4, for four different air flow rates. The maximum possible air flow rate is 0.0075 m^3/s. The total pressure drop across the bed depth is about 20 mm of water column. Due to this, the air blower power requirement will be lesser than that for saw dust gasification.

7.3.5 Groundnut shells

The pressure drop along the depth of a bed of groundnut shells is shown in fig. 7.5, for eight different air flow rates. The maximum possible air flow rate in the case of groundnut shells is 0.0102 m^3/s. It has been found that the total pressure drop across the bed depth is about 6 mm of water column. Due to this, the air blower power requirement will be considerably lesser than that for saw dust, coir pith and wood shavings gasification.

7.3.6 Charcoal

The pressure drop along the depth of a bed of charcoal is shown in fig. 7.6, for nine different air flow rates. The maximum possible air flow rate is 0.0108 m^3/s. The total pressure drop across the bed depth is about 3 mm of water column. Due to this, the air blower power requirement will be lesser than that for wood gasification.

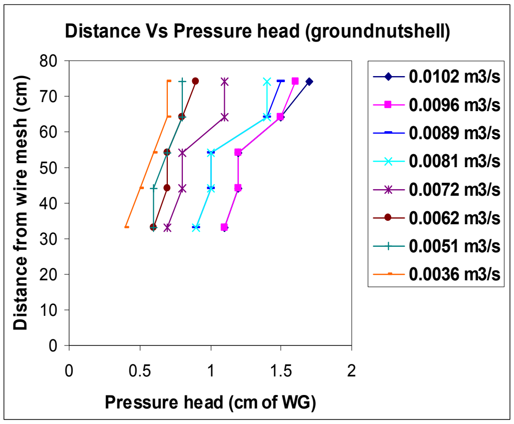

Fig.7.5 Pressure drop for groundnut shells

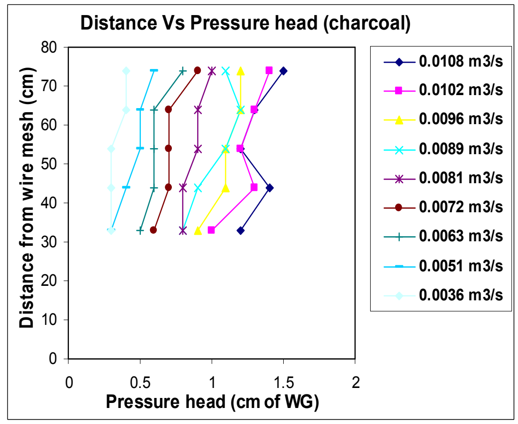

Fig. 7.6 Pressure drop for charcoal

The inlet static head (in cm of WC) required to cause different air flow rates in forced draft mode of operation of gasifier for six different biomass are shown in fig. 7.7.

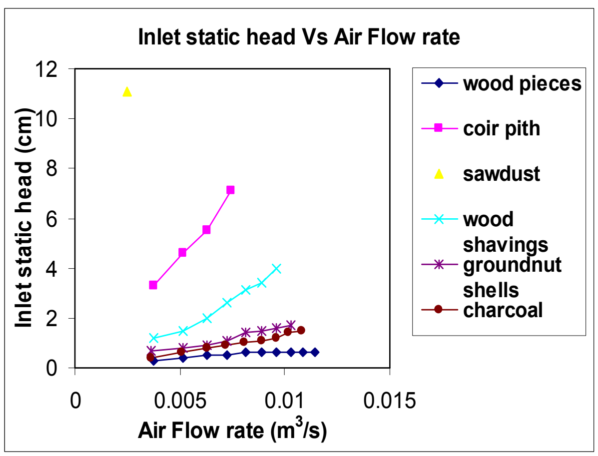

Fig. 7.7 Plot of Inlet static head vs Air flow rate

7.4 Temperature distribution during gasification

The results of gasification of two types of biomass namely wood pieces and groundnut shell are presented in fig. 7.8 and fig. 7.9 respectively. The temperature distributions along the depth of wood pieces and groundnut shell beds are shown in the figures, besides the fuel feeding rate and the bed height, for entire test duration.

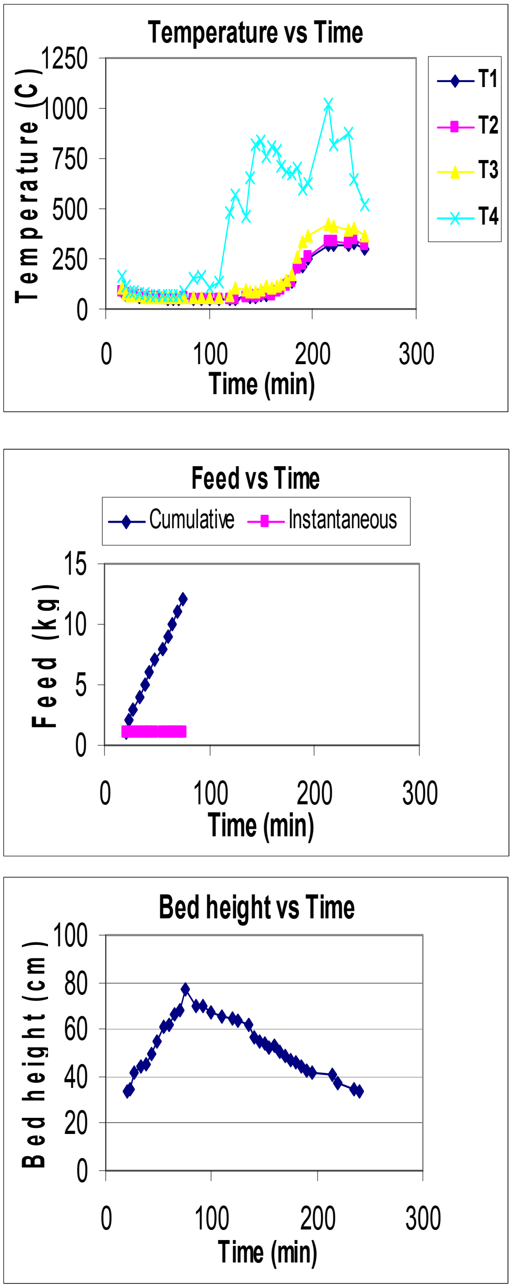

Fig.7.8 Temperature distribution, fuel feeding and bed height change during gasification of wood pieces

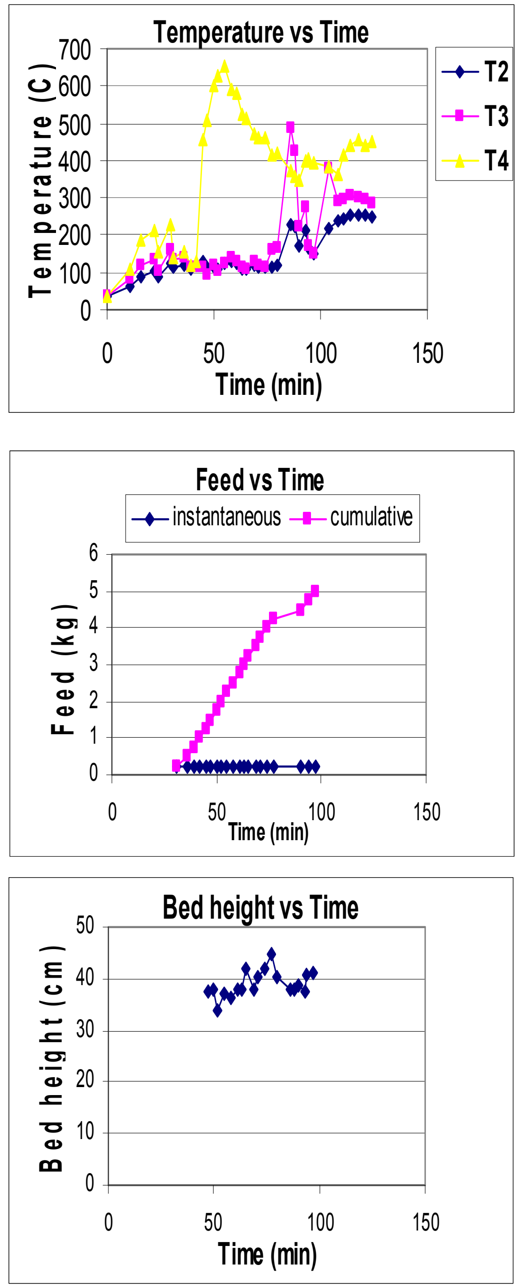

Fig.7.9 Temperature distribution, fuel feeding and bed height change during gasification of g.n. shells

During steady state operation of the gasifier, the heat transfer from oxidation zone to upper packed column of biomass caused drying and devolatilization of raw biomass, which was fed at a constant rate. The rate of downward movement of biomass was equal to the rate of upward progress of oxidation zone. But towards the end of experiment, when biomass feeding was stopped, the biomass level decreased gradually inside the gasifier as gasification was allowed to continue by supplying air. The drying and devolatilization zones shrunk while the oxidation zone extended upwards. As a result, the top layer of biomass bed underwent high temperature oxidation. Due to this, the radiation heat loss from red-hot biomass bed to the reactor inner surfaces increased. In the final stage of each biomass gasification trial, as the contents of gasifier became char, char gasification took place. The quality of producer gas was better towards the end of experiment, which could be observed for both wood pieces and groundnut shell gasification.

Channeling and bridging problems were experienced during gasification of groundnut shells in packed bed. By agitating the bed, these problems were overcome. Clinkers were also formed in the case of groundnut shell gasification, whereas no such phenomenon occurred in wood gasification. This was due to lower ash fusion temperature of groundnut shell ash. This can be overcome if bed temperature is maintained lower than ash fusion temperature. One of the methods of achieving this, is to decrease the char residence time.

Chapter 8

CONCLUSIONS

8.1 Properties of loose biomass

From the values of various properties determined for certain loose biomass, the following observations are made:

- Loose biomass have lesser bulk density and higher bed voidage.
- Surface area of bed per unit volume of bed is higher for loose biomass.
- Flow of loose biomass inside the gasifier is hampered by their inherent characteristics.
- Charification decreases bulk density and apparent particle density but increases fractional voidage.

8.2 Pressure drop in gasifiers

From the experiments conducted to determine pressure drop in biomass beds, the following points are concluded:

- The pressure drop for air flow is highest in the case of saw dust bed and is least for the bed of charcoal.
- For the same air flow rate through the bed, higher inlet air pressure is necessary in the case of saw dust.
- The pressure drop depends very much on the physical structure of biomass particle. The pressure drop is inversely proportional to the particle diameter.
- The pressure drop is directly proportional to the air flow rate for all biomass.
- For the same pressure drop and air flow rate, bed height of wood pieces can be more than that of loose bioresidues.
- Equations can be used to determine pressure distribution along the depth of biomass bed.

8.3 Gasification tests

From the gasification tests, the following points are concluded:

- Gasification of wood pieces is easier and particulate content in producer gas is also lesser.
- Gasification of groundnut shells is also good but particulate content in producer gas is more. Because of this, more elaborate cleaning of producer gas becomes essential before supplying it to the engine.

- When the bed height of groundnut shells is maintained low, producer gas generation is better but frequency of fuel feeding increases.
- By agitating the bed of groundnut shells, the problems of choking and bridging can be overcome and producer gas generation will be better.
- Dissimilar physical properties of biomass control the chemical reactions differently.

It is possible to use non-woody loose bioresidues in the small scale packed bed type of gasifiers with only minor modifications in the design and operation. In the larger commercial packed bed type of gasifiers, loose bioresidues can be used if the bed height is maintained at a minimum level and if the bed is agitated at regular interval of time.

RELATED LITERATURES

1. E. M. H. Khater, N. N. El-Ibiary, I. A. Khattab and M. A. Hamad, *"Gasification of rice hulls"*, Biomass and Bioenergy, Vol. 3, No. 5, pp. 329-333, 1992.
2. Valentino M. Tiangco, Bryan M. Jenkins and John R. Goss, "*Optimum specific gasification rate for static bed rice hull gasifiers"*, Biomass and Bioenergy, Vol. 11, No. 1, pp. 51-62, 1996.
3. Anil Kr Jain and John R. Goss, *"Determination of reactor scaling factors for throatless rice husk gasifier"*, Biomass and Bioenergy, 18 (2000), pp. 249-256.
4. M. Dogru, C. R. Howarth, G. Akay, B. Keskinler, A. A. Malik, *"Gasification of hazelnut shells in a downdraft gasifier"*, Energy, 27 (2002), pp. 415-427.
5. Jae Ik Na, So Jin Park, Yong Koo Kim, Jae Goo Lee, Jae Ho Kim, *"Characteristics of oxygen-blown gasification for combustible waste in a fixed-bed gasifier"*, Applied Energy, 75 (2003), pp. 275-285.
6. R. N. Singh, U. Jena, J. B. Patel, A. M. Sharma, "Feasibility study of cashew nut shells as an open core gasifier feedstock", Renewable Energy, 2005, pp. 1-7.
7. B.N. Baliga, S.Dasappa, V.Shrinivasa and H.S.Mukunda, "*Gasifier based power generation: Technology and Economics*", Sadhana, Vol. 18, Part I, pp 57-75, 1993.
8. P. Hasler, Th. Nussbaumer "*Gas cleaning for IC engine application from fixed biomass gasification*", Biomass and Bioenergy, Vol.16, pp. 385 -395, 1999.
9. A.Ramachandra, "*Performance studies on wood gas run IC engines*", Proceedings of the National Meet at Mysore, Recent advances in Biomass Gasification and Combustion, 1993.
10. "Biomass Thermochemical Characterization" Indian Institute of Technology, New Delhi, 1997.