Biomass Gasification of Agro-Waste:- A Potential Assessment For Jabalpur, Region

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Abstract: **A study was conducted for the use of thermo-chemical biomass gasification for producing bio fuels as the energy potential for the Jabalpur district. The downstream processes for gasification considered for the analysis are similar to other biomass processing methods. Present study was carried out to find the availability of methane and hydrogen gas in three major crops residue i.e. wheat, rice and maize for Jabalpur district MP through downdraft gasification process. During the analysis ultimate and proximate analysis were carried out which shows a rich potential as a gasification feedstock. For the above analysis CFD based tool is being used and it has been found that methane yields more in rice husk and less in maize stalks and average yields was 1 ton per 2.76 tons of biomass residue. The CFD tools also suggest that around 4 % of methane and 10% of hydrogen by volume fraction is available in gas produced by these crop residues. The result will be helpful for academicians and person involved in energy generation through Gasification from biomass.**

Key Words- Biomass **Gasification, SYN Gas, Sampling, Bomb Calorimeter, ANSYS etc.**

I-INTRODUCTION

Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuels or chemical feedstock. Pyrolysis, partial oxidation, and hydrogenation are related processes. Combustion also converts carbonaceous materials into product gases, but there are some important differences. For example, combustion product gas does not have useful heating value, but product gas from gasification does. Gasification packs energy into chemical bonds while combustion releases it. Gasification takes place introducing (oxygen-deficient) environments requiring heat; combustion takes place in an oxidizing environment giving off heat.

The purpose of gasification or pyrolysis is not just energy conversion; production of chemical feedstock is also an important application. In fact, the first application of pyrolysis of wood into charcoal around 4000 B.C.E. was not for heating but for iron ore reduction. In modern days, gasification is not restricted to solid hydrocarbons. Its feedstock includes liquid or even gases to produce more useful fuels. Partial oxidation of methane gas is widely used in production of synthetic gas, or *syngas*, which is a mixture of H_2 and CO.

Biomass also includes gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic materials. In the United States, there has been much debate on a legal definition.

Biomass includes only living and recently dead biological species that can be used as fuel or in chemical production. It does not include organic materials that over many millions of years have been transformed by geological processes into substances such as coal or petroleum. Biomass comes from botanical (plant species) or biological (animal waste or carcass) sources, or from a combination of these. Common sources of biomass are:

- *Agricultural:* food grain, bagasse (crushed sugarcane), corn stalks, straw, seed hulls, nutshells, and manure from cattle, poultry, and hogs
- Forest: trees, wood waste, wood or bark, sawdust, timber slash, and mill scrap
- *Municipal:* sewage sludge, refuse-derived fuel (RDF), food waste, waste paper, and yard clippings
- Energy: poplars, willows, switch grass, alfalfa, prairie bluestem, corn, and soybean, canola, and other plant oils
- Biological: animal waste, aquatic species, biological waste.
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Table1.1 Two major group of biomass and their sub classifications

Virgin	Terrestrial biomass	Forest biomass, Grasses, Energy crops, Cultivated crops
	Aquatic biomass	Algae, water plant
Waste	Municipal waste	Municipal solid waste ,Bio solids , sewage, Landfill gas
	Agriculture solid waste	Livestock and manures, Agricultural crops waste
	Forestry residues	Bark, leaves floor residues
	Industrial wastes	Demolition wood, sawdust waste oil or fat

1.2 Biomass Conversion

The bulky and inconvenient form of biomass is a major barrier to a rapid shift from fossil to biomass fuels. Unlike gas or liquid, biomass cannot be handled, stored, or transported easily, especially in its use for transportation. This provides a major motivation for the conversion of solid biomass into liquid and gaseous fuels, which can be achieved through one of two major paths.

- Biochemical (fermentation) and
- Thermo-chemical (pyrolysis, gasification).

A brief description of these follows.

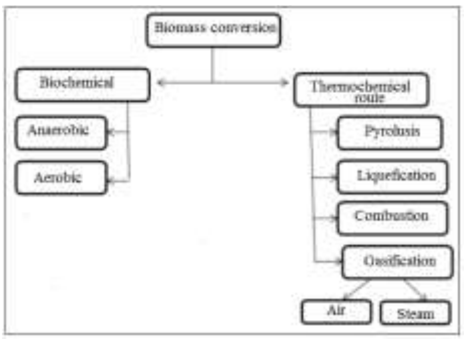

Fig. 1.1: Two paths, biological and chemical for conversion of biomass into fuel, gases, or chemicals.

1.3Thermochemical Conversion

In thermo-chemical conversion, the entire biomass is converted into gases, which are then synthesized into the desired chemicals or used directly. Production of thermal energy is the main driver for this conversion route that has four broad pathways:

- Combustion
- Pyrolysis
- Gasification
- Liquefaction

Gasification

Gasification converts fossil or non-fossil fuels (solid, liquid, or gaseous) into useful gases and chemicals. It requires a medium for reaction, which can be gas or supercritical water (not to be confused with ordinary water at subcritical condition). Gaseous mediums include air, oxygen, subcritical steam, or a mixture of these. Presently, gasification of fossil fuels is more common than that of non-fossil fuels like biomass for production of synthetic gases. It essentially converts a Potential fuel from one form to another.

There are three major motivations for such a transformation:

- To increase the heating value of the fuel by rejecting non-combustible components like nitrogen and water.
- To remove sulphur and nitrogen such that when burnt the gasified fuel does not release them into the atmosphere.
- To reduce the carbon-to-hydrogen (C/H) mass ratio in the fuel.

In general, the higher the hydrogen content of a fuel, the lower the vaporization temperature and the higher the probability of the fuel being in a gaseous state. Gasification or pyrolysis increases the relative hydrogen content (H/C ratio) in the product through one the followings means:

Direct: Direct exposure to hydrogen at high pressure.
Indirect: Exposure to steam at high temperature and pressure, where hydrogen, an intermediate product, is added to the product.
Pyrolysis: Reduction of carbon by rejecting it through solid char or CO_2 gas.

II – LITRETURE REVIEW

Dumbleton, F. (et al 2001) has studied the applications (a low-temperature device for Marigold flower drying and a high-temperature appliance for heat treatment process).

The study evaluated the thermal and environmental performance of these two applications. The study reported that the fuel cost could be reduced by 75% when the system operation is shifted from fossil fuel to biomass gasifier-based operation. In addition significant environmental benefits in terms of reduction in CO_2 and SO_2 were reported in this study. [7]

Mukopadhyay (2001) evaluated the socioeconomic & environmental impact of biomass gasifier-based power generation plant installed and operated at Sundar bans, India. The study used emission factors from the literature and attempted to estimate the CO2 and SO2 emissions. Economic benefits in terms of benefits of cost ratio (BCR) and internal rate of return (IRR) are reported in this paper.

Kapur et al. (1998) have assessed the potential and financial viability of technologies for using rice-husk gasifier for electricity generation. Dhingra and Kishore (1999) reported their experience in development an improvement of the gasifier-based thermal application suitable for small-scale industries. This study also analysed the economic feasibility of the gasifier system.

Kammen and Pacca (2004) worked out the economics of electricity generated from a diverse range of fossil fuel, nuclear, and renewable energy sources with energy efficiency options. Their estimation takes into account of costs of generated and delivered electricity and power, wholesale and retail marketplace cost, life-cycle accounting systems, premiums associated with political, social and environmental risks.

Concise project definition: motivation for current work

Most biomass energy in India is derived from owned sources like farm trees or cattle, or is collected by households from common property lands. The biomass energy consumption is primarily limited to meet cooking needs of households and traditional industries and services in rural areas. In absence of a developed energy market in rural areas, most biomass fuels are not traded nor do they compete with commercial energy resources.

Electricity production in India largely depends on fossil fuel whose reserve is now shortens and the government is now focusing on the alternating sources to harness electricity to meet the continuous increasing demand. To reduce the dependency on fossil fuels, biomass to electricity could play a vital role in this regard.

This paper presents to find out the biomass based power generation potential of Jabalpur district through gasification technology, which is an efficient thermo chemical process as discussed earlier for distributed power generation. The agricultural residue can be the best resources as the biomass.

Jabalpur is a grass root level institution centrally located in the district of Madhya Pradesh, which comes under Kymore Plateau and Satpura Hills Agro Climatic Zone.Crops like Paddy, Pigeon pea, Soybean, Maize, Sesame in kharif and Wheat, Gram, Pea and Mustard in rabi are grown predominantly in the district.Productivity of important Kharif and Rabi crops of the district are given in Table.

Table 1.1 Productivity of important Kharif and Rabi crops of the district

Crop	Area (ha)	Productivity (Kg/ha)
Rice	64184	941
Soybean	2248	891
Arhar	6798	1257
Maize	4298	1666
Wheat	87879	2243
Gram	66430	1141
Mustard	4147	1827

It has been observed that the total power generation from the agricultural residue through the Gasification can be higher.

Aim and objectives of the study

"The research objective of the study is to find out the amount of power generation potential of Jabalpur district based on gasification of agricultural residue of three major crops i.e. Wheat Maize and Rice."

III- Research Methodology

Biomass is highly diverse in nature and classified on the basis of site of origin such as field and plantation biomass, industrial biomass, forest biomass, urban waste biomass and aquatic biomass. However, most common source of biomass is wood waste and agricultural wastes.

In this work, the focus is made mainly on waste agricultural biomass (WAB) in the Jabalpur region because this region has a large agriculture base, generates huge quantities of waste agriculture biomass and most of which is currently unutilized.

Total area of Jabalpur district is about 367 km^2,the economy of Jabalpur is primarily agriculture based and the main food crops are sorghum, wheat, rice and coarse grain such as Kodo millet, little millet and Italian millet.

Important among commercial crops are pulses, oilseeds, cotton, sugar cane and medicinal crops. The state is poised for a breakthrough in soybean cultivation. In the state Kharif crops occupy 60% and rabi crops 40% area with 71.4 % area under food grain production. Nearly 59% of landholders are marginal whereas small farmers share 18% of farmland.

The main crops are wheat, rice, pulses, oilseeds, maize etc. Nearby is Bargi Dam on the river Narmada for irrigation, water supply & power generation. The town is surrounded by several lakes & water tank used for culture in them & in rivers

Crop residues represent the non-edible plant parts which are left in the field after harvest and or remain as by products after crop processing, for example, extraction or milling [11]. These residues contribute significantly to the biomass sector of the district and can potentially be used as energy source. Being an energy source, crop residues are used for several other purposes such as fodder and raw manufacturing material.

To find out the energy potential, the two major production crop's residue i.e. Wheat and Rice is considered.

To accomplish the study following steps are adopted:

1. Sampling the biomass residues

2. Ultimate and Proximate Analysis of samples
3. Gasifier modeling using CFD
4. Analysis for hydrogen and methane
5. Assessment of Biomass Potential

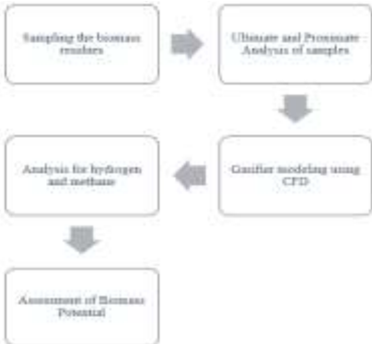

Figure 3.1 Procedures for Assessment

3.1 Sampling the biomass residues

The samples are collected from the fields after harvesting as shown in figure 3.2

Figure3.2 Wheat Residues after harvesting in the field

Figure3.3 Rice Residues after harvesting in the field

Figure3.4 Briquettes from wheat straw

Figure3.5 Fine powder form Briquettes from rice straw

Figure3.6 Maize Residues after harvesting in the field

Figure3.6 Fine powder form Briquettes of Maize Residues

3.2 Ultimate and Proximate Analysis of samples

The agro wastes properties like moisture content was determined after drying a sample at 105ºC according to ASTM D2016-25. To obtain the ash content, a dried sample of 2g is burned at 800ºC during 5h according to ASTM D-5142. The volatile matter was determined according to ISO 562/1974. It was measured by introducing a dry sample of 1g into a crucible with a top at 950ºC for 5min. The percentage moisture content (PMC) was found by weighing 2g of the sample and oven drying it at 105°C until the mass of the sample was constant. The change in weight after 60min was then used to determine the sample's Moisture Content

The fixed carbon (FC) was calculated by
FC % = 100 % - ash % - moisture content - volatile matter % (Tabareset al., 2000).

The Gross Calorific Value (GCV) was measured by a PARR 1261 bomb calorimeter (figure 3.7) in a dry basis using samples of 1g according to the standard method (ISO, 1976).

Figure 3.7 Bomb Calorimeter

Ultimate Analysis involves the estimation of important chemical elements that makes up the biomass, namely carbon, hydrogen, oxygen, nitrogen and Sulphur. The basic method for doing an ultimate analysis is to burn a sample of biomass in a platinum crucible in a stream of air to produce carbon dioxide and water.

3.3 Assessment Methods

The assessment of the actual CH4 in biomass can be processed

I. Using the software tool
II. Using the higher order mathematical calculations.

We work on the feasibility of the resources, to assess the gasification, software tool i.e. CFD analysis is used.

Gasifier Modelling Using CFD

ANSYS FLUENT's interactive solver set-up, solution, and post-processing make it easy to pause a calculation, examine results with integrated post-processing, change any setting, and then continue the calculation within a single application. Case and data files can also be read into ANSYS CFD-POST for further analysis with advanced post-processing tools and to compare results from different cases side-by-side.

- Pre-processing
- Meshing
- Solver
- Post-Processing

Model descriptions: A typical diagram of pilot scale biomass gasifier, (established at JNKVV Jabalpur,) is drawn at design modular with following specifications:

Length (cylinder):	15 feet
Diameter (inlet/outlet):	1 foot
Thickness of body (solid):	0.15 inches
Symmetry:	about XY plane
PART:	FLUID SOLID (suppressed body)

The boundary condition for each segments in the gasifier are specified in FLUENT. FLUENT has a wider angel of boundary conditions that permit flow to enter and exit the solution domain. FLUENT provides 10 types of boundary cell types for the specification of flow inlets and exits: velocity inlet, pressure inlet, mass flow inlet, pressure outlet, pressure far-field, outflow, inlet vent, intake fan, out let vent, and exhaust fan.

IV- RESULTS & ANALYSIS

The proximate Analysis is carried out for the three major crop residues with the help of Bomb calorimeter as described in previous chapter.

The three major crops for the analysis is considered for the perspective of Jabalpur District are as

1. Wheat Stalks
2. Rice Husk
3. Maize Stalks

4.1 Proximate analysis of the Biomass

Results from proximate analysis are reported in Table 4.1. Moisture content is of important interest since it corresponds to one of the main criteria for the selection of energy conversion process technology. Low moisture content is required for the condition when it is going to be used as the biomass fuel while those with high moisture content are more appropriate for biological-based process such as fermentation or anaerobic digestion.

Table 4.1 Proximate analyses of agricultural residues

Properties	Rice Husk	Wheat Straw	Maize Stalks
Moisture (%)	4.3	1.0	8.41
Ash (%)	20.49	7.0	5.25
Volatile Matter (%)	61.2	71.3	78.31
Fixed Carbon (%)	14.01	19.8	16.03

The proximate analysis results show the value of properties available in all the three different biomass described above.

Figure 4.1 Downdraught Gasifire Model

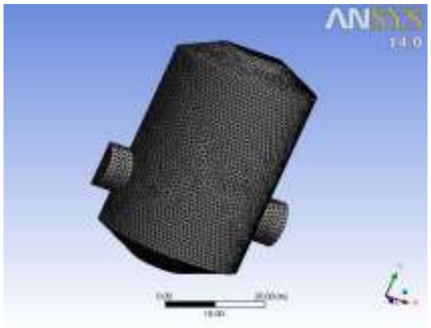

Figure 4.2Mesh Geometry of Downdraught Gasifire Model

4.2.1 The results obtained for the Rice Husk

The following results have been obtained during the analysis of gasification process of Rice Husk.

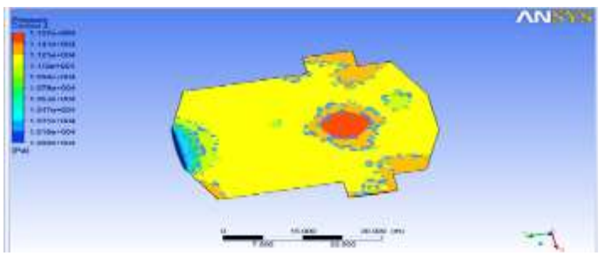

Figure 4.3Pressure Contour for Rice Husk

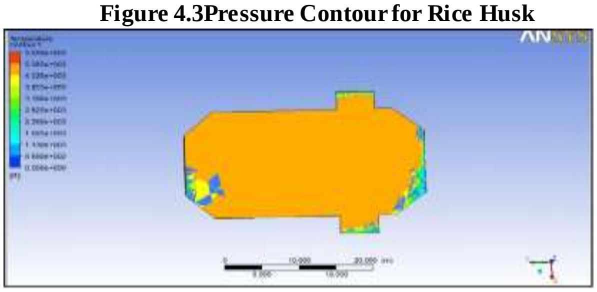

Figure 4.4Temperature Contour for Rice Husk

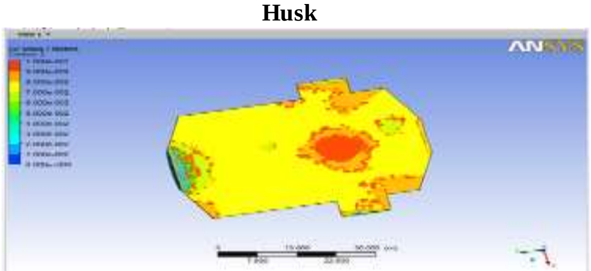

Figure 4.5Hydrogen mass fraction Contour for Rice Husk

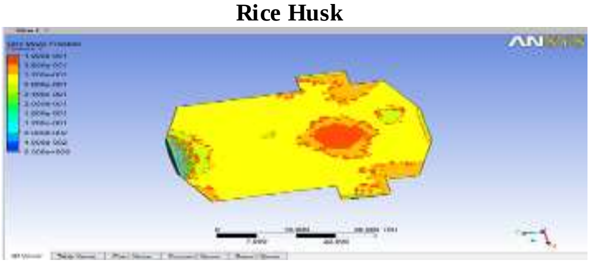

Figure 4.6CH_4 mass fraction Contour for Rice Husk

Figure 4.3 and 4.4 shows the Pressure and Temperature contour respectively.The maximum value of temperature and pressure are achieved during the combustion process in the combustion chamber.

Figure 4.5 shows the hydrogen and figure 4.6 shows the Methane mass fraction percentage as the output of the rice husk gasification.The mass fraction for hydrogen is about 10% and for methane is about 40%.

4.2.2 The results obtained for the Wheat Straw

As per the inlet properties for gasification is considered for the Rice husk, in the same condition the analysis is done for the Wheat straw as the bio fuel.

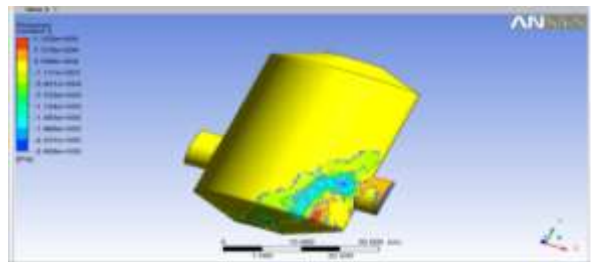

Figure 4.7Pressure Contour for Wheat Straw

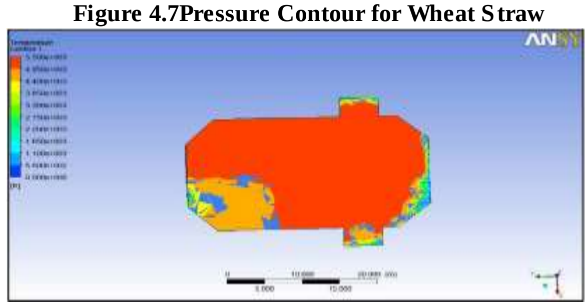

Figure 4.8Temperature Contour for Wheat Straw

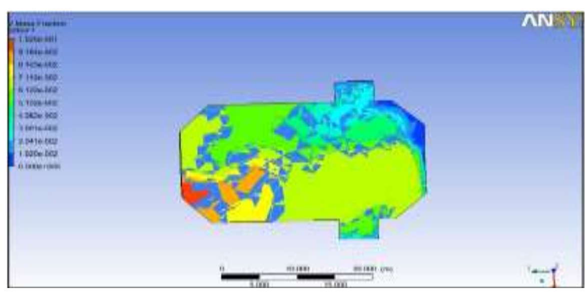

Figure 4.9H_2 mass fraction Contour for Wheat Straw

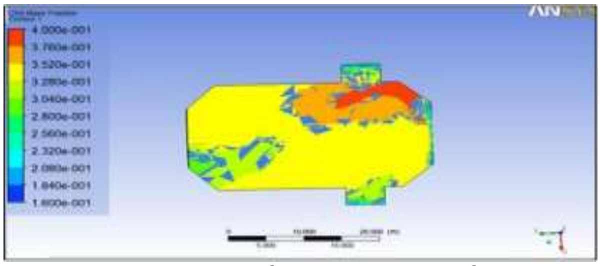

Figure 4.10 CH_4 mass fraction Contour for Wheat Straw

Figure 4.7 and 4.8shows the Pressure and Temperature contour respectively.The maximum value of temperature and pressure are achieved during the combustion process in the combustion chamber.

Figure 4.9 shows the hydrogen and figure 4.10 shows the Methane mass fraction percentage as the output of the rice husk gasification.The mass fraction for hydrogen is about 9.4% and for methane is about 39.6%.

4.2.3 The results obtained for the Maize Stalks

As per the inlet properties for gasification is considered for the Rice husk and Wheat straw and with different proximate analysis results obtained, the analysis is done for the Maize Stalks as the bio fuel.

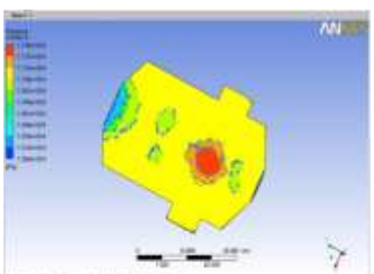

Figure 4.11Pressure Distribution Contour for Maize Stalks

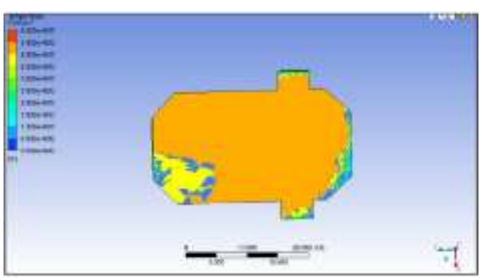

Figure 4.12Temperature Distribution Contour for Maize Stalks

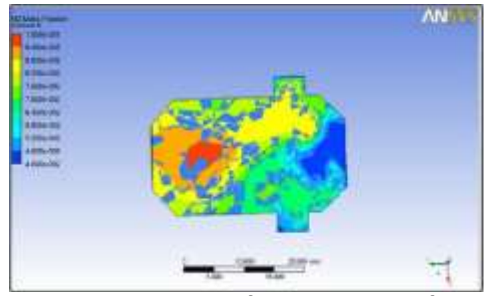

Figure 4.13 H_2 mass fraction Contour for Maize Stalks

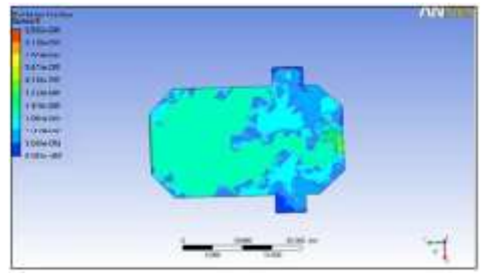

Figure 4.14 CH_4 mass fraction Contour for Maize Stalks

Figure 4.11 and 4.12shows the Pressure and Temperature contour respectively.The maximum value of temperature and pressure are achieved during the combustion process in the combustion chamber.

Figure 4.13 shows the hydrogen and figure 4.14 shows the Methane mass fraction percentage as the output of the rice husk gasification.The mass fraction for hydrogen is about 9.6% and for methane is about 35.36%.

V – ANALYSIS WITH CONCLUSIONS

"Assessment of the Potential of Biomass Gasification in Jabalpur Region"

The product of the gasification process is the Producer gas or SYN gas depends upon the process involved. In the case of Producer gas the CH_4 is the main constituent. The objective of this chapter is to find out the potential of agri-biomass (crop residues) produced in the Jabalpur region to produce the producer gas.

5.1 Crop production in Jabalpur District

Jabalpur is a grass root level centrally located in the district of Madhya Pradesh, which comes across the Kymore Plateau and Satpura Hills Agro Climatic Zone.

The Jabalpur district has 1393 villages and spread in 5,19,757 hectare geographical area. The climate of the district is more suitable for cultivation for oilseed, pulses, cereals and horticultural crops, with the annual rain fall of 1358 mm.

Crops like Paddy, Pigeon pea, Soybean, Maize, Sesame in kharif and Wheat, Gram, Pea and Mustard in rabi are grown mainly; for the most part in the district. The total irrigated area under is about 28% out of which only 18% is double seasoned cropped in this district. Figure 5.1 shows the map of District farming in micro level.

Figure 5.1 District map for farming situation.

5.1.1 Major crops production in the district

Various types of crops are produced predominantly in the district. The table 5.1 shows the productivity of Rabi and Kharif crops in the district.

Table 5.1 Productivity of important Kharif and Rabi crops of the district

Crop	Area (ha)	Productivity (Kg/ha)
Paddy	64184	941
Soybean	2240	891
Arhar	6798	1257
Maize	4290	1666
Wheat	87879	2243
Gram	66450	1141
Mustard	4147	1027

From the above table it is obvious that the three major crops for both the seasons are paddy (rice) maize and Wheat. For the present assessment work all the three major crops has been considered.

Table 5.2 shows the total production of these three major crops for the last three years depends on the data provided online by the government of Madhya Pradesh. And on the other hand table 5.2 shows the average crop residue of Rice, wheat and Maize crops after the harvesting which can be used as the biomass for further energy production.

Table 5.2 Crop production for last three years

Crops production (Tonnes)	Assessment Year 2011-12	Assessment Year 2012-13	Assessment Year 2013-14	Average for last three years
Rice	93156	169606	76621	118639.3
Wheat	243281	299369	332705	291785
Maize	5117	8781	5995	6631

Table 5.3 Total residue production with percentage of fractions of some selected agricultural crops

Crops	Average production of last three years	Fractions	Amount of Fractions (Residue available for 1 kg of grain)	Crop Residues (tonnes)
Rice	118639.3	Husk	0.2 Kg	23727.9
Wheat	291785	Stalks	1.5Kg	437677.5
Maize	6631	Stalks	2 Kg	13262

The methane and hydrogen are the main parts of the producer gas. As per the results obtained by the Finite element analysis using the downdraught gasifier the methane and hydrogen production are depicted in Table 5.3.

Table 5.3 The Maximum amount of CH_4 and H_2 that can be produced with the help of Downdraught Gasifire as per the results obtained by FEA method

Crops	Crop Residues (tonnes)	Amount of methane Percentage	Amount of Hydrogen Percentage
Rice	23727.9	40	10
Wheat	437677.5	39.6	9.4
Maize	13262	35.36	9.6

5.2 Power Generation Potential from Biomass

The producer gas so obtained is a low calorific value gas with typical higher heating value in the range of 5.4–5.7 MJ/m^{3}. The producer gas can be directly burned in a burner to provide thermal energy or it can be used as a fuel in an engine to provide mechanical power or electricity.

It is obvious from the above results that the 1 kg of rice husk can produce 40 % mass fraction of methane and 10 % Hydrogen. Similarly Wheat and Maize Stalks can produce 39.6 and 35.36% of methane and 9.4 and 9.6 % of hydrogen respectively. Table 5.4 shows the Power generation capacity for the three agri-biomass in terms of total methane (producer gas) production.

Table 5.4 Total Methane that can be produced.

Crop residue	Total Production (tonnes)	Amount of Methane
Rice Husk	23727.9	9491.1
Wheat Stalks	437677.5	157563.7
Maize Stalks	13262	4641.7
Total	474667.4	171696.5

Methane has the lower heating value about 50,000 KJ/Kg. The total amount of methane that can be generated is about 171696.5 tonnes. Approximate about 8.54×10^{12}KJ energy can be produced with the utilization of producer gas.

H_2 can be used as a transportation fuel in fuel-cell based automobiles, as a zero-emission fuel. It should be realized that H2 is not an energy carrier, but rather an energy source. Hence, sources of energy are needed to produce hydrogen. H2 has the highest energy content on a mass basis. Use of H_2 in fuel cells has gained attention because of its high efficiency (around 60%) as compared to efficiency of IC engines (20–38%).

The product gas from biomass gasification can be used to produce heat and electricity using a combined heat and power (CHP) system called integrated gasifier combined cycle (IGCC or BIGCC, Biomass-fired IGCC). The main advantages of producing heat and electricity using gasification over direct combustion are

(a) Fuel-gas based technologies such as gas engines or gas turbines can achieve higher efficiencies than combustion efficiency,

(b) The overall efficiency of gasification is higher because gaseous fuels, having improved combustion characteristics, burn more efficiently than solid fuel, and

(c) Production of gas provides an opportunity to remove contaminants that ultimately produce NOx and SOx emissions.

Conclusion

Present study reveals that gasification route of energy generation from biomass residue is a potential sustainable energy sources. It will also add in clean and green India mission (Swakch Bharat Abhiyaan).

Present results confirm that CH4 and Hydrogen in the stalk is in the ratio of 4 and 10% which is higher that the results aided in the literature. Also the energy yields are higher if calculated in absolute condition.

Three biomass i.e. maize stalks, rice husk and wheat straw have been considered for the study. For the assessment of biomass gasification downdraft gasifire has been considered.

Biomass potential has been observed for the Jabalpur district. The total amount of methane that can be generated is about $18745.3 \times 103 m^3$

Approximate about 18745300×32800 KJ or 170790463.3 kWh energy can be produced with the utilization of producer gas. Total amount of saving could be about 853952316.4 Rs per year.

Apart of energy generation this source of energy can be fruitful to reduce the air pollution of the region. We have an example; as per the report published by delhiair.org, the one of the reason for Delhi air pollution is the air flow patterns from Afghanistan and Pakistan region pick up burn components as they passed over the densely urbanized area of Punjab and Haryana where farmers burn the straw in their fields as they don’t have proper utilization of the residues and air pull this pollution into Delhi.

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