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A Study on Feasibility of Using Oryza Sativa Residues for Power Generation

Phool Singh Chauhan
Chemical Eng. Dept., IIT Kanpur, Kanpur, India
Research scholar at JJT University, Jhunjhunu, India

Anurag Tewari
Chemistry Department, PSIT College of Engineering,
Kanpur, India

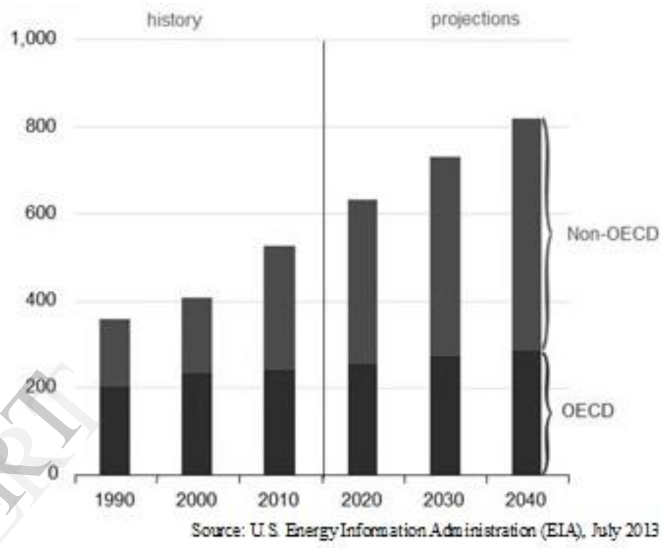
Abstract—**Energy, in the forms of electricity and heat, is the most dynamic factor for the development. Fossil fuels like coal and petroleum are the conventional sources for generating electricity. However, they are not sustainable as they take very long time to get replenished in nature. They also produce large quantities of toxic polluting emissions, endangering atmosphere. Biomass based are non-polluting and sustainable, can be grown through natural carbon cycle of cultivation as energy crops and also available as domestic, municipal and industrial waste. In this study, a non-woody biomass species *Oryza sativa*, an agricultural crop cultivated around the world, have been experimented for co-firing with coal to generate electricity and enhance adoptability of biomass based fuels for sustainable growth and preservation of biodiversity.**

Keywords—renewable energy; energy efficiency; biofuel

I. INTRODUCTION

Energy is an important factor in the progress of human civilization. Energy is required for various activities in domestic, commercial and industrial establishments for generating heat and light, and moving machines. It is also essential for transportation of material and people from one place to another, telecommunication systems and climate control [1]. Traditionally, major part of energy including electricity is obtained from fossil fuels like coal and petroleum products. Petroleum based fuels harm our environment through emissions of toxic gases and particle substances and also have negative effects on animal and plant lives. Much health related problems and illnesses have been reported to be due to emissions from petroleum diesel. These emissions have been related to many cases of cancer, cardiovascular and respiratory disease, asthma and infections in the lungs. Fossil fuels produce huge amounts of green house gases (GHG) and other particulate matters like fly ash causing severe damage to the environment through increased levels of pollution. These, along with increasing levels of other toxic emissions, are resulting in global warming with severe climatic changes and posing danger for survival of all living things on the earth.

These fossil fuels are result of very long and complex chemical conversions of the materials buried under the earth surface millions of years ago. As power plants and industrial processes consume very large quantities of fossil fuels and their natural reserves will take extremely long time to get replenished in nature, they are limited in supply and will not last forever. Also, serious socioeconomic issues are involved in the utilization of the fossil fuels [2].



Source: U.S. Energy Information Administration (EIA), July 2013

Fig. 1. World Energy Consumption Trends (in quadrillion Btu)

As shown in Fig. 1, ever growing demand of energy is increasing the problem from bad to worse. The growing concern regarding the harmful effects of the use of conventional fossil fuels led the researchers around the world to look for replacement of them. The solution of the problem lies in the suitable alternative sources to satisfy the growing demand of energy [3]. However, these alternative sources must have to meet some very important challenges. They should be non- polluting in nature to preserve the environment and keep the planet habitable. Also, they must be renewable and available in abundance to be replenished easily for the sustainability of the supply against the demand [4]. These factors help in preserving natural biodiversity along with sustainable growth and progress of human society. By using biomass based fuels in the place of petroleum diesel, not only we will be helping the environment with a much better alternative, but would significantly reduce several health risks [5].

II. EXPERIMENTAL WORK

A. *Selection of Plant Species*

Energy related proximity values of a worldwide available non-woody biomass plant species have been studied and compared with the values for lignite coal as fossil fuel. Mixtures of biomass species with coal samples have also been tested to explore the viability for co-firing of the same in power generation plants.

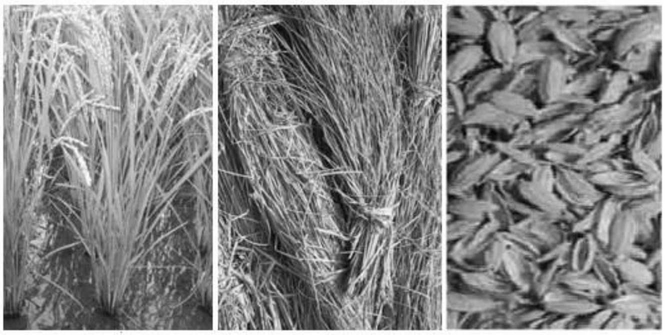


Fig. 2. Oryza sativa plant, straw and husk

Oryza sativa (locally known as Dhaan), the Asian Rice has been selected as cultivated biomass species for the study. It is second most used staple food in the world after wheat. About 20% of the world population depends on it. It is grown all over the world except arctic regions. Huge quantities of straw and husk are produced as residue/ waste material after harvesting is over. Rice husk, as secondary residue, contains large amounts of silica and is also used to extract variety of commercially profitable byproducts. But straw, as primary residue, is generally left to rot in the fields. Also, large amounts of the straw are burned to clear fields for next crop, emitting smoke and gases and resulting in dangerous levels of atmospheric pollution.

Plant of *Oryza sativa* is 100-200 cm high and is cultivated mostly during rains as it requires large amount of water. Straw and husk of *Oryza sativa* can be considered as easily available non-woody biomass feedstocks. The husk as feedstock, 20% of the paddy mass, is available at rice milling plants in huge quantities and is used to generate heat for drying of the crop. The straw, 30% of the paddy mass, is a little difficult to collect as it is scattered around fields over large areas. However, it is very economical form of feedstock which is available throughout the world in abundance. Use of straw as a biomass fuel source also solves the serious problem of emission of toxic air pollutants when burned in the open fields. Therefore, rice straw has been chosen for the second biomass species component as a part of the present study. Different components of *Oryza sativa* biomass plant species are shown in Fig. 2.

B. *Energy Analysis of Components of Biomass Species*

Energy analysis of biomass based fuels is important to get an estimate of their energy contents and amount of polluting emissions from their combustion process [6]. Both, the woody and non-woody, parts of biomass feedstock in the fresh state contain large amounts of moisture [7]. This moisture content needs to be removed to increase the calorific value of feedstock. Removal of moisture also decreases gross weight and thus makes transportation of the biomass economical. The drying process depends on the selected biomass species. Different components of the selected biomass species *Oryza sativa* were collected and chopped into small pieces. They were air dried to reduce moisture content in laboratory in hot air chamber. The dried out components of plant species and coal samples were then processed into suitable powdered forms for the study. Dried biomass components were grinded in laboratory to small particle sizes. Proximate analysis of prepared samples was done to determine various parameters related to their chemical compositions and energy content.

Proximity analysis of the samples consisted of the measurement of moisture contents, volatile matters, fixed carbon and ash content and calorific values [8-10]. The details of all the measurements are described in the following subsections:

I) *Determinatio of Moisture Contents*

The air-dried and powdered samples were weighed and put on glass discs. They were heated in a hot air oven for one hour at a temperature of 105 ºC ± 5 ºC. The samples were then taken out and weighed again on a digital analytical balance to measure the loss in weight. The percentage moisture content is calculated as the percentage weight loss of the sample using following formula:

$$\text{Moisture content (\%)} = \frac{\text{Mass of test sample} - \text{Mass of residue}}{\text{Mass of test sample}} \text{ X } 100 \qquad (1)$$

II) *Determination of Ash Contents*

Ash content of a sample was determined by the measuring of residual mass after complete combustion. A measured mass of the air-dried and powdered sample was put into a silica dish and heated in a muffle furnace for one hour keeping the temperature at 775 ºC ± 5 ºC. The sample was heated till completion of the combustion process. The residue was cooled in desiccators and weighed on a digital analytical balance to measure the loss in mass. The percentage ash content is calculated as the percentage weight loss of the sample.

$$\text{Ash content (\%)} = \frac{\text{Mass of ash X } 100}{\text{Mass of test sample}} \qquad (2)$$

III)*Determination of Volatile Matter Content*

Volatile matter (VM) content of a sample was determined by heating a measured mass of sample kept in a closed silica crucible into a muffle furnace for 10 minutes at a temperature of 900 ºC ± 5 ºC. The sample was then left in air for cooling. De-volatized sample was further weighed on a digital analytical balance to measure the mass reduction. The percentage volatile matter content of the sample was calculated by using the formula:

$$\text{VM content (\%)} = \text{\% mass reduction} - \text{\% moisture content} \qquad (3)$$

IV)*Determination of Fixed Carbon Content*

Percentage fixed carbon (FC) content in a sample was calculated by using the previously obtained parameters and the following eq. (4).

$$\text{FC (\%)} = 100 - (\text{\% Moisture} + \text{\% VM} + \text{\% Ash}) \qquad (4)$$

V) *Determination of Calorific Values*

The calorific value of the test samples were determined by using bomb calorimeter (Model: 6200; Make: Parr Instrument Company, USA) with Parr, model: 1108P, oxygen bomb. This calorimeter is an integrated system having arrangement of automatic filling of oxygen at defined pressure. The water jacket is manually filled and is automatically maintained at programmed temperature by the calorimeter controller. The system can accommodate unusual sizes of samples for precision measurements. The test typically takes about 6 minutes to complete.

VI) Determination of Ash Fusion Temperatures

The ash fusion temperature of the residual ash is a very important parameter for using the fuel in the boiler of a power plant for steam generation. The fusibility at lower temperatures may result in clinker formation and thus hampering the power production. The ash fusion temperature is determined by heating the fuel ash sample molded in a cone shape into a muffle furnace in excess of 1000 ºC. The shape of cone is carefully monitored with an increase in temperature of the furnace. The four temperatures are presented as:

Initial deformation temperature (IDT), when first sign of change in shape of tip of cone is seen,

Softening temperature (ST), when height and width of ash mold shrink to equal sizes,

Hemispherical temperature (HT), when ash softens and turns into a hemispherical shape and

Fluid temperature (FT), when very low viscosity molten ash flows in a nearly flat thin layer.

III. RESULTS AND DISCUSSION

The experimental results from proximity analysis of selected biomass species components, coal and biomass-coal mixtures are presented in tabular and graphical forms [8]. Proximate analysis of crop residue components of selected biomass species and coal

Analysis of various components of *Oryza sativa* biomass species and briquetted biomass component mixtures with fossil coal are shown in Figures 3-6. It can be seen from the experimental data obtained for the analysis of the biomass species components, that they have very marginal differences. Although, this makes very difficult to get a solid decision, but it appears from the data that *Oryza sativa* has a high ash content and also high fixed carbon contents. It can also be seen that volatile matter is less and ash content is more for the mixtures with 5-10% of biomass species components and 95-90% coal respectively. But, volatile matter is more and ash content is less, for mixtures of 20-25% biomass species components and 80-85% coal respectively.

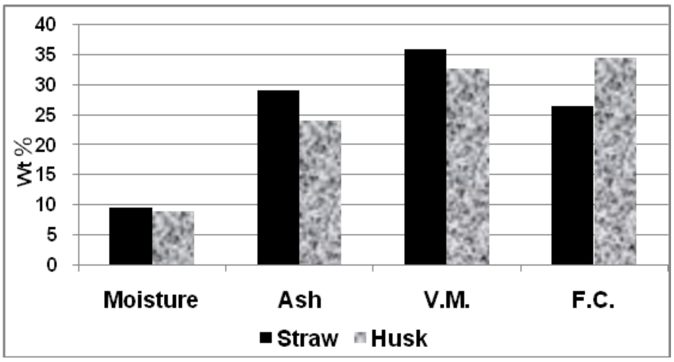


Fig. 3. Proximate analysis of *Oryza sativa* crop residue components

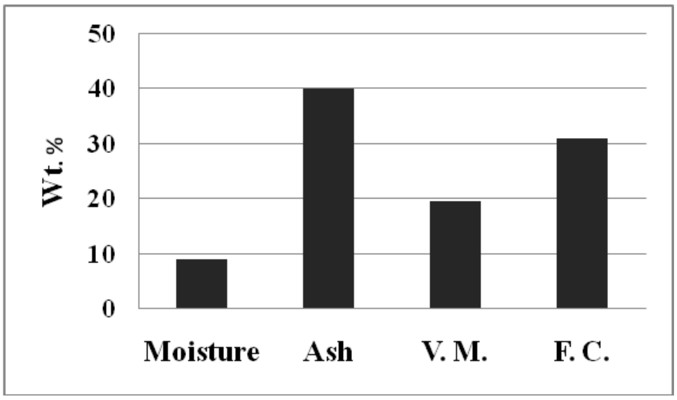


Fig. 4. Proximate analysis of lignite coal sample

A. Ash fusion temperature determination of biomass species:

Low ash fusion temperature results in clinker creation in the boiler and this affects the boiler operation in the power generation plants. Therefore, determination of ash fusion temperature of a fuel is very important factor in safe operation of boiler for using it in the power plant. The four temperatures are described as:

The data for ash fusion temperatures (IDT, ST, HT and FT) of biomass species and their mixtures with coal are listed in Table I.

B. Calorific Values of Biomass Species Components

Calorific value of a biomass based fuel provides valuable information regarding the energy content of the fuel and the amount of the heat and electricity to be produced. Therefore, this is an important parameter for deciding their quality to use in the power plants for generating electricity efficiently. Calorific values of husk components are higher than that of straw components of the biomass species.

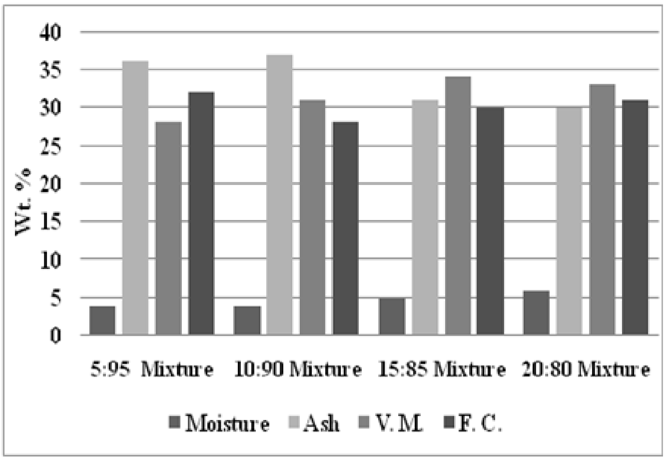


Fig. 5. Proximate analysis of mixture of *Oryza sativa* straw component and Coal

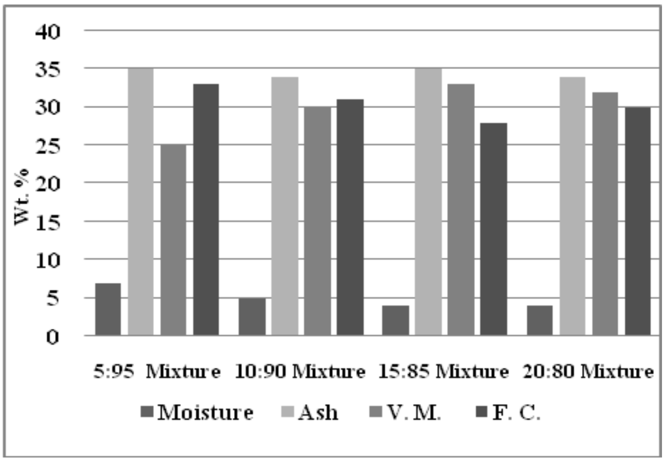


Fig. 6. Proximate analysis of mixture of *Oryza sativa* husk component and Coal

Calorific values of the coal mixed with different components in different ratios of biomass species are shown in Fig. 5 and Fig. 6. They show that calorific value of coal mixed with components of *Oryza sativa* biomass species. Highest energy value is observed in when 80% biomass components are mixed with 20% of coal for the biomass species. The mixtures containing 90-95 % of biomass components and 10-5% of coal respectively has lower energy values of the biomass species under present study.

Comparative data show the difference in coal and the biomass species studied under the present research work. It shows that the biomass species components have calorific values are lower in comparison to coal but ash content is also lower. Therefore, feedstock from the biomass species under study results in more power (electricity and heat) generation in the power plants with added benefits of lower levels of emissions of GHGs and suspended particulate polluting materials.

The energy value of *Oryza sativa* biomass species components on the dry mass basis, are shown in Table II. The yield of the biomass species components per unit land area has been derived from the data published by agriculture related departments of United Nations and Indian government. The accuracy of the data at a particular location depends on the variety of crop and climate of the season. Therefore, an average has been taken from the available data for past 5 years.

TABLE I. ASH FUSION TEMPERATURES

Biomass Species and Biomass – Coal mixture	**Ash fusion temperatures (0C)**			
	IDT	**ST**	**HT**	**FT**
Oryza sativa	1058	1249	>1400	>1400
Biomass : Coal	1160	1296	>1450	>1400
Biomass : Coal	1189	1297	>1450	>1400

TABLE II. ENERGY VALUE OF *ORYZA SATIVA* CROP RESIDUE

Biomass Component	**Heat Content (Kcal/ton)**	**Biomass Production (tons/hectare)**	**Energy Content (Kcal / hectare)**
Straw	2235×10^3	1.154	2579.2×10^3
Husk	2875×10^3	0.876	2518.5×10^3
Total	$\mathbf{5110 \times 10^3}$	**2.030**	$\mathbf{5097.7 \times 10^3}$

IV. CONCLUSION

Efficiency tests were done to analyze the amount of power generated from single unit of land for the selected biomass species. Coal and biomass mixture ratio of 80:20 provides highest energy value in comparison to other mixture ratios for mixtures with the biomass species under study. Ash fusion temperatures in case of the species have been observed higher than the boiler operating temperature and thus rule out formation of clinker in the boiler. The study shows the feasibility of utilization of these widely available agricultural residues for power generation.

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