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Anodyne Practice of Turning Composite Fuel into Green Energy at Mini Thermal Power Plants in India

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The exploitation of non-renewable energy resources since last few decades has been a foremost concern for today's generation. Most of the energy demand (about 63%) of India is outfitted by thermal power plants, leading to massive emission of CO_2, thereafter, fly ash generation causing threat to eco-system. India being second largest producer of rice paddy globally also harvests large number of crops such as wheat, sugarcane, corn, etc. accreting substantial amount of biomass annually. In association with the current agenda for sustainable development, biomass (Rice Husk) co-firing with coal has been identified as most practicable solution for the energy generation in modern times particularly, for small scale power plants at rural sector. The paper explains comparative economy in power generation with the help of three cases based on theoretical assumptions. Composite fuel with biomass: coal ratio of 80:20 and 90:10 predicts about 8-10% economy in energy generation related with pure coal-based power plants. The leftover from this process is termed as composite ash, utilization of which is essential for environmental safety. Being diverse in composition than coal fly ash (CFA), composite ash can be turned into sodium silicate, powdered silica and further Molecular Sieves. All these products find commercial utility in chemical industries as an ion exchange, adsorbent, detergent-builder, abrasive, fertilizer, etc.

Keywords: Composite ash, Economic, Energy, Molecular Sieve, Rice Husk

1 Introduction

A major share of energy demand (nearly 63%) in India is satisfied with the help of thermal power plants.[1] Although India produces the largest amount of coal (728.72 MT per annum) after China and USA, the obtained coal is of low grade, containing up to 40% ash.[2, 3] Thermal power plants emit a large amount of CO_2 leading to carbon footprints; results enormous fly ash a post combustion product causing potential threat to the environment. Pozzolanic properties of fly ash make it usable as an additive to concrete for strengthening; it is also actionable in many other applications.[4, 5] Considering the energy generation scenario in the past two decades, thermal power plants utilize coal as a primary fuel for combustion. A fair amount of literature is available with detailed studies regarding the qualitative analysis of residue generated from thermal power plants and its environmental impact.[6-12] To mitigate the future energy crisis and to establish sustainable development in society, increasing use of renewable energy sources are in vogue. According to reports, renewable energy accounts for 36% of India's entire power capacity mix at the end of the calendar year 2019.[13] Although renewable energy sources such as wind, solar, hydrothermal, etc. exist, each of them have their limitations as stated in literature.[14]

1.1 Hydrothermal Energy

Hydroelectricity generation is associated with the construction of large dams. Although they created a reliable power supply, irrigation and flood control benefits, the dams manifestly flooded large areas of fertile land and displaced thousands of local inhabitants.[15] Despite this, it is conveyed that the share of hydrothermal energy is nearly 12.4% of the overall energy demand of India.[16]

1.2 Solar Energy

Solar power is considered a green source of energy, as it does not emit greenhouse gases while generating electricity. It is a sustainable and inexhaustible source of energy. According to information available, India

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added over 7 GW (preliminary figures) of solar capacity in C.Y. 2019; cumulative solar installations in the country stood 35.6 GW at the end of the year, representing 9.6% of the total installed power capacity mix. It accounted for about 26.7% of all renewable energy in the country.[17]

1.3 Wind Energy

Winds are generated by complex mechanisms involving the rotation of the earth, heat energy from the sun, the cooling effects of the oceans and polar ice caps, temperature gradients between land and sea, and the physical effects of mountains and other obstacles. The wind is a broadly distributed energy resource. Wind energy accounts for 10% of the complete energy established in India.[19] Windmills' installation requires huge land area, the power of wind varies from place to place and hence this source is restricted to uncommon areas of the country only. It has also been observed that people living in the vicinity of engineering wind turbines are subjected to wind turbine syndrome.

1.4 Nuclear Energy

Nuclear power is the fifth-largest source of electricity in India after coal, gas, hydroelectricity, and wind power. As of March 2018, India has 22 nuclear reactors in operation in 7 nuclear power plants, with an aggregate installed capacity of 6,780 MW. Nuclear power produced a total of 35 TWh and supplied 3.22% of Indian electricity in 2017(19). Primarily uranium is used as fuel for the energy generation in nuclear power plants; the mining and handling of uranium are perilous. Also, it is to be considered that the waste generated from these power plants remains radioactive for a long time.

1.5 Biomass

Biomass sources include forest residues, animal waste, farm waste, woody materials, etc. Biomass is the only renewable energy source that can be substituted in organic petroleum (i.e. fuel for energy generation). Biomass consumes the CO_2 from the atmosphere during growth and releases during the combustion thus completing the CO_2 cycle in the environment and not contributing to greenhouse emission.[20] Thus, biomass sources are termed as CO_2 neutral. Henceforth coal combustion blended with biomass reduces fossil-based CO_2 emissions to a healthy extent. When biomass is combusted, the release of CH_4 from land-filling is avoided besides mitigating the greenhouse effect.[21] Biomass serves a variety of energy needs such as heat required for boilers, heating houses during winters, providing process heat for industries, etc. Reports state that India is the second-largest producer of Rice husk after china with the production in our country being 120 million tons per annum.[22, 23] However, the effective as well as systematic consumption of this biomass (Rice husk), is still uncharted resulting in unfortunate situations such as the Delhi Air pollution crisis during the winters of the year 2019 caused due to firing of this biomass in the fields by Haryana farmers.[24] In such a scenario, the utilization of rice husk as biomass for co-firing with coal will be advantageous for the eco-system as well as the energy sector.

Co-firing is the simultaneous combustion of two or more energy sources to create one or multiple energy carriers.[25] Primarily there are three routes for the biomass co-firing namely direct co-firing, indirect co-firing, and parallel co-firing. In direct co-firing, the biomass and coal are together sent to common pulverizer for milling and directly feed to a boiler for combustion. Whereas, the concept of indirect co-firing involves, converting solid biomass into clean fuel gas, using a biomass gasifier. The gas can be burnt in the same furnace as the coal. For this reason, it is also possible to use biomass, which is difficult to grind. The gas can be cleaned and filtered before use, to remove impurities. This principle is less researched than direct co-firing. The parallel co-firing concept involves the establishment of separate boilers for biomass and coal, biomass producing low-grade steam, being utilized in coal-fired power plants to increase co-firing efficiency. All three methods possess merits and demerits as well. However, direct co-combustion is the popular method for co-firing and is extensively used because of its low cost and easy applicability.[26]

Figure 1 depicts the schematic flow of setup utilized for co-firing in India; Generally rectangular fluidized bed combustor is used for co-firing at bulk level.[27] However for small scale co-firing, coal fired fluidized bed furnace with few modification such as separate inlet for biomass is sufficient enough to carry out the operation.

Co-firing of biomass has advantages over raw biomass combustion. Here the continuous supply of biomass is not an issue as a primary fuel in the form of coal is always prevailing for boilers. Moreover, biomass co-firing reduces the emission of flue gases such as CO_2, NO_x, and SO_x, etc.[28, 29] Owing to low

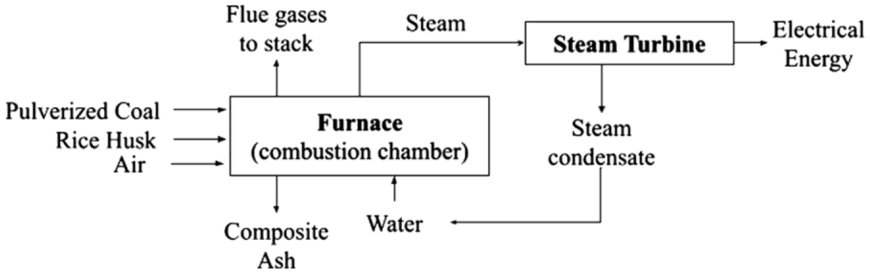

Fig. 1 — Schematic layout of small-scale co-firing power plant.

sulfur content of biomass compared to other fuels, causing decline in air pollution to a good extent. As co-firing utilizes the same thermal power plant setup with minor modifications, economical disputes regarding capital costs are curtailed.[30] The cost of composite fuel i.e. biomass blended with coal would be often less than that of primary fuel (coal), plummeting the operating cost eventually. Voluminous studies regarding the co-firing of variety of biomass with coal for energy generation are available in the literature. Several factors such as boiler efficiency, gaseous and particulate emissions, and combustion characteristics are extensively described in the literature.[31-37]

The ash generated from the co-combustion is termed as composite ash. The composition of this ash is dissimilar from fly ash as it constitutes 85 to 90% amorphous silica chiefly with a trace of alumina and carbon particles also pose environmental pollution. Due to varied compositions, this ash is found to be inapplicable in various fields, particularly in housing construction. Thus, proper ways for the disposal of this ash are yet to be context.

Current paper deals with the energy as well as cost-benefit analysis for a mini thermal power plant based on theoretical assumptions for different compositions of biomass and coal. According to the study conducted by authors, shorthanded literature is available for the energy analysis for a thermal power plant. These cases also propose a cost-effective solution for the utilization of composite ash generated in addition to CFA as well. Besides this, experiments have been simultaneously conducted to produce Molecular sieve 4A using composite ash and published elsewhere. [38]

2 Materials and Methods

To study the impact, number of coal samples has been procured from nearby thermal power plants and rice husk was collected through farmers end in the vicinity of Nagpur city.

2.1 Energy extraction from the composite Fuel

According to the power plant data, during the initial steps, the coal was fed to pulverizer to crush and reduce its grain size. The blending of coal with biomass in prefixed ratio was done in the blower functioning as a pneumatic conveyor. The blended biomass was combusted in a furnace to produce electricity by steam generation. The leftover of post combustion is then transferred into the stack where composite ash was separated with the help of an Electrostatic Precipitator (ESP). Such a power plant merely produces energy up to 8-10 MW which can be utilized in serving energy requirements of rural areas in the country. It is noteworthy that the power plant can be up scaled to 20- 25 MW if connected in grid.

The physical & thermal Properties of rice husk & coal that has been cited from literature are mentioned below in Table 1. [39-41] The heat of combustion values for coal and rice husk was obtained in laboratory using bomb calorimeter.

2.3 Energy and mass balance analysis

2.3.1 Energy and Mass balance for a 25 MW Power Plant

Considering a 25 MW power plant operates for 24 hours. Hence, the minimum amount of energy generated will be

$$25\ \text{MW}\times 24\ \text{h} = 600\ \text{MW-h/day} \quad \ldots (1)$$

Converting this energy into joules as:

$$600\ \text{MW}\times 3600\text{s} = 2.16\times 10^{6}\ \text{MJ/ day} \quad \ldots (2)$$

Now approximately 40% of heat generated in the boiler will essentially occur as electric energy so, in order to achieve energy generation mentioned in equation (2), the required heat generation will be 5.40×10^{6} MJ/ day which is calculated as:

$$2.16\times 10^{6}/0.4 = 5.40\times 10^{6}\ \text{MJ/day} = \mathbf{E} \quad \ldots (3)$$

Where, **E** is the minimum energy generation requirement in order to produce desired power. The Gross Calorific Value of Rice husk was found to be

Table 1 — Physical & Thermal Properties of Rice Husk & Coal

Sr No	Physical & Thermal Properties	Unit of Measurement	Rice Husk	Coal
1	Moisture Content	%	11-12	7.5-9
2	Bulk Density	Kg/m3	96-100	700-1100
3	Carbon Content	%	35-37	57-59
4	Hydrogen Content	%	8-9	4-5
5	Oxygen Content	%	34-36	10-12
6	Nitrogen content	%	8.5-10	1.0-1.5
7	Sulphur content	%	Nil	0.4-0.6
8	Silicon	%	8-9	Nil
9	Ash Content	%	NA	25-28
10	Gross Calorific Value	MJ/ton	14700-14750	22600-22650

14705.24 MJ/ton, and for Coal it is found to be 22634.7 MJ/ ton used in thermal power plant.[42]

Further the amount of Coal required to satisfy the above mentioned demand of energy can be calculated as:

$$5.40\times 10^{6}\ \text{MJ}/\ 22634.7\ \text{MJ} = 238.57\ \text{tons} = \mathbf{M} \qquad \ldots (4)$$

Where, M represents mass of coal combusted in power plant using traditional method.

The equivalent CO_2& H_2O generation in pure coal burning can be calculated as:

$$M\times Wc\times(44/12) = M_{CO2}\ ;\ M\times W_H\times(18/2) = M_{H2O}$$

Where, Wc & W_H are the carbon and hydrogen content present in the fuel.

Therefore, CO_2& H_2O generation in case of pure coal by putting a fix value for carbon and hydrogen from literature is

$M_{CO2} =$ 238.57 × (58.96/100) × (44/12) = 515.75 tons or (515.75 ×1000)/(600×1000) = 0.859 kg/kWh

M_{H2O} = 238.57× (4.16/100) × (18/2) = 89.32 tons or (89.32 ×1000)/(600×1000) = 0.148 kg/kWh

However, in current scenario new approach for the energy generation is used namely co-firing of coal and biomass in variable composition. Therefore, the actual amount of energy generated **(E_{cf})** using this route can be calculated as:

$$\mathbf{M}\times F_c\times C_c + \mathbf{M}\times F_{Rh}\times C_{Rh} = \mathbf{E_{CF}} \qquad \ldots (5)$$

Where, $F_c$and C_c represents the mass fraction and calorific value of coal respectively, whereas $F_{Rh}$and $C_{Rh}$are indicating mass fraction and calorific value of rice husk.

2.3.2 Calculations for composite Fuel (Coal 20 parts and Rice Husk 80 Parts)

Amount of coal is taken to be 20% of fuel and Rice Husk is 80% of the fuel. Therefore, the stoichiometry can be assigned as F_c= 0.2 and F_{Rh} =0.8

Here amount of Coal required can be calculated as

$$M_c = F_c\times \mathbf{M} = 0.20\times 238.57\ \text{tons} = 47.714\ \text{tons}. \qquad \ldots (6)$$

In the similar way amount of Rice Husk required,

$$M_{Rh} = F_{Rh}\times\mathbf{M} = 0.80\times 238.57\ \text{tons} = 190.856\ \text{tons}. \qquad \ldots (7)$$

Net energy generated from this composite fuel can be calculated as,

$$(M_c\times C_c) + (M_{Rh}\times C_{Rh}) = \mathbf{E_1} \qquad \ldots (8)$$

(47.714 ×22634.7) + (190.856 ×14705.4) MJ= 3.88×10^6 MJ (approx.)

But as stated by equation (3), the required amount of energy is 5.40×10^6 MJ/day and hence the shortage of energy is calculated as

$$\mathbf{E\text{-}E_1} = (5.40\times10^{6} - 3.88\times10^{6}\ \text{MJ}) = 1.52\times 10^{6}\text{MJ} \qquad \ldots (9)$$

This energy difference is attributed to the variance in calorific value of rice husk and coal. In order to fulfill this surplus energy demand, additional amount of biomass required can be calculated as:

$$(\mathbf{E- E_1})/\ C_{Rh} = [5.40\times10^{6}\ \text{MJ} - 3.88\times10^{6}\ \text{MJ}]/\ 14705.24 = 103.36\ \text{tons} \qquad \ldots (10)$$

Total amount of Rice Husk required is 190.856 tons + 103.36 tons= 294.22 tons … (11)

The equivalent CO_2& H_2O generation in this case is calculated as

$$(M_c\times W_{CC} + M_{Rh}\times W_{CRH})\times(44/12) = M_{CO2}\ ;\ (M_c\times W_{HC} + M_{Rh}\times W_{HRH})\times(18/2) = M_{H2O}$$

W_{CC} &W_{HC} are the carbon & hydrogen content in coal whereas W_{CRH} & W_{HRH} are the carbon & hydrogen content in rice husk.

Therefore, CO_2& H_2O generation in case of 80:20 composite fuel ratio is

$M_{CO2} =$ [47.741 × (58.96/100) +294.22 ×(37.05/100)] × (44/12) = 502.9 tons or (502.9×1000)/(600×1000) = 0.838 kg/kWh

M_{H2O} = [47.741 × (4.16/100) + 294.22 × (8.8/100)] × (18/2) = 250.89 tons or (250.89 ×1000)/(600×1000) = 0.418 kg/kWh

2.3.3 Calculations for composite Fuel (Coal 10 parts and Rice Husk 90 Parts)

Amount of coal is taken to be 10% of fuel and Rice Husk is 90% of the fuel. Therefore, the ratio of fuel can be assigned as Fc= 0.1 and F_{Rh} = 0.9

Here amount of Coal required can be calculated as

M_c=F_c × **M**= 0.10× 238.57 tons= 23.857 tons. … (12)

In the similar way amount of Rice Husk required,

M_{Rh}= F_{Rh}×**M** =0.90× 238.57 tons= 214.731 tons. … (13)

Net energy generated from this composite fuel can be calculated as,

(M_c× C_c) + (M_{Rh}× C_{Rh}) = $\mathbf{E_1}$ … (14)
(23.857 ×22634.7) + (214.731×14705.24) MJ= 3.69×10^6 MJ (approx.)

But as stated by equation (3), the required amount of energy is 5.40×10^6 MJ/day and hence the shortage of energy is calculated as

$\mathbf{E\text{-}E_1}$= (5.40×10^6- 3.69×10^6 MJ) = 1.71×10^6MJ … (15)

This energy difference is attributed to the variance in calorific value of rice husk and coal. In order to fulfill this surplus energy demand, additional amount of biomass required can be calculated as:

($\mathbf{E\text{-}E_1}$)/ C_{Rh} = [5.40×10^6 MJ – 3.69×10^6 MJ]/14705.24 = 116.28 tons … (16)
Total amount of Rice Husk required is 214.731 tons + 116.28 tons= 331.011 tons … (17)

The equivalent CO_2& H_2O generation in this case is calculated as
(M_c×W_{CC} + M_{Rh}× W_{CRH}) × (44/12) = M_{CO2} ; (M_c×W_{HC} + M_{Rh}× W_{HRH})×(18/2) = M_{H2O}

W_{CC} &W_{HC} are the carbon & hydrogen content in coal whereas W_{CRH} & W_{HRH} are the carbon & hydrogen content in rice husk.

Therefore, CO_2& H_2O generation in case of 80:20 composite fuel ratio is
M_{CO2} = [23.857 × (58.96/100) +331.011 ×(37.05/100)] × (44/12) = 501.25 tons or (501.25×1000)/(600×1000) = 0.835 kg/kWh
M_{H2O} = [23.857 × (4.16/100) + 331.011 × (8.8/100)] × (18/2) = 271.09 tons or (271.09 ×1000)/(600×1000) = 0.451 kg/kWh

3 Results and Discussion

3.1 Cost benefit analysis

This analysis is based on the present cost of coal and rice husk per ton. From sources it is found that the present coast of coal and Rice Husk are ₹ 5500 and ₹ 3200 per ton.
a. For the traditional method of combustion the cost of coal is

₹ 5500 × 238.57ton = ₹ 13, 12,135 … (18)

b. In the similar way the cost of composite fuel for first case composite fuel consumed in 80:20 ratio can be calculated as:

(47.714×₹5500) + (294.22×₹3000) = ₹11,45,087 … (19)

c. Likewise, cost involved in referred process where composite fuel is consumed in 90:10 ratio (23.857× ₹5500) + (331.011× ₹3000) = ₹ 11,24,246 … (20)

3.2 Net profit analysis

As observed in the previous discussions, the cost of composite fuel is less than the pure coal used as a fuel in traditional method. Thus, the profit in co-combustion method is calculated as:

For 80:20 ratio of composite fuel, ₹13, 12,135 – 11,45,087 = ₹1,67,048 per day.

For 90:10 ratio of composite fuel ₹13, 12,135 – 11,24,246 = ₹1,87,889 per day.

Also, amount of coal saved in the process was found to be 190.856 tons and 214.713 tons per day for the cases 1 and 2 respectively. Calculating cost per unit (per KW-h) of electricity produced, for this the cost of fuel is divided by the energy capacity of plant in KW-h then,

For varying compositions, the manufacturing cost would be,

A. Pure Coal = ₹13,12,135/(600000 kW-h) = ₹2.18/ kW-h

B. 80:20 Blend composite Fuel = ₹11,45,087/(600000 kW-h) = ₹1.90/ kW-h

C. 90:10 Blend composite Fuel = ₹11,24,246/(600000 kW-h) = ₹1.87/ kW-h

3.3 Ash production

Ash is the prime by-product of coal based thermal power plants and its utilization is important for

Table 2 — CO_2 and H_2O emissions from composite fuel

Sr No	Fuel Cases	Quantity For 600 MW/day Plant Capacity		Quantity per kW-h Energy Generated	
		CO_2 (kg)	H_2O (kg)	CO_2 (kg/kW-h)	H_2O (kg/kW-h)
1	Pure Coal	515.75	89.32	0.859	0.148
2	RH: Coal (80:20)	502.9	250.89	0.838	0.418
3	RH : Coal (90:10)	501.25	271.09	0.835	0.451

environmental safety. However, the utilization of fly ash has definite directions due to its fixed chemical composition and pozzolanic behavior, making it a valuable additive to concrete for increasing the strength. Fly Ash Based Polymers as Wood Substitute, Portland pozzolanic cement are some of the other important uses.[43]

Nevertheless, the co-combustion of biomass with coal results in the production of residue termed as composite ash. Unlike fly ash the chemical composition of such ash is unpredictable due to certain issues. Primarily it depends upon the actual stoichiometry of biomass with coal followed at power plant for particular combustion period suggesting its effective utilization could be a challenging task.

3.4 Composite ash utilization into value-added products

On cramming the composition of composite ash, about 85-90% silica in amorphous form as well as 3to 5% of alumina is reported. Henceforth, it can be inferred that composite ash can be converted into Zeolites or Molecular Sieves; the method is reported elsewhere.[44-47] Composite ash can also convert into commercial-grade sodium silicate by alkali extraction and further into precipitated silica.[48-50] Products have a wide range of applications in the chemical industry as adsorbents, in wastewater treatment, gas separation, etc.[51-53]

The predicted amount of CO_2& Water generation in all 3 cases are tabulated and presented in Table 2. It is noteworthy that the other parameters of flue gas composition vary according to practical conditions of combustion such as pressure, temperature etc.

Since the composition of rice husk represents low sulphur, nitrogen and coal content, it results in to reduction in SOx, NOx and CO to a great extent. Experiments for theoretical estimations to study the impact of co-firing on flue gas emissions with particular tuning of biomass with coal are under vogue.

3.5 Advantages of mini thermal power plant

The raw material i.e., Rice husk as biomass is abundantly available in ample amount in our country. As mentioned earlier the flue gas emissions are reduced with the use of biomass and hence these power plants are eligible for the subsidies provided by the government. Also, this concept favors the conservation of coal heading a step towards sustainable development. Furthermore, farmers in rural areas can surely increase their income by using biomass as a source of additional revenue. Also, the amount of energy generated from this power plant is sufficient to cater to the requirement of a small village. The energy grid system can be applied to the system to provide energy equivalent to a 100 MW thermal power plant. Considering the economic aspect, a complimentary benefit of nearly 10 % can be obtained by using biomass as fuel for these power plants, and effectively a profit up to ₹ 1 lakh can be expected per day.

3.6 Process constraints

Due to the seasonal availability of biomass, it is often found difficult to store a large amount of biomass in power plant vicinity. Further, the maximum amount of energy generated is quite low i.e., up to 20-25 MW and hence it can be utilized to cater to the need of small district places or limited population cities. Also, the co-firing furnace is not commonly employed in India hence difficult to find the suppliers and fabricators.

4 Conclusion

Energy generation using composite fuel is proven to be an eco-friendly and cost-effective way, also supporting sustainable development. The amount of energy generated by such electric utility stations is low which is up to 8 to 25MWh thereafter identified as ‘Mini Thermal Power Plants’. These power plant model can be proposed to be utilized where the situations for the consumption of biomass are out of hand. The values generated for energy and mass balanced are based upon the plant capacity of 25MW running for 24hrs.Though we have represented the composition of fuel as 80: 20 and 90: 10 ratios however the mass of biomass in both the cases will required more than precalculated amount to certain extent to make the energy requirement. Besides cost benefit, it can curtail CO2 emission up to 0.021 to

0.024Kg per KWh. Further, the issue of composite ash generated during the co-firing plant could be resolved by producing value-added products like Silica and Molecular sieve 4A on large scale.

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