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Thermo Economic Evaluation for Co-Firing Power Generation Station

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ABSTRACT

The main objective of the current proposed work is to study the technical, environmental and economical feasibility of the implantation of co firing technology in a Biomass power plant with pulverised low rank coal. Co-firing biomass and coal increases the use of sustainable fuels without large capital investments, and takes advantage of the high efficiencies obtainable in coal-fired power plants. Fuel diversity is another advantage of biomass/coal co-firing. Co-firing reduces the need for a constant supply of biomass required as in a biomass power plant, and is a viable way to decrease the emissions of greenhouse gases and other pollutants from power-generating facilities. As a result, using renewable and sustainable energy resources, such as biomass co-firing, for electricity production exhibits great potential in the near future. The use of dedicated biomass feed stocks for electricity generation could help to reduce the accumulation of greenhouse gases. This work focuses on minimization of overall unit cost of electricity with a maximum performance.

Introduction

It would be difficult to replace the fossil fuels in the near future. Coal, based on known deposits, is expected to last for at least 119 years if consumed and produced at the current rates. Coal-fired power plants accounted for 41% of global electricity production in 2006 and are expected to account for 44% in 2030. Depleting supplies of fossil fuels and growing greenhouse gas emissions have driven the global interest in sustainable and environmentally friendly energy systems.

Co-firing is the burning of more than one type of fuel simultaneously. The fuel can be mixed with the coal outside the combustor, or the fuels can be added to the combustor separately. The most common type of facility for co-firing is large, coal-fired power plants. One of the reasons biomass is a good combination for co-firing with coal is that both biomass and coal are solid fuels. Co-firing biomass with coal is one of the ways to reduce greenhouse gas (GHG) emissions from coal-fired power plants. Combined with efficiency improvements, co-firing biomass leads to substantial reductions in CO_2 emissions from large scale power generation.

Most notably, biomass has a higher fraction of hydrogen and oxygen, and less carbon than coal. As a result, biomass tends to generate less energy than coal about two-thirds as much, on a mass basis. In addition, the differences in composition cause biomass to have a higher fraction of volatile matter. This difference can affect the optimum sizing and design of the combustion chamber, as well as the ideal flow rate and location of combustion air. Co-firing in existing coal-fired plants is advantageous as it can be implemented in a relatively short period of time and with small investment.

Capata and Sciubba [6] described the feasibility of different power cycles from both thermodynamic and operative points of view. Tsatsaronis and Winhold (1984) carried out detailed mass, energy, exergy and money balances for a reference steam power plant and investigated the effect of the most important process parameters on the exergic efficiency. Anil et al. solved the equations containing four atom balances C, O, H, and N and the equilibrium relations for gas compositions using MATLAB in atmospheric conditions.

The main aim of the work presented here was based on the technical, environmental and economical feasibility of the implantation of co firing technology in a Biomass power plant with pulverised low rank coal.

Thermodynamic Analysis

Thermodynamic model

The schematic flow diagram of a steam power cycle is shown in Figure 1. The temperature-entropy diagram for the proposed model is shown in Figure 2. High pressure steam from the boiler enters the steam turbine to generate power. The exergy analysis of the fuel is performed to obtain the air fuel ratio and the quantity of air required to combustion and it's been determined with the help of ultimate analysis of the fuel. And certainly it's been calculated for 1MW of co-firing power plant.

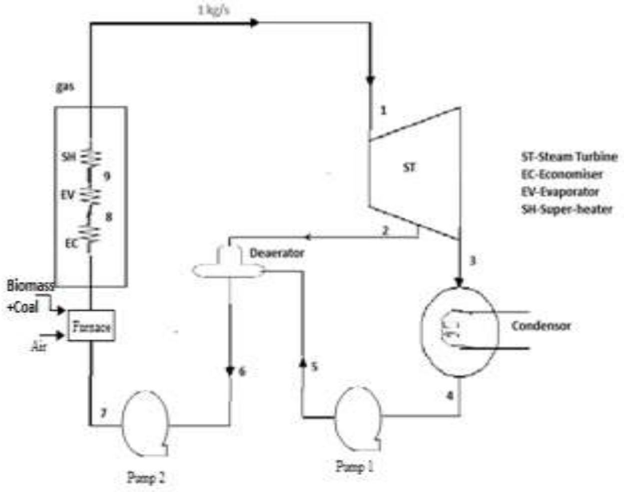

Fig1.Schematic diagram for a Co-firing power plan

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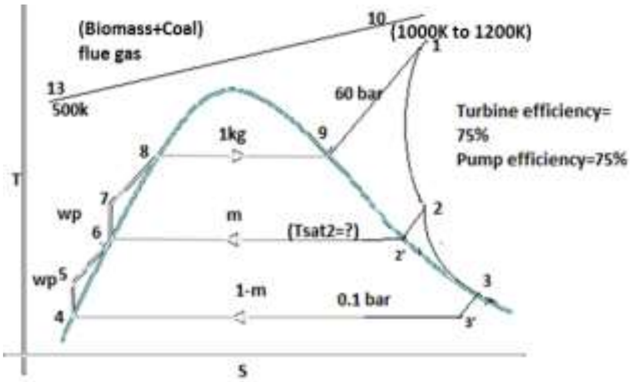

Fig 2.T-S diagram for the Co-firing power plant

Characteristics of Fuels

Proximate Analysis

Product	Fixed Carbon%	Volatile Matter%	Ash%	Moisture%
Rice Husk	19.1	54.2	18.8	7.9
Coal	34.69	20.70	38.63	5.98

Ultimate analysis

Product	C%	H%	O%	N%	S%	Ash%	Moisture%
Rice Husk	38.1	4.7	29.3	1.5	0.1	18.5	7.8
Coal	37.69	2.66	5.78	1.07	0.8	47	5.0

Gas composition of complete combustion

Co-firing share of coal (Pc) is defined as the ratio of the mass of coal to the total mass of coal and biomass mixture and can be written as

$$Pc = \frac{\text{Mass of Coal}}{\text{Mass of Coal} + \text{Mass of Biomass}}\ x\ 100 \qquad (1)$$

Similarly, co-firing share of biomass, also named as co-firing ratio (Pb) is the ratio of the mass of biomass to the total mass of coal and biomass mixture and can be written as:

$$Pb = \frac{\text{Mass of Biomass}}{\text{Mass of Coal} + \text{Mass of Biomass}}\ x\ 100 \qquad (2)$$

The biomass and coal is defined by a general formula as $Ca_{11}Ha_{12}Oa_{13}Na_{14}$ and $Ca_{21}Ha_{22}Oa_{23}Na_{24}$. The reactions are solved using chemical combustion energy equation. The products contain CO_2, H_2, H_2O, and N_2. The following is the chemical reaction in co-firing combustion

$$f_c(Ca_{11}Ha_{12}Oa_{13}Na_{14})+f_b(Ca_{21}Ha_{22}Oa_{23}Na_{24})+air \rightarrow Product \qquad (3)$$

The molar flow rate of the reactants is the sum of molar flow rate of carbon, hydrogen, oxygen, sulphur, ash, moisture, and air. The molar flow rate of all the reactants, excluding air can be found from the ultimate analysis of the fuels.

$$a1 = \frac{PbCb + PcCc}{Mc} \qquad (4)$$

The coefficients a_2, a_3, a_4 are determined, respectively. In equations a1 to a5 are the molar flow rates of carbon, hydrogen, oxygen, nitrogen, and moisture, respectively. The subscripts c and b denote coal and biomass, while the letters P, M, and m represent the percent share of co-firing, molecular weight, and mass respectively.

Combustion

Using the results of the fuel analyses for the co-firing materials the air fuel ratio, chemical equilibrium calculations were performed for representative combustion over a range of reaction temperature.

$$Ca_1Ha_2Oa_3Na_4 + a_5\ (O_2 + 3.76N_2) + a_6H_2O \rightarrow b_1CO_2 + b_2\ H_2O + b3O_2 + b4N_2 \qquad (5)$$

The value of b_1, b_2, $b3$, $b4$ can be determined from the exergy balance of above equation.

$$H_{f,fuel}+a_5\ (h_{T},o_{2+}\ 3.76\ h_{T,N2})+\ a_6\ h_{f,h2o(l)} = b_1(h_{f,co2}+h_{T,co2})_+ b_2(h_{f,H2O}+h_{T,H2O})+b_3(h_{T,O2})_+ b_4(h_{T,N2}) \qquad (6)$$

Theoretical work done of the turbine has been calculated by the formula

$$W_T= (h_1-h_2) + (1-m)\ (h_2-h_3) \qquad (7)$$

$$\text{Cycle Efficiency}= (W_T - W_{p1} - W_{p2})/\ (m_{1*}(h_1-h_7)) \qquad (8)$$

And the cycle efficiency was been calculated as 41.74%

6. Integration of combustion to Boiler feed

The temperature of boiler is varied from 1000°C to 1200°C and T_{13} is 300°C.

$$h_{10}=b_1h_{T,\ co2+}\ b_2h_{T,\ h2o+}\ b_3h_T,\ o2_+\ b_4h_{T,\ N2} \qquad (9)$$

$$h_{13}=b_1h_{T,\ co2+}\ b_2h_{T,\ h2o+}\ b_3h_{T,\ o2+}\ b_4h_{T,\ N2} \qquad (10)$$

Exergy Balance

$$(h_{10} - h13) = m_s\ mol\ (h_1-h_7) \qquad (11)$$

Power has been calculated by the formula $P= m_s\ mol\ W_{net}$ (kJ/kg.mol) (12)

The calorific value of fuel is 14992.225 KJ/kg and molecular weight of the fuel is calculated for different combustion temperature which is used over.

$$m_s = 1000kw\ /\ w_{net}\quad (kg/sec\ for\ 1MW) \qquad (13)$$

The Efficiency of the plant is found by $(P/m_f.CV)$ *100; (14)

CV-Calorific Value

Economics of co-firing

The economic evaluation of co-firing coal with biomass is complex. The evaluation must include several components. The price of the fuel is frequently a very important, if not the most important, determinant of a plants economic viability, particularly if high percentages of biomass fuel are used. Biomass fuel prices can be either positive or negative within an extremely broad price range. Operating and maintenance costs are dependent on the technology used to store, process and burn the fuels and the potential impact of fuel characteristics on plant performance, including efficiency. The latter cost projection can be complicated by the variable nature of some waste fuels.

De and Assadi [5] developed a tech-economic model to investigate the economics of biomass co-firing. The model is based on the pilot plant test results for co-firing and heat and mass balances. Total additional cost as well as additional specific costs can be estimated with the help of this model. The model can also be applied to assess the economic feasibility of retrofitting for biomass co-firing as well to estimate the required incentives or this purpose.

Basu et al. [4] carried out an economic analysis of an existing 150 MW pulverized coal fired power plant in Eastern Canada by considering all three co-firing options (direct, indirect, gasification based). Capital and operating costs were calculated to determine the internal rate of return (IRR). CO_2 reduction cost was also computed for these three options and this cost was also compared with CO_2 sequestration cost. The cost of CO_2 sequestration was higher than that of all three technologies. IRR of direct co-firing observed to be more than twice than that of indirect co-firing. But large uncertainties of fouling and corrosion of super heaters in case of direct co-firing make this option less feasible. Although the capital investment required for the implementation of indirect co-firing is the highest, the risk of uncertainties is the least minimum.

Result and Discussion

A thermo economic analysis has been carried out in order to investigate plant efficiency, Power output, and cost of power. The net work output of cycle, in the percent of lower heating value as well as exergy of biomass, is expressed as energy efficiencies respectively to evaluate the cycle. The variation of plant efficiency with respect to co-firing ratio has been plotted and there is a gradual increment in the plant efficiency. The cost of power per kWh is calculated with respect to the total cost and variable cost of the co-firing plant. The cost of unit power varies with respect to the co-firing ratio. Co-firing based system will perform at different co-firing conditions and for different combinations of fuels if they are considering retrofitting of their existing coal-based plants for biomass co-firing.

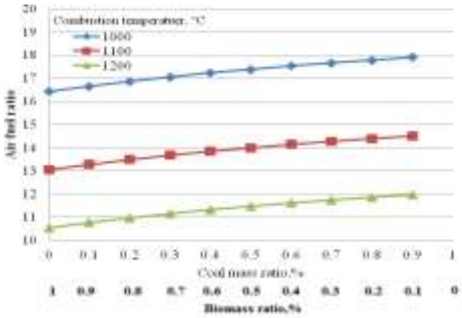

Fig 1. Variations in air fuel ratio with combustion temperature and Co firing mass ratio

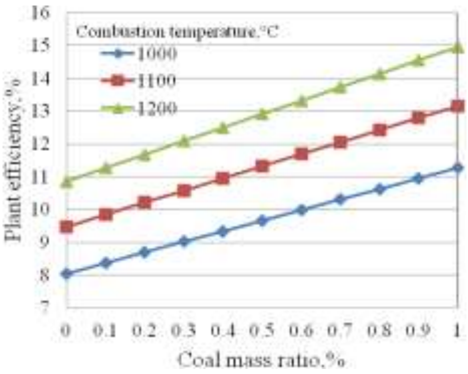

Fig 2. Variation of Plant efficiency with combustion temperature and coal mass ratio

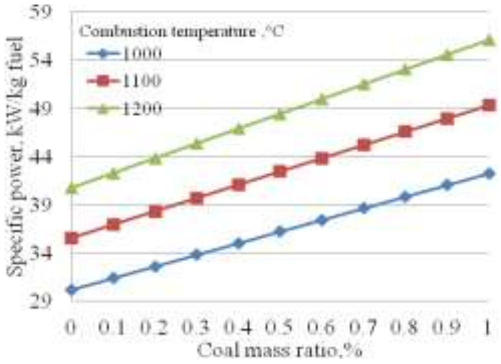

Fig 3. Variation of Specific power with combustion temperature and coal mass ratio

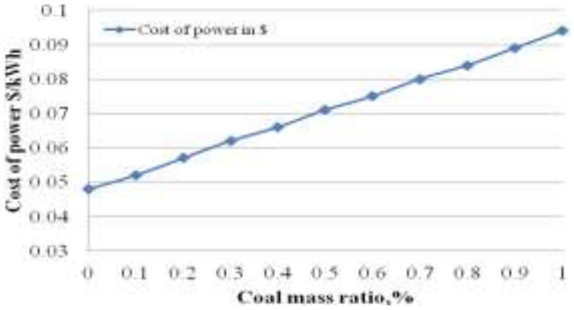

Fig 4. Variation of Cost of power /kWh in USD with coal mass ratio

Conclusion

In current work, the economical feasibility of co-firing fuel ratio is analyzed with the help of energy cycle. Using MAT Lab, the co-firing ratio is iterated and a graph is plotted with respect to air fuel ratio, plant efficiency, specific power, and unit cost of power (USD) for 1MW. The efficiency of plant varies with respect to change in coal-biomass ratio. The results show that, co-firing based system will perform at different co-firing conditions and for different combinations of fuels if they are considering retrofitting of their existing coal-based plants for biomass co-firing. And from literature the unit cost of power is 0.08 USD.

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