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.

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.

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

Characteristics of Fuels

<table>
<thead>
<tr>
<th>Product</th>
<th>Fixed Carbon%</th>
<th>Volatile Matter%</th>
<th>Ash%</th>
<th>Moisture%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Husk</td>
<td>19.1</td>
<td>54.2</td>
<td>18.8</td>
<td>7.9</td>
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<tr>
<td>Coal</td>
<td>34.69</td>
<td>20.70</td>
<td>38.63</td>
<td>5.98</td>
</tr>
</tbody>
</table>

Ultimate analysis

<table>
<thead>
<tr>
<th>Product</th>
<th>C%</th>
<th>H%</th>
<th>O%</th>
<th>N%</th>
<th>S%</th>
<th>Ash%</th>
<th>Moisture%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Husk</td>
<td>38.1</td>
<td>4.7</td>
<td>29.3</td>
<td>1.5</td>
<td>0.1</td>
<td>18.5</td>
<td>7.8</td>
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<tr>
<td>Coal</td>
<td>37.69</td>
<td>2.66</td>
<td>5.78</td>
<td>1.07</td>
<td>0.8</td>
<td>47</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Gas composition of complete combustion

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

\[ Pe = \frac{\text{Mass of Coal}}{\text{Mass of Coal} + \text{Mass of Biomass}} \times 100 \]  

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:

\[ Pb = \frac{\text{Mass of Biomass}}{\text{Mass of Coal} + \text{Mass of Biomass}} \times 100 \]  

The biomass and coal are defined by a general formula as \( C_{a1}H_{a2}O_{a3}N_{a4} \) and \( C_{b1}H_{b2}O_{b3}N_{b4} \). 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 \( f_{e}(C_{a1}H_{a2}O_{a3}N_{a4}) + f_{b}(C_{b1}H_{b2}O_{b3}N_{b4}) + \text{air} \rightarrow \text{Product} \)

\[ \text{Product} = \text{bl} \cdot \text{bl} \cdot \text{C} + \text{Pe} \cdot \text{Ce} \]  

The coefficients \( a_1 \), \( a_2 \), \( a_3 \), \( a_4 \), are determined, respectively. In equations 1 to 5 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.

\[ C_{a1}H_{a2}O_{a3}N_{a4} + a_4 \cdot (O_2 + 3.76N_2) + a_3H_2O + b_1CO_2 + b_2H_2O + b_3O_2 + b_4N_2 \]  

The value of \( b_1 \), \( b_2 \), \( b_3 \), \( b_4 \) can be determined from the exergy balance of above equation.

H_{inlet} \cdot a_5 (H_{f,CO_2} + 3.76 H_{f,N_2}) + a_5 (H_{f,CO_2} + H_{f,N_2}) + b_1 (H_{f,CO_2} + H_{f,N_2}) + b_2 (H_{f,H_2O} + H_{f,H_2O}) + b_3 (H_{f,H_2O} + H_{f,H_2O}) + b_4 (H_{f,N_2} + H_{f,N_2})

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

\[ W_T = (h_{t-h_2}) + (1-m) (h_{t-h_3}) \]  

Cycle Efficiency = \( \frac{W_T - W_{pt} - W_{p2}}{W_{p1} - (h_{t-h_3})} \)  

And the cycle efficiency was been calculated as 41.74%.

Integration of combustion to Boiler feed

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

\[ h_{10} = b_1 (H_{f,CO_2} + H_{f,N_2}) + b_2 (H_{f,H_2O} + H_{f,H_2O}) + b_3 (H_{f,H_2O} + H_{f,H_2O}) + b_4 (H_{f,N_2} + H_{f,N_2}) \]  

Exergy Balance

\( h_{10} - h_{13} = m \cdot W_{int} \) (kJ/kg.mol)

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.

\( m = \frac{10000 \text{kw}}{W_{int}} \) (kg/sec for 1MW)

The Efficiency of the plant is found by \( (P/m_{CV}) * 100 \); 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). CO₂ reduction cost was also computed for these three options and this cost was also compared with CO₂ sequestration cost. The cost of CO₂ 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 MATLAB, 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.

References
8. Economics of co-firing waste materials in an advanced pressurized fluidized bed combustor, Donald L.Bonk, 1995, ASME.