WASTE ENERGY RECOVERY IN IRON AND STEEL INDUSTRIES FOR CO$_2$ EMISSION REDUCTION: A CASE STUDY

Nallapaneni Manoj Kumar, M. S. P Subathra and Orville Damaso Cota

Department of Electrical and Electronics Engineering, Karunya University, Coimbatore, Tamil Nadu (INDIA)

Received January 10, 2015 Accepted July 10, 2015

ABSTRACT

In this paper a study on waste energy recovery in iron and steel industries is presented, the major by-products are heat energy, Blast Furnace Gas (BFG), Coke Oven Gas (COG) which are widely vented to the atmosphere without proper utilization. On account of this, it is an important task for iron and steel industries to effectively utilize these by-products so as to reduce the impact of Green House Gas (GHG) emissions on the environment. On the contrary, the power generated through these by-products will replace the major quantity of electricity that could have been generated by burning fossil fuels in thermal power plants which are the major sources of GHG, thus GHG emission reduction could be achieved. For effective emission reductions, it requires specially designed mechanical systems namely expansion turbines, pressure turbines, coke oven batteries and heat recovery which are used as a case to reveal the improved efficiency of energy and CO$_2$ emission reduction approximately 6,09,874.5968 tCO$_2$/yr.

Key Words: Waste energy recovery, BFG, COG, GHG, Emission reduction, tCO$_2$

INTRODUCTION

It is well known fact that iron and steel industries are one of the leading energy-intensive industries owning to their process needs, which are highly dependent on fossil fuels and contributes to 15% of anthropogenic GHG emissions in world scenario. As for IEA, iron and steel industries contributes approximately 5% of the total world’s CO$_2$ emissions. This is because of the dependence on fossil fuels mainly coal, crude oil, natural gas for energy production to meet out the energy requirements. The increase in the production levels in industries have a great influence in energy consumption levels, to meet this energy demand many of the industries uses coal as the major source for power generation. As we know fossil fuel fired power plants influence climate via both the emissions of long lived CO$_2$ and short lived ozone and aerosol precursors. The list of long lived GHG emissions such as CO$_2$, CH$_4$, N$_2$O, HFC and PFCs are listed (Table 1) along with their average life time in the atmosphere including global warming potential (Intergovernmental Panel on Climate Change’s AR5 2007). According to U.S. Department of Energy India is the third largest CO$_2$ emitting country in the world with an average carbon dioxide emission growth of 5.7% per year over a period 1950-2008. The detailed information about the emissions are shown in Fig. 1, which are taken from carbon dioxide information analysis center. Fig. 2 shows the greenhouse gas emission as for 2007 statistics, India accounts 1904.73 MtCO$_2$ GHG emissions from various sectors among which 22% is contributed by industrial sector i.e. 412.55 MtCO$_2$ out of which the contribution of the iron and steel manufacturing sector is about 28.4% i.e. 117.008 MtCO$_2$ or 6.2% of the total India’s GHG emission. From the above statistics, it is clear that the steel sector is one of major emitters of GHG to the atmosphere in various forms as gases, heat, dust and volatile compounds. In this context, it is a great task for steel industries to manage their emissions as for the prescribed
levels by pollution control boards and also in 2010, Government of India passed a notice to industries to reduce their emission by 25% as on 2005 levels by 2020 (UNFCCC).

Table 1: Major long lived GHG emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Avg. life time in the atmosphere</th>
<th>100-year global warming potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Moves among the ocean-land system</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>N₂O</td>
<td>121</td>
<td>265</td>
</tr>
<tr>
<td>Fluorinated gases</td>
<td>Few weeks -Thousands of years</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Source: Intergovernmental Panel on Climate Change (IPCC), AR5

Fig. 1: Emissions by India as per 2010 in metric tons of carbon

Fig. 2: Sector wise emission of GHG

In such scenario iron and steel industries are strongly committed in reducing their CO₂ emissions by implementing advanced emission control and monitoring measures so as to take
action against increasing emissions. The objective of this paper is to understand and quantify the \( \text{CO}_2 \) emission reduction in \( \text{tCO}_2 \) with proper utilization of waste fuels in iron and steel plants such as heat energy, blast furnace gas and coke oven gas using a waste energy recovery units. The waste energy recovery units that are described in this paper are expansion turbines, pressure turbines and heat recovery systems which use the pressure and heat energies of these by-products to generate power by reducing the environmental effects due to these by-products. Thus reducing the carbon dioxide emission which are quantified in \( \text{tCO}_2 \).

**AIMS AND OBJECTIVES**

To understand the details process of power generation and emission reduction.

**MATERIAL AND METHODS**

Indian steel sector includes many joint iron and steel works namely RINL-VSP,TATA, JSW, JSPL etc., among all of these industries only RINL-VSP is considered in this study mainly focusing on \( \text{GHG} \) emission reduction by utilizing the \( \text{GHG} \) intensive fuels for power generation. In general, three approaches are used for estimating \( \text{GHG} \) emissions shortly called Emission Estimation Techniques (EETs) given as below, namely4,5

1. Sampling or direct measurement
2. Mass balance approach
   (Emission calculation using fuel analysis)
3. Emission factors and emission modeling

The above mentioned methodologies are obtained from IPCC 2006 and UNFCCC guidelines, according to these guidelines \( \text{CO}_2 \) emissions are estimated by multiplication of gas energy content to its relative emission factors. In this paper, we use mass balance approach to estimate \( \text{CO}_2 \) emissions from combusting BFG, COG along with coal in multifuel firing boilers for power generation. Thus, a quantitative analysis is applied to evaluate \( \text{CO}_2 \) emissions based on law of conservation of mass. Following the guidelines of IPCC and also UNFCCC, the amount of \( \text{GHG} \) emissions are calculated using following equations.7,8

\[
\text{PEfc} \cdot j, y = \sum FCI \cdot j, y \times COEFi \cdot y, y \ldots .. (1)
\]

\[
\text{COEFi}, y = Wc, i, y^* \frac{44}{12} \ldots .. (2)
\]

\[
\text{COEFi}, y = \text{ncvi}, y^* \text{ECFO}_i, y \ldots .. (3)
\]

Where \( \text{PEfc} \cdot j, y \) is the \( \text{CO}_2 \) emissions from fossil fuel combustion in process ‘j’ during the year ‘y’ taken in \( \text{tCO}_2/\text{yr} \). \( FCI \cdot j, y \) is the \( \text{CO}_2 \) emission coefficient of fuel type ‘i’ in year ‘y’ taken in \( \text{tCO}_2/\text{mass unit} \) of the fuel. \( \text{Wc, i, y} \) refers to the weighted average net calorific value of the fuel type ‘i’ in year ‘y’ taken in \( \text{GJ/mass or volume unit} \). \( \text{FCO}_i, y \) is the weighted average \( \text{CO}_2 \) emission factor of fuel type ‘i’ in year ‘y’ taken in \( \text{tCO}_2/\text{mass or volume unit} \). \( \text{ECFO}_i, y \) is the weighted average \( \text{CO}_2 \) emission coefficient of fuel type ‘i’ in year ‘y’ taken in \( \text{tCO}_2/\text{GJ} \) of the fuel. As per the UNFCCC-CDM equation-1 one gives the emission that are released due to the combustion of fossil fuel but in this case \( \text{CO}_2 \) emission coefficient can be calculated using any one of the equations-2 and 3 based on the availability of data. It is prefered to proceed with equation-2 when all the sufficient data is available rather the equation-3. Calculating the \( \text{CO}_2 \) emission coefficient needs either the fossil fuel composition which we are firing in the boilers or the net calorific value in \( \text{GJ/mass or volume unit} \). The data required in this study is taken from RINL-VSP specifications, central and state government organisations and from standard publications. Most of the data related to emission factors is taken from IPCC, Central Electricity Authority.

In the same study, few waste energy recovery systems does not undergo any fuel buring in the power generation process, instead they use only pressure energy of gas or waste steam or heat energy to generate power. In such cases \( \text{CO}_2 \) emission reductions are calculated by multiplying the amount of energy that is generated over a period of time to its relative emission factor given as follows.\(^9,10\)

---

Baseline Emission= $EE_g \cdot EF_{grid_y}$ \ldots (4)

Emission reduction is calculated by subtracting the emission that are produced due to the self energy consumption of power generation unit.

Emission Reductions = (Baseline Emission - Emissions that are released due to self energy consumption) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5)

Where $EE_g \cdot y$ is the electrical energy generated in the year ‘y’ taken in MWh and $EF_{grid_y}$ is the emission factor of southern grid electricity taken in tCO$_2$/MWh, CEA.\textsuperscript{11}

**Case study : Waste energy recovery systems**

A case study has been formulated for reducing CO$_2$ emissions with the use of advanced technical measures like gas expansion turbines, back pressure turbines, coke oven battery power plant\textsuperscript{12}. Within iron and steel industries, BFG and COG are the fundamental by-products gases. The detailed gaseous composition with properties is given in Table 2. BFG is produced in the blast furnace division of the plant when iron ore is reduced to hot metal accomplished through reaction with coke, dolamite and other gaseous fuels\textsuperscript{13}. BF is the heart of iron and steel manufacturing process and it releases more than half of the CO$_2$ emissions in the plant: The RINL-VSP having three blast furnace divisions BF-1, BF-2 and BF-3 of capacity 3200m$^3$, 3200 m$^3$ and 3800 m$^3$ respectively with BFG top pressure 2.0-2.6 KSC is studied here.\textsuperscript{14-16} Coke ovens are another strongest source for CO$_2$ emissions in the plant during the conversion of coal into coke in the absence of air. In RINL-VSP there are four coke oven batteries which produce 3.2 MT dry coke, each battery of 7 meters tall and having 67 ovens. These by-product gases are then passed through the High Pressure Network (HPN) or Low Pressure Network (LPN) which are then internally recycled to meet the heat demands of the steel manufacturing process in substitute to some extent of natural gas. In some cases these gases are used in the captive power plants of industry for power generation.\textsuperscript{17} In major cases these gases are burned to produce energy, but before burning with turbine technologies shown in (Fig. 3 to Fig. 5). We can extract the pressure energy of the BFG before it is given to LPN and from LPN it is circulated in the plant. Similarly, back pressure turbines used to generate power from coke dry quenching steam.

**Table 2 : Composition and properties of by-product gases**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Blast Furnace Gas (BFG)</th>
<th>Coke Oven Gas (COG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas composition</td>
<td>$N_2$-54%, CO-25%, CO$_2$-18%, H$_2$-1.8%, O$_2$-0.5%, CH$_4$-0.4%</td>
<td>H$_2$-56.7%, CH$_4$-27.8%, CO-6.4%, $N_2$-3.5%, CO$_2$-2.3%, O$_2$-0.5%, H$_2$S-0.4%, Napthalene-0.65 g/Nm$^3$</td>
</tr>
<tr>
<td>Calorific value</td>
<td>700 kcal/Nm$^3$</td>
<td>4400-4700 kcal/Nm$^3$</td>
</tr>
<tr>
<td>Density</td>
<td>1.28 Kg/Nm$^3$</td>
<td>0.42-0.45 Kg/Nm$^3$</td>
</tr>
<tr>
<td>Properties</td>
<td>Poisonous, No smell, Heavier than air</td>
<td>Explosive, No colour, Smells like H$_2$S and Naphtha, Lighter than Air</td>
</tr>
</tbody>
</table>

Source: Rashtriya Ispat Nigam Limited-Visakhapatnam Steel Plant

**Fig. 3 : Gas expansion turbine station**
RESULTS AND DISCUSSION

In general, accurate emission estimation is not an easy task. It involves many monitoring methods or approaches which is beyond the scope of this work. However, in this paper emissions reductions are estimated as per the guidelines of IPCC and UNFCCC. In this study an approach towards iron and steel industry is considered mainly focusing on the by-product gases. In many cases these gases are not properly utilised in the industries result in the release of GHG emissions. These emissions can be reduced with the use of waste energy recovery units shown in (Fig. 3 to Fig. 5) that generates power using these by-products as a fuel, resulting in the emission reduction, quantified in tCO₂e shown in Table 3.

Table 3: Emission reductions in tCO₂ using waste energy recovery

<table>
<thead>
<tr>
<th></th>
<th>GETs</th>
<th>BPTS</th>
<th>COB-4 power plant</th>
<th>Multi-fuel firing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Emissions</td>
<td>1, 13, 245.44</td>
<td>70, 778.4</td>
<td>61, 341.28</td>
<td>6, 73, 142.4</td>
</tr>
<tr>
<td>Emissions due self-energy consumption</td>
<td>4,290</td>
<td>390</td>
<td>390</td>
<td>-</td>
</tr>
<tr>
<td>Emission Reduction</td>
<td>1, 08, 955.44</td>
<td>70, 388.4</td>
<td>60, 951.28</td>
<td>3,58, 111.7538</td>
</tr>
</tbody>
</table>

Emission factor analysis

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. In general, an emission factor is the ratio between the amount of pollution generated and the amount of a material processed during the industrial operation. A wide variety of sources can use emission factors to estimate emissions.
CO₂ emission factor of by-product gas is given as follows:

\[ EF = \frac{PC \times Mwp}{Mwf} \]  

Where:
- \( EF \) is the emission factor of the fuel,
- \( PC \) is the pollutant concentration in fuel in %,
- \( Mwp \) is the molecular weight of pollutant emitted
- \( Mwf \) is molecular weight of pollutant in fuel.

Using equation (6) emission factors of BFG and COG are calculated by referring to the Table 2 for PC values. The emission factors of BFG and COG are found to be 0.8525 Kg/Nm³ and 0.7169 Kg/Nm³ respectively. Electricity emission factor for southern grid (RINL-VSP comes under this grid) is 0.8426 tCO₂/MWh taken from Central Electricity Authority Board. We can also evaluate the emission factor of grid electricity by considering the combined margin.

However, in this study emission factor of electricity that is consumed in the industrial requirement is calculated using build margin and operating margin, this is calculated because the electrical energy consumed in industrial is not only from the coal but it is of all kinds including renewable energy and the value is computed as 1.3 tCO₂/MWh.

**Emission reduction in GETs**

GETs represents the Gas Expansion Turbines shown in Fig. 3, located in blast furnace zone between the blast furnaces BF-1 and BF-2, designed to operate at a high top pressure of 2.0 -2.6 KSC with a generating capacity 24 MW (Each blast furnace is connected to gas expansion turbine of 12 MW capacity). In this recovery system high pressure BFG is first cleaned in the gas cleaning plant and expanded in gas turbine driving electric generators to generate power using the pressure energy of BFG. The BFG after passing through the turbine is fed to BFG distribution network and is used as a fuel in multi-fuel firing boilers.

The possible emission reductions with full operating capacity and with 100% efficient system (i.e., generated capacity is 2, 10,240 MWh) is approximately equal to 1, 77,148.224 tCO₂/yr, but it is not possible in the actual scenario. With continuous monitoring, it is clear that the system is working approximately 7000 operating hours with an operating capacity about 80% on annual basis and expected electrical energy generated by this project activity is computed as 1, 34,400 MWh and the possible emissions are estimated as 1, 13, 245.44 tCO₂/yr (evaluated by multiplying electricity emission factor to electrical energy generated using pressure energy of BFG).

These emissions are termed as baseline emissions, represent the GHG emissions that would occur in the absence of this project activity. However, the project activity involves on-site consumption of electricity, 1100 MWh for gas cleaning and 2% losses during the transmission and distribution, taking this into an account emission are estimated approximately as 4, 290 tCO₂/yr. Now the emission reductions with the use of GETs are calculated according to equation (5) as 1, 08, 955.44 tCO₂/yr.

**Emission reduction in BPTS**

Coke making is essential process in iron and steel industries which consumes heat energy, the heat energy spent in this process is recovered as steam and power using BPTS shown in Fig. 4. Two such recovery systems are installed having a capacity of 7.5 MW each and a 13 MW condensing turbine at COB4 power plant, work in tandem to generate power out of the Coke Dry Quenching (CDQ) steam. The possible emission reductions in BPTS with 100% efficient system working for full time per one year (i.e., generated capacity is 1, 31, 400 MWh) is approximately equal to 1, 10, 717.64 tCO₂, but it is not possible in the actual scenario. It is clear that system is working approximately 7000 operating hours in a year with an operating capacity about 80% and expected electrical energy generated by this project activity is computed as 84,000 MWh and the possible emissions are 70, 778.4 tCO₂/yr. These emissions are termed as baseline emissions, However, the project activity involves self-energy consumption assumed as 100 MWh and 2% transmission and distribution losses, steam loses are neglected, taking this into an account emission are estimated approximately as 390 tCO₂/yr. Now the emission reductions with the use of BPTS is calculated according to equation (5) as 70, 388.4 tCO₂/yr.
Emission reduction in COB-4 power plant

COB4 power plant shown in Fig. 5 represents the coke oven battery-4 power plant which generates power out of CDQ steam. Total power generation capacity of the COB4 power plant is 13 MW and it has a 7 ata controlled extraction provision through which 7 ata steam requirement of coke oven by-product plant can be met, instead of going for static pressure reduction. The base line emission from this system are evaluated as 61,341.28 tCO$_2$/yr, however this involves the self-energy consumption almost similar to BPTS i.e. 390 tCO$_2$/yr. Using equation (5) it is estimated that total emission reduction due to this energy recovery system is 60, 951.28 tCO$_2$/yr.

Emission reduction in multi-fuel firing boilers

In iron and steel industries BFG passed through expansion turbines is directed to multi-fuel firing boilers along with COG, coal and oil.

Total capacity of captive power plant is 315 MW and the total energy generated with this activity is computed as 17, 64, 000 MWh by considering the plant operating hours as 7000 hrs and operating capacity as 80%. The amount of heat required for 17, 64,000 MWh is 6350.4 TJ (Unit conversion 1MWh=3.6 GJ). If coal alone used, the emissions released would be 6, 73, 142.4 tCO$_2$/yr (Emission factor of coal is taken from IPCC 2006 i.e. 106 tCO$_2$/TJ). This leads to a severe impact on the environment, so to limit this to certain extent we are using by-product fuels along with coal which indirectly reduces the coal consumption. A typical fuel mix is done as Pulverized Coal-46.0%, COG-30%, BFG-23%, Furnace Oil-0.07%. Heat liberated by firing these fuels according to their fuel percentage contribution is given as 2971.9872 TJ, 1905.12 TJ, 1460.592 TJ and 4.44528 TJ respectively. Emission released with the use of 46.0% coal is 3, 15, 030.6432 tCO$_2$/yr. Emission reduction with the use of 30 % COG and 23% BFG are evaluated as 3, 58, 111.7568 tCO$_2$/yr.

CONCLUSION

The purpose of this paper is to quantify the emissions in iron and steel industry in terms of tCO$_2$ equivalents by using the waste energy recovery units. Amount of emission reduction are evaluated using statistical tools obtained from IPCC, UNFCCC. The base line emissions of GETs, BPTS, COB-4 Power Plant, Multifuel firing are found to be approximately 1, 13,245.44, 70, 778.4, 61,341.28 and 6,73,142.4 tCO$_2$ on annual basis respectively. However the amount of total emission reductions are found to be 1, 08, 955.44, 70, 388.4, 60, 951.28, and 3, 58, 111.7538 tCO$_2$ equivalent on annul basis respectively. Scope for reducing emissions in industries are dealt in detailed. From this study, it is clear that waste energy recovery system plays a crucial role in generating power from by-products gases in the iron and steel industries by reducing the emission. These results shows a staggering reduction in the amount of GHG that could have been released into the atmosphere. The analysis of emission inventory clearly states the role of waste energy recovery systems in iron and steel industries for CO$_2$ emission reduction.

ACKNOWLEDGEMENT

Authors are highly thankful to the Professor G. H. Krishna Kumar for sole responsibility of the issues related in the present paper lies with the authors only.

REFERENCES

4. S.S. Krishnan, Venkatesh Vunnam, P. Shyam Sundar J. V. Sunil A. and Murali Ramakrishnan, A study of energy efficiency in the Indian iron and steel industry, Center for study of science


8. UNFCCC, Consolidated baseline methodology for GHG emissions from waste energy recovery projects, Version 4.0.0., (2011).


