Environmental Analysis of Coal-Fired Power Plants in Ultra-Supercritical Technology Versus Integrated Gasification Combined Cycle

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ABSTRACT

This study evaluates and compared the performance of coal-fired power plants in ultra-supercritical (USC) versus integrated gasification combined cycle (IGCC). System performance in terms of environmental analysis. Base on the exhaust emissions than IGCC and USC in terms of SO2, CO2, CO, and H2S. The IGCC system is modeled and simulated with post-combustion capture and both of them used sub-bituminous coal from the Indramayu PLTU. The result display that with the same amount of raw materials (20 ton/h coal) the IGCC produce lower exhaust emissions than USC. IGCC produced 7.80 ton CO2-eq./MWh and USC of 27.93 ton CO2-eq./MWh. IGCC technology for the long term will be better than USC because it has produced greater electrical power with the amount of material the same coal standard and produces lower exhaust emissions.

Keywords: Clean Coal Technology, USC, IGCC, environmental analysis, sub-bituminous
INTRODUCTION

Coal contributed the largest share of global electricity generation in 2015 by 39%, followed by 23% for natural gas, 16% for hydro and 11% for nuclear (Figure 1) Until 2050, the share of coal, although declining, will remain the largest, with coal continuing to function as a basic electricity source ((IEEJ), 2017).

**Figure. 1** Global Power Plant Energy Sources [Reference Scenario]((IEEJ), 2017)

Combustion of fuel produced high exhaust emission especially CO\(_2\) gases which increased pollutant concentration in air. Coal contributed 44% of total global CO\(_2\) emissions and became the largest source of GHG (greenhouse gas) emissions, which trigger the acceleration of climate change. In 2017 the composition of Indonesia's electricity production was projected to be 55.6% using coal, and in 2026 coal use would still 50.4% ((persero), 2017).

In addition, Indonesia had signed a Paris Agreement in 2015 where Indonesia should reduce CO\(_2\) emissions by 29% in 2030.

The existing technology in the electricity sector was Ultra Supercritical (USC) and Integrated Gasification Combined Cycle (IGCC). The study of this research is to compare the efficiency of both of these technologies to environmental analysis aspect using Unisim and
Promax Simulation Program. The coal data was obtained from Indramayu PLTU. The data of this research were compared to the Intergovernmental Panel on Climate Change Guidelines to obtain the calculation. From report Huaneng Greengen Co the result shows that USC has higher exhaust emissions than IGCC in terms of SO₂, CO₂, NOₓ, CO and slag (Co., 2008).

Much research has been done to improve equipment efficiency and optimization in the (CCT) power plants by analyzing processes from various aspects such as energy (first law of thermodynamics), exergy (second law of thermodynamics), economy and environmental (4-E). The main purpose of this paper is to analyze the previous work done by researchers related to CCT power plant 4-E analysis. If anyone extracts the ideas for the development of the concept of using the article, we will achieve our goal. This review also indicates the scope of future research in the clean coal technology power plants.

**METHODOLOGY**

**Process description**

The flowsheet of the IGCC process used in the analysis is shown in Figure 2. The process is composed of the following five integrated blocks: coal sizing and slurry preparation, gasification, syngas cooling, and cleaning, acid gas removal (AGR), CO₂ gas Removal and combined cycle power section. However, Figure 2, directly shows the flow diagram of the process of separating H₂S until the process of generating electricity from the syngas of the gasifier reactor output and Figure 3 shown the cryogenic CO₂ separation. Figure 4. Shown the flowsheet of the process of USC. The process is composed of the following two integrated blocks: boiler subsystem and the steam turbine system.

**Modeling, simulation, and calculation**

An IGCC post-combustion and USC plant integrated with CO₂ capture are modeled and simulated using UniSim Design® R450 and Promax® 4.0 simulation software. The composition of syngas products and IGCC process
model based on experimental data (Asif, Bak, Saleem, & Kim, 2015; Wang, 2017). The USC proses model is based on the validated model of Yang, et al. and Zhou, et al. (Yang et al., 2013; Zhao et al., 2017). The Cryogenic is based on a reference model (Air Liquide Indonesia. PT). The model is based on a steady-state operation. In the heat exchanger, there is a pressure drop of 5 psi. Pump efficiency of 65%, Turbine efficiency, and compressor of 75%. Coal specification was obtained from the Indramayu PLTU and mass was 20000 kg/h shown in Table 1.

![Figure 2. Schematic of the IGCC system with Promax® 4.0](image)

![Figure 3. Schematic of the cryogenic CO₂ separation system](image)
Table 1. Composition analysis of coal

<table>
<thead>
<tr>
<th>Composition</th>
<th>Value (% wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximate analysis</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>14.34</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>37.63</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>43.47</td>
</tr>
<tr>
<td>Ash</td>
<td>4.56</td>
</tr>
<tr>
<td>Ultimate analysis</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>55.42</td>
</tr>
<tr>
<td>H</td>
<td>4.20</td>
</tr>
<tr>
<td>N</td>
<td>0.71</td>
</tr>
<tr>
<td>S</td>
<td>0.1</td>
</tr>
<tr>
<td>O</td>
<td>20.67</td>
</tr>
<tr>
<td>Ash</td>
<td>4.56</td>
</tr>
<tr>
<td>Calorific value, HHV (kcal/kg)</td>
<td>4236</td>
</tr>
</tbody>
</table>

Environmental analysis is carried out based on the calculation of GHG emissions (CO\textsubscript{2}) in the energy sector in the power plant sub-sector. The methodology used in calculating this emission is the method established by the Intergovernmental Panel on Climate Change Guidelines in the
2006 IPCC Guidelines. The application of this method has been stipulated in LHK Ministerial Regulation Number P.73 / Men LHK / Setjen / Kum.1 / 12/2017 dated 29 December 2017 concerning the Implementation and Reporting Guidelines for Greenhouse Gas Inventories. Broadly speaking, the calculation of GHG emissions/removals is obtained through multiplying data on activities with emission factors, the Global Warming Potential (GWP) index was used to evaluate the climate change impact. The GWP index allows all of the GHG flows during the operation period, $m_{GHG}^{op}$, to be expressed on a CO$_2$_eq basis as shown in the simple equation:

$$m_{GHG}^{op} = \sum_{j=1}^{N} m_{j}^{GHG} \times GWP_{j}$$ (1)

According to the Intergovernmental Panel on Climate Change (IPCC 2007), the GWP index evaluated over 100 years was considered to be 1 for CO$_2$, 28 for CH$_4$ and 265 for N$_2$O (Restrepo, Miyake, Kleveston, & Bazzo, 2012).

RESULTS AND DISCUSSION

Environmental analysis

The environmental model predicted an emission from the process of 7.249 ton CO$_2$-eq./MWh to IGCC and 25.97 ton CO$_2$-eq./MWh to USC. The power plant emissions correspond to 87.7%, followed by the pre-burning process (belt conveyors, fans, mills, and others) with 7.3%. The mining and transport stages account for 5% (Restrepo et al., 2012). Figure 5. Shown GHG emissions for IGCC and USC. Table 2 shown the gas emission produce from IGCC and USC.

**Figure 5.** GHG emissions for IGCC and USC
Table 2. Gas emission produce from IGCC and USC

<table>
<thead>
<tr>
<th>Emission</th>
<th>IGCC (kg/h)</th>
<th>USC (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.005</td>
<td>12.493</td>
</tr>
<tr>
<td>CO₂</td>
<td>37351.860</td>
<td>43936.008</td>
</tr>
<tr>
<td>Methane</td>
<td>165.744</td>
<td>-</td>
</tr>
<tr>
<td>H₂S</td>
<td>23.293</td>
<td>-</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.088</td>
<td>39.959</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.457</td>
<td>-</td>
</tr>
</tbody>
</table>

Gas emission produces on IGCC technology shown in Table. 2 in kg/h and then convert to tons/year and N₂O emission obtained from CO₂ emissions produced are multiplied by the mass of coal and the emission factor N₂O. CO₂ emissions produced amounted to 295826.73 tons/year, of CH₄ emissions 1312.70 tons/year and N₂O emissions of 7864.594 tons/year and then multiplying with Global Warming Potential (GWP) index to obtain CH₄ emissions of 36755.49 tons of CO₂-eq/year and emissions of N₂O 2084117.36 tons of CO₂-eq/year and total GHG emissions of 2416699.58 tons of CO₂-eq/year.

These emissions are the emissions generated in the power plant process and it is assumed that the pre-burning process (belt conveyors, fans, mills, and others) emissions are 7.3% and the mining and transport stages account for 5%. The total GHG emissions produced are divided by the total net power produced which is 42 MWh or 333373.91 MWh/year. after being divided by total electricity production, the following emissions were obtained: 7.249 tons of CO₂-eq./MWh in the power plant process, 0.529 tons of CO₂-eq./MWh on the Pre Burning process, 0.003 tons of CO₂-eq./MWh in Transport and 0.016 tons of CO₂ -eq./MWh on Mining so that total GHG emissions
amounted to 7.80 tons of CO₂-

In USC technology the emissions
calculation would equal with IGCC,
The CO₂ produced is 347973.18
tons/year, of CH₄ emissions
61672.762 tons/year and N₂O
emissions are 9250.914 tons/year and
then after multiplying with Global
Warming Potential (GWP) index to
obtain emissions of CH₄ 1726837.34
tons CO₂-eq/year and N₂O emissions
2451492.295 tons CO₂-eq/year and
total GHG emissions of 5083038.062
tons CO₂-eq/year. The total GHG
emissions produced are divided by
the total net power produced which is
22 MWh or 174266.70 MWh/year.
After being divided by the total
electricity production, the following
emissions are obtained 25.97 tons
CO₂-eq./MWh in the power plant
process, 1.90 tons CO₂-eq./MWh on
the Pre Burning process, 0.01 tons
CO₂-eq./MWh at Transport and 0.06
tons CO₂-eq./MWh on Mining so that
the total GHG emissions are 27.93
tons of CO₂-eq./MWh.

Another gas emission produced is
IGCC, producing CO emission of
0.005 kg/h, H₂S 23.293 kg/h, SO₂
0.088 Kg/h and Ammonia 0.457 kg/h
while USC produces CO emissions
of 12.493 kg/h and SO₂ of 39.959
kg/h.

CONCLUSIONS
This paper conducted a
comprehensive study to evaluate and
compare the performance of coal fire
power plants between ultra-
supercritical (USC) and integrated
gasification combined cycle (IGCC).
Both processes are modeled and
simulated, and environmental
analysis is used to evaluate the
results. The following conclusions
can be derive:

- Total GHG emissions for
  IGCC was 7.80 tons of CO₂-
eq./MWh and USC of 27.93
  tons of CO₂-eq./MWh.
- Another gas emission
  produced is IGCC, producing
  CO emission of 0.005 kg/h,
  H₂S 23.293 kg/h, SO₂ 0.088
  kg/h and Ammonia 0.457
  kg/h while USC produces CO
emissions of 12.493 kg/h and SO\(_2\) of 39.959 kg/h.

IGCC technology requires a greater investment because there are several additional tools such as gasifiers gas turbines and H\(_2\)S removal, but when compared to USC, this technology for the long term will be better because it has produced greater electrical power with the amount of material the same coal standard and produces lower exhaust emissions.

ACKNOWLEDGEMENTS
The author would like to thank for the support provided by all parties involved in writing this paper especially the mentors, Universitas Indonesia which has funded this research through the scheme of Hibah Publikasi Internasional Terindeks Untuk Tugas Akhir Mahasiswa (PITTA B) No. NKB-0691/UN2.R3.1/HKP.05.00/2019 and Institut Teknologi Indonesia (persero), P. P. (2017). Rancangan Usaha Penyediaan Tenaga Listrik (RUPTL) PLN 2017-2026. Retrieved from


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doi:https://doi.org/10.1016/j.energy.2016.12.07