Installation of Turbocharged Fluidized Bed Combustion System for Efficient Sludge Incineration

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Abstract
The Bureau of Sewerage, Tokyo Metropolitan Government (henceforth TMG) has established a total incineration system for the whole amount in 2003 to extend sludge disposal site life in Tokyo Bay. Therefore the emissions caused by the sludge treatment were increased. To cope with this problem, we have worked positively to reduce the energy usage and the amount of GHG emissions. Especially, we have been working on several stages of incineration technologies development to reduce them. Previously, we had developed the incinerators that could reduce the large amount of nitrous oxide (henceforth N₂O) due to the sludge combustion and carbon dioxide (henceforth CO₂) due to using auxiliary fuel. Recently, we developed a turbocharged fluidized bed incinerator which enabled to reduce not only sludge combustion origin N₂O and auxiliary fuel origin CO₂ but also the amount of electricity consumption. Owing to this, we can reduce the large amount of energy and GHG emissions from the incinerator compared with previous types. We report the effect of the turbocharged fluidized bed incineration technology.

Keywords
Sludge incinerator, reduction of greenhouse effect gas, energy conservation, turbocharger

BACKGROUND
Sewerage plays basic roles to ensure the dependable and comfortable living environment and to form good water environment as the requisite infrastructure to support the livelihood of the people and the urban activities. For example, Sewerage contributes to improve the life environment by treating waste water, protect people from flooding hazard by draining stormwater and conserves the quality of public water environment. Though, on the other hand, the bureau of sewerage, TMG (henceforth our bureau) uses slightly more than 1 percent of power consumption of total annual consumption of the Tokyo metropolitan area to provide these sewerage services. In addition, it is expected that energy usage and GHG emissions caused by sewerage services activities will increase because of increasing in population and trying to improve sewerage services (flooding countermeasures, improving combined sewerage, etc.) .Thus, we are responsible for the reduction of power consumption as a major power consumer.

Thereafter, we formulated the global warming countermeasures plan named “Earth Plan 2004” that aims to reduce GHG emissions caused by sewerage services activities by 6 percent or more relative to FY 1990 by FY2009 ¹), and we had been trying to reduce GHG emissions based on this plan. After that, we had achieved the goal of “Earth Plan 2004” and we formulated “Earth Plan 2010” to reduce GHG emissions furthermore in FY2010. The “Earth Plan 2010” aims to reduce GHG emissions caused by sewerage services activities by 25 percent or more relative to FY 2000 by FY2020 ²). In addition, we also formulated the master plan to enhance energy efficiency and to promote energy management for sewerage works of Tokyo named “Smart Plan 2014”. It aims to have at least 20 percent of total energy consumption for renewable energy and energy conservation by FY2024 ³). We have been trying to reduce GHG emissions and the energy usage based on these plans.
Figure 1 shows the percentage of GHG emissions caused by TMG’s activities in FY 2015. The total amount of GHG emissions was around 2.3 million t-CO₂ and we emitted 35 percent of it.

![Figure 1. Breakdown of GHG emissions caused by TMG’s activities in FY 2015](image)

We incinerate dewatered sludge that is produced during the waste water treatment process to reduce of volume significantly and we mainly dispose incinerated ash into final disposal site in Tokyo Bay as wastes. The reason why we incinerate dewatered sludge and try to reduce of volume is because we don’t have enough space to construct a new disposal site in Tokyo Bay and we need to extend the life of the present site. On the other hand, we use a large amount of energy to incinerate dewatered sludge.

The amount of GHG emissions caused by the sludge treatment was 570,000 t-CO₂/year and accounted for 53.5 percent of our bureau’s total GHG emissions (1,065,000 t-CO₂/year) in FY2000 that is base year as the reduction target in “Earth Plan 2010”. After that, we could reduce the amount of GHG emissions caused by the sludge treatment to 401,000 t-CO₂/year and accounted for 42.8 percent of the total GHG emissions in FY2009. Especially, one tonne of N₂O that is mainly emitted by the sludge incineration process is equivalent to 298 tonnes of CO₂. Therefore, we have worked positively to reduce N₂O emissions.

We have installed the turbocharged fluidized bed combustion system which is one of the high-temperature and energy-saving incinerators those can reduce GHG emissions significantly by improving the combustion system compared with previous type of incinerators. Furthermore, we have operated it at a few waste water treatment plants to reduce the energy usage and GHG emissions much further than the previous type of the incinerators from FY2013. We report the energy-saving effect and GHG emissions reduction effect by installing the turbocharged fluidized bed combustion system.

**OUR TACKLE THE GHG EMISSIONS RELATED TO SLUDGE INCINERATION**

We have been trying to reduce GHG emissions caused by sludge incineration by operating incinerators with ingenuity and by installing new type of incinerators.

At the first stage, we have focused on N₂O caused by sludge incineration. It is generally known that we can decrease the amount of N₂O emission when we incinerate sludge at higher temperature⁴⁻⁵ (Figure2). Therefore we set a target to reduce sludge incineration origin N₂O emission by 70 percent by raising incineration temperature from 800°C (1472°F) to 850°C (1562°F) and we had been trying to reduce N₂O emission. On the other hand, the increase of incineration temperature
was accompanied by some disadvantages such as the shortened interval of maintenance and repairs of the incineration. Moreover, auxiliary fuel usage was increased. Therefore, auxiliary fuel origin CO₂ was also increased.

Figure 2. Correlation chart between incineration temperature and N₂O emission

At the second stage, we developed the “multilayer burning fluidized bed incinerator” that can reduce N₂O by approximately 50 percent and auxiliary fuel origin CO₂ by approximately 20 percent compared with the conventional fluidized bed incinerators of the first stage. One of the biggest features of this incinerator is that combustion air is blown into not only the bottom but also the middle of the incinerator. Therefore, it can form high temperature layer in the middle of the incinerator for the thermal decomposition of N₂O. (Figure 3, Figure 4).

Figure 3. Image of GHG emissions reduction (relative value)

Figure 4. Multilayer burning fluidized bed incinerator

Supplying air both of bottom and middle layers of the incinerator in order to improve combustion efficiency
As a result of the first stage and the second stage efforts, we had achieved GHG emissions reduction of N₂O from incineration process by approximately 65 percent and CO₂ originated from auxiliary fuel by approximately 50 percent compared with the amount of GHG emissions in FY2000 (Figure 5). Though, GHG emissions caused by using electricity for the sludge treatment process were broadly flat, therefore we needed to use less electricity to reduce the total GHG emissions moreover.

![Figure 5. Transition of our bureau’s GHG emissions](image)

**THE TURBOCHARGED FLUIDIZED BED COMBUSTION SYSTEM**

We have installed the turbocharged fluidized bed combustion system and have operated it from FY2013 to reduce further energy usage and GHG emissions. It consists of a fluidized bed incinerator combined with a turbocharger (Figure 6). The compressor connected to the turbine directly is driven by the combustion gas emitted from the incineration process and it takes in outside air to generate compressed air and supply it as the combustion air to the bottom of the incinerator. Therefore, the internal pressure of the incinerator becomes positive. The positive pressure inside of the incinerator contributes to reduce the amount of GHG emissions as below. First, the higher temperature range (around 880°C (1472°F)) formed in the middle layer of the incinerator expedites thermal decomposition of N₂O. Second, the turbocharged fluidized bed incinerator can be made more compact compared with the conventional incinerators, due to its internal pressurized condition and high incineration rate. Therefore, we can decrease the heat discharge from the surface of the incinerator and we can reduce auxiliary fuel usage. Third, we use the turbocharger to supply combustion air. Therefore the forced draft blower that is necessary for the conventional fluidized bed incinerators is not needed. Moreover, because the pressure inside of the incinerator is positive, the induced draft fan discharging the exhaust gas out of the system that is necessary for the conventional fluidized bed incinerators is not needed. These features contribute to use less electricity in incineration process substantially. It was the world’s first technology to use pressure for incinerating dewatered sludge and the turbocharged fluidized bed incinerator was installed at Asakawa water reclamation center (or waste water treatment plant) that is one of our facilities in FY2013. We operate this system at three waste water treatment plants (Asakawa, Kasai and Shingashi) now.
RESULT OF INTRODUCTION OF THIS SYSTEM

Contribution to energy reduction

As mentioned above, we can reduce electricity usage and auxiliary fuel usage for incineration process by installing the turbocharged fluidized bed combustion system compared with the conventional incinerators.

We show the result of the installation the turbocharged fluidized bed incineration system at Shingashi water reclamation center as an example. We used electricity for the incineration process approximately 3.5million kWh/year and we use auxiliary fuel approximately 920,000 Nm³/year for operating the previous type of incinerator in FY2012. Then, thanks to installing the turbocharged fluidized bed incineration system, we could reduce electricity usage for incineration process by 53 percent (1.6million kWh/year) and auxiliary fuel usage by 87 percent (120,000 Nm³/year) in FY2016. In addition, compared with specific energy consumption, the previous incinerator used 92.2kWh to incinerate 1 wet ton of sludge. On the other hand, the turbocharged fluidized bed incinerator used 37.9kWh (59 percent reduction) to incinerate 1 wet ton of sludge. Furthermore, the previous incinerator used 24Nm³ to incinerate 1 wet ton of sludge. On the other hand, the turbocharged fluidized bed incinerator used 2.7Nm³ (89 percent reduction) to incinerate 1 ton of dewatered sludge (Figure7).

Figure6. Turbocharged fluidized bed combustion system

Figure7. Comparison of specific energy consumption
**Contribution to GHG emissions reduction**

We set the target to reduce 40 percent or more CO\(_2\) emissions caused by using electricity for the incineration process, 50 percent or more N\(_2\)O emissions caused by incinerating sludge and 20 percent or more CO\(_2\) emissions caused by using auxiliary fuel for incineration process compared with the conventional fluidized bed incinerators (at the first stage).

Figure 8 shows the comparison of GHG emissions caused by incinerating sludge at the Shingashi water reclamation center. The CO\(_2\) conversion factor of electricity is 0.489 t-CO\(_2\)/thousand kWh and the CO\(_2\) conversion factor of auxiliary fuel is 2.244 t-CO\(_2\)/thousand Nm\(^3\). Then, we emitted GHG emissions approximately 11,000 t-CO\(_2\)/year including sludge incineration origin N\(_2\)O from conventional fluidized bed incinerator in FY2012. On the other hand, as the result of installing the turbocharged fluidized bed combustion system, we could reduce GHG emissions by 73 percent (approximately 3,000 t-CO\(_2\) emitted).

Table 1 shows the comparison of CO\(_2\) emissions intensity (t-CO\(_2\)/wet-t) between the conventional fluidized bed incinerator and the turbocharged fluidized bed incinerator. Compared with the conventional incinerator, we could reduce CO\(_2\) emissions intensity of sludge incineration origin N\(_2\)O by 77 percent, auxiliary fuel origin CO\(_2\) by 89 percent and electricity origin CO\(_2\) by 58 percent by installing of turbocharged fluidized bed combustion system.

![Figure 8. Comparison of CO\(_2\) emissions](image)

**Table 1. Reduction of CO\(_2\) emissions intensity**

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Conventional Fluidized Bed Incinerator</th>
<th>Turbocharged Fluidized Bed Incinerator</th>
<th>Reduction Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2) emissions caused by using electricity</td>
<td>t-CO(_2)/wet-t</td>
<td>0.045</td>
<td>0.019</td>
<td>▲57.8%</td>
</tr>
<tr>
<td></td>
<td>kWh/wet-t</td>
<td>92.2</td>
<td>37.9</td>
<td></td>
</tr>
<tr>
<td>CO(_2) emissions caused by using auxiliary fuel</td>
<td>t-CO(_2)/wet-t</td>
<td>0.055</td>
<td>0.006</td>
<td>▲89.1%</td>
</tr>
<tr>
<td></td>
<td>Nm(^3)/wet-t</td>
<td>24.4</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>N(_2)O emissions caused by incinerating sludge</td>
<td>t-CO(_2)/wet-t</td>
<td>0.185</td>
<td>0.042</td>
<td>▲77.3%</td>
</tr>
</tbody>
</table>
CONCLUSION

We could reduce CO\textsubscript{2} emissions caused by using electricity for the incineration process by installing the turbocharged fluidized bed combustion system. Moreover, it also turned out that the N\textsubscript{2}O emissions caused by incinerating sludge and CO\textsubscript{2} emissions caused by using auxiliary fuel could also be reduced substantially. We have been trying to reduce GHG emissions based on “Earth Plan 2010”. Thus, we could achieve the goal of “Earth Plan2010” ahead of schedule. Therefore, we formulated new global warming countermeasures plan named “Earth Plan 2017” that aims to reduce GHG emissions caused by sewerage services activities by 30 percent or more relative to FY 2000 by FY2030\textsuperscript{(6)} and we are trying to reduce GHG emissions furthermore in FY2016. To achieve this goal, we are advancing the development of new incineration system. For example, “energy self-sustaining incinerator system” is that it utilizes waste heat to generate enough electricity for its own consumption. Hereafter, we continue to try to reduce energy usage and GHG emissions further to achieve the goals of “Smart Plan 2014” and “Earth Plan 2017” by introducing new ideas and new technologies actively.

REFERENCE

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