Development strategy of environmentally friendly sewerage sludge incineration technologies in Bureau of Sewerage Tokyo Metropolitan Government

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1. ABSTRACT

More than half of total greenhouse gas (GHG) emissions from Sewage activities in Tokyo had been originated from the sludge incineration process. Tokyo Metropolitan Government (TMG) has been working on several stages of incineration technologies development to reduce the GHG emissions. Previously, we had developed sludge incinerators that reduce large amount of sludge combustion origin nitrous oxide (N\(_2\)O) and auxiliary fuel origin carbon dioxide (CO\(_2\)). Recently, we developed a turbocharged fluidized bed incinerator which enabled to reduce the amount of electricity consumption for the first time. Together with the reduction of N\(_2\)O and auxiliary fuel origin CO\(_2\), the GHG emissions from the incinerator are largely reduced compared with previous types.
We have evaluated the effect of the turbocharged fluidized bed incineration technology. Progress of the incinerator development for further reduction of GHG emissions is also reported.

**KEYWORDS:** Sludge incinerator, reduction of greenhouse gas, turbocharger

2. BACKGROUND

TMG is accelerating various efforts to become “A City that Leads the World in Preserving the Environment; Tokyo” towards the 2020 Olympic and Paralympic Games which take place in Tokyo.

The sewerage services contribute to a good water environment, while discharging a large amount of GHG. Bureau of Sewerage discharged 42% of total GHG emissions from TMG activities in FY 2000 (Figure 1). Therefore, Bureau of Sewerage, TMG, formulated a set of global warming countermeasures named “Earth Plan 2010” that aims to reduce GHG emissions from sewerage services activities by 25% or more relative to FY 2000 by FY 2020, and thereby we are promoting practical measures, such as innovating incinerator technologies. As of FY 2014, the contribution of Bureau of Sewerage descended to 37%.
Figure 1. Breakdown of greenhouse gas emissions from TMG activities in FY 2000

Figure 2 shows the breakdown of the GHG emissions from Bureau of Sewerage, TMG activities in FY 2000. The emission from the sludge incineration processes is outstanding, which amounts to 570,000 t-CO$_2$/year and accounts for more than the half of the total emission (1,065,000 t-CO$_2$/year). The breakdown of the emission from the sludge incineration processes is as follows; sludge combustion origin N$_2$O: 381,000 t-CO$_2$/year, auxiliary fuel origin CO$_2$: 67,000 t-CO$_2$/year, electricity origin CO$_2$: 122,000 t-CO$_2$/year. It is important for the global warming countermeasures of the sewerage services to reduce all of these factors including electricity which was difficult before.

Figure 2. Proportion of GMG emissions of Bureau of Sewerage, TMG in FY 2000
3. REDUCTION OF GHG EMISSIONS FROM INCINERATION PROCESS
   (1ST AND 2ND STAGE)
TMG has promoted technological innovation of sludge incinerators to reduce GHG emissions in stages.
At the first stage, we focused on N\textsubscript{2}O which has about 300 times more greenhouse effect per unit mass than CO\textsubscript{2}.
We could reduce 50% of N\textsubscript{2}O emissions by raising the incineration temperature from 800°C (1472°F) to 850°C (1562°F) because higher incineration temperature expedites thermal decomposition of N\textsubscript{2}O.
At the second stage, we developed two types of incinerators which can reduce N\textsubscript{2}O and CO\textsubscript{2} emissions from auxiliary fuels. One is the "multilayer burning fluidized bed incinerator" that we made combustion air supplied from not only the bottom but also the middle of the incinerator and raised combustion efficiency due to high temperature layer formed in the middle of the chamber.
The other is the "sludge gasification incinerator" that decomposes organic components of sludge and turns it into combustible gas. Waste heat emitted from high-temperature-combustion (900°C, or 1652°F) of the combustible gas is reused efficiently for drying sludge prior to incinerate. Flow charts of these types of incinerators are shown in Figure 3.
These two types of incinerators could achieve the reduction target of N\textsubscript{2}O emissions by 50% and CO\textsubscript{2} emissions from auxiliary fuels by 20% compared with the conventional fluidized bed incinerators of the first stage.

Figure 3. Multilayer burning fluidized bed incinerator and Sludge gasification incinerator (Example)

As a result of the first stage and the second stage efforts, N\textsubscript{2}O emissions from incineration process and CO\textsubscript{2} emissions originated from auxiliary fuels had reduced significantly (Figure 4). Thus the contribution of the incineration process descended from more than the half of the total GHG emissions of Bureau of Sewerage in FY 2000 to approximately 40% in FY 2014.
On the other hand, we did not see much progress in reducing CO\textsubscript{2} emissions from the electricity, and it was our next challenge to reduce electricity consumption in the incineration process.
4. FURTHER REDUCTIONS OF GHG EMISSIONS BY THE PRESSURE-SUPERCHARGED FLUIDIZED BED INCINERATOR (3RD STAGE)

At the third stage, we have developed turbocharged fluidized bed incinerator targeting to reduction of the electricity consumption which was not possible for conventional incinerators (Figure 5). The newly developed incinerator was initially introduced to two water reclamation centers (WRC), or wastewater treatment plants, in Tokyo: Asakawa WRC and Kasai WRC. One of advantages of the turbocharged fluidized bed incinerator is that it does not require large blowers, as conventional incinerators do, for supplying combustion air. This feature could reduce electricity consumption significantly.

We incorporated the incinerator with a turbocharger, widely used for watercrafts and automobiles, to supply combustion air (Figure 6). Therefore, the forced draft blower, necessary for the conventional fluidized bed incinerators, is not needed.

Another feature is that the pressure inside of the incinerator is positive. Therefore, the draft fan discharging the exhaust gas out of the system is not needed.

Electricity used in incineration process is reduced significantly by eliminating the forced draft blower and the induced draft fan.

Also, we can utilize a general-purpose turbocharger, which is available in the market and it will contribute to save the operation and maintenance cost.
5. RESULT OF THE INTRODUCTION OF THE TURBOCHARGED FLUIDIZED BED INCINERATORS

The development target of the turbocharged fluidized bed incinerator was set to reduce 40% or more CO₂ emissions originated from electricity, compared with conventional fluidized bed incinerators (first stage; incinerating at 850°C). We set the same reduction targets for N₂O (50% or more) and auxiliary fuel origin CO₂ (20% or more) as the second stage.

Figure 7 shows comparison of GHG emissions at each stage of incineration technologies. The turbocharged fluidized bed incinerator was able to reduce more than 50% of CO₂ emission originated from the electricity, which exceeded the target. Also, N₂O and auxiliary fuel origin CO₂ emissions were significantly reduced. Details of the operational results of the two WRCs are
shown in Table 1.

The positive pressure inside of the incinerator contributes to the huge reduction through two aspects. One is the higher temperature range (around 880°C, or 1616°F) formed in the middle layer of the incinerator which expedites thermal decomposition of N₂O (64% or more). The other is that the turbocharged fluidized bed incinerator could be made compact compared with the conventional ones, due to its internally pressurized condition and high incineration rate (Figure 8). The benefit of smaller incinerator body is the less surface area which leads to less heat discharge. As a result, it reduced 39% of CO₂ emission originated from auxiliary fuel.

![Figure 7. GHG emissions at each stage of incineration technologies](image-url)

**Table 1. Reduction of GHG emissions at Asakawa WRC and Kasai WRC**

<table>
<thead>
<tr>
<th></th>
<th>Asakawa WRC (60t/day incinerator)</th>
<th>Kasai WRC (300t/day incinerator)</th>
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<tbody>
<tr>
<td></td>
<td>Conventional fluidized bed incinerator*1 (1st stage)</td>
<td>Turbocharged fluidized bed incinerator (3rd stage)</td>
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<td></td>
<td>CO₂ emissions from auxiliary fuels</td>
<td>571</td>
</tr>
<tr>
<td></td>
<td>CO₂ emissions from electricity used</td>
<td>587</td>
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<tr>
<td></td>
<td>N₂O emissions from sludge incineration process</td>
<td>2,873</td>
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</tbody>
</table>

*1 Conventional incinerators indicate the high-temperature (850°C) incineration-type fluidized bed incinerators that we had used at these plants.

*2 At Kasai WRC, auxiliary fuel is not required because the low water content of incinerated sludge (74%) allows self-sustained incineration.
6. FURTHER IMPROVEMENT OF FACILITIES AFTER STARTING OPERATIONS

Inside of conventional incinerators is usually kept in negative pressure for safety reasons. On the other hand, the turbocharged fluidized bed incinerator adopted new combustion system that utilizes the turbocharger and keeps its inside pressure positive. This new combustion system had some specific troubles at initial operations.

6.1 Dust collector breakage

Breaking of an exhaust gas dust collector, set upstream of the turbocharger, made dust leaks. The leaked dust could wear the fast rotating turbine and cause serious trouble. The cause of this defect had been identified as thermal deformation of a metal cell plate holding ceramic filters inside the dust collector, which made filters touch each other and damaged them (Figure 9). In addition to that, failure in detection of dust collecting malfunction allowed continual dust inflow to the turbocharger. As a counter measure, we replaced it with a reinforced metal cell plate.

![Figure 8. Effect of pressurizing of the incinerator internally](image-url)
6.2 **Standalone operation disability because of insufficient air supply**

This system is designed as a blower assists the fluid bed draft only during a startup process. Once the combustion stabilized, the turbocharger is supposed to blow enough air into the incinerator, and then the blower shuts down, and contributes to save electricity. During initial operations, the turbocharger could not supply enough amount of air for the standalone operation, so the blower had to keep assisting even though the startup process had been completed. We identified that the cause was a mismatch of the operating condition and the compressor capacity of the turbocharger. As a countermeasure, the shape of the turbine blades was changed. In addition, pipes around the turbocharger were enlarged in order to reduce pressure loss. At the end, the turbocharger supplied enough air to the incinerator for the stand alone operation.

6.3 **Necessity of the malfunction detection system for the case of duct clogging**

Dust deposition on an exhaust gas duct made the pressure difference increased, and the surge at the turbocharger damaged the supports of the duct. Kurozumi et al. 1) revealed the causes of the deposition and suggested effective countermeasures. Pushing the introduction of advanced wastewater treatment methods to our plants, the amount of phosphorus contained in sludge has been increased. Meanwhile, sludge combustion temperatures have been raised in order to expedite N₂O thermal decomposition. As the ratio of phosphorus to metals exceeds a certain level, low-melting-point materials are formed and melt in the incinerator. Then the melted materials solidify and clog in the waste gas duct. Kurozumi et al. 1) found that a metal additive to the sludge cake is effective to prevent the clogging. They defined the clogging prevention factor which was evaluated as the ratio of metals to phosphorus contained in the...
sludge cake, and estimated the required amount of the metal additive based on the factor. Referring to this study, we started adding the metal additive in the sludge cake in order to prevent the duct from clogging. We also installed a differential-pressure detecting procedure to the dust collector to be able to early detect of the dust collector malfunction, and make the incinerator stop immediately in case of an emergency, protecting the facilities.

Because the turbocharged fluidized bed incinerate system keeps its combustion chamber in positive pressure, serious damaged and injuries can be caused by sudden pressure fluctuate or breakdown of the turbocharger due to dust intrusion. Therefore, we immediately investigated the causes of the troubles and took countermeasures mentioned above, together with the incinerator manufactures. We established a safe and reliable turbocharged fluidized bed incinerate system based both of the advanced failure detection and emergency shut-down procedure.

7. FUTURE DEVELOPMENT STRATEGY
Performance of the turbocharged fluidized bed incinerator enables us to set advanced GHG emissions reducing targets of 50% for N₂O, 40% for electricity origin CO₂, and 20% for auxiliary fuel origin CO₂. Other competing manufactures also collaborated with TMG and made innovations through other types of incinerators (step grate stoker incinerator, multilayer burning fluidized bed incinerator using supercharger, and sludge gasification incinerator using supercharger) aiming at these targets. Furthermore, now we are at the fourth development stage that will realize an “energy self-sustaining incinerator system”: utilizing waste heat and supplying electricity by itself (Figure 10). The system consists of ultra-low water content centrifugal dehydrators, sludge incinerators, and electric generators utilizing waste heat from the incinerators. The lower water content (around 71%) of combusted sludge cake not only eliminates auxiliary fuels at all, but also keeps enough amount of waste heat for generating electricity more than that used in the system (in annual perspective). The installment of the system will reduce the GHG emissions further more. As for the electric generating, we considered costs of the generating, and constrained those below the market buying electricity price.
8. CONCLUSION

The turbocharged fluidized bed incinerator was proved to be able to reduce CO₂ emissions from electricity, that any conventional technologies could not achieve. It also turned out that the N₂O emissions from sludge incineration process and CO₂ emissions from auxiliary fuels could also be reduced substantially, which were not included in the original targets. Those facts show that the system we have developed so far would largely contribute to reduce GHG emissions. In addition to that, some other incineration systems were led to innovative technologies which were the same level as the turbocharged fluidized bed incinerator, and achieved the tall reduction targets of GHG emissions we required.

The further development has established the energy self-sustaining incinerator system that utilizes waste heat to generate enough electricity for its own consumption. It cuts almost all of electricity origin CO₂ emission. We are currently planning to build an energy self-sustaining incinerator system at Shingashi WRC. This system requires certain scale and constant full load operation in order to maximize its energy efficiency. Therefore, we examine the specifications of incinerators planned to build and introduce this system when the requirements match. If the requirements do not match for the energy self-sustaining incinerator system, then we will select the turbocharged fluidized bed incinerator, or other incinerators at the same GHG emissions reduction level. We will choose suitable systems from these two levels of technologies, and steadily progress the reduction of GHG emissions. Our next target of the incinerator development is utilization of low temperature waste heat to further electricity generation, maximizing the use of potential sewerage energy.
9. ACKNOWLEDGEMENTS
The authors acknowledge the staffs of manufactures who developed, constructed and improved new incineration technology in order to reduce GHG emissions.

10. REFERENCE