Performance of Fluidized-bed Incineration Facilities and their Potential

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Abstract

In the course of equipment improvement work of a non-shredding type fluidized-bed incineration facility, which is an original technology of EBARA, a low excess air ratio combustion technology composed of a slow combustion process and exhaust gas recirculation has been introduced. During operation with a combustion air ratio of 1.27, the CO and NOx concentration of the exhaust gas were 2.4 ppm and approximately 20 to 25 ppm respectively, demonstrating operation performance comparable to or higher than the latest, newly constructed incinerators, with a low excess air ratio and reduced CO and NOx concentrations. In this paper, the performance and features of the fluidized-bed incineration technology is explained from a technological perspective by taking the above case as an example, and a future outlook on the potential of fluidized-bed incineration facilities is presented.

Keywords: Fluidized-bed, Waste incinerator, Low excess air ratio, Combustion control, Exhaust gas recirculation, Carbon monoxide, Nitrogen oxides

1. Introduction

The twin interchanging fluidized-bed incinerator (TIF), which was first introduced to the market in 1984, was an original Ebara technology. We have delivered TIFs as well as internally circulating fluidized-bed boilers (ICFBs) etc., which are derivatives of the TIF technology, to 110 facilities in Japan and to 37 facilities overseas to date.

This TIF technology has recently been upgraded and is now known as the “next-generation type fluidized-bed incinerator.” It is outfitted with advanced functions, and it adopts low excess air ratio combustion and exhaust gas recirculation technology backed by the actual operation of the twin interchanging fluidized-bed gasifier (TIFG). It has also achieved improved combustion stability, higher power generation efficiency, and control of steam output and electricity generated. As previously reported, the latest waste-to-energy facilities for municipal solid waste adopting this technology achieve constant operation with stable waste treatment and reduced fluctuations of the amount of electricity transmitted.

We have recently implemented the low excess air ratio combustion and exhaust gas recirculation technology, which is adopted for the above-mentioned next-generation type fluidized-bed incinerator, in a project of equipment improvement work (life extension work) of an existing non-shredding type fluidized-bed incineration facility, and realized outstanding combustion stability.

In this paper, we refer this project as an example to explain the performance and features of the fluidized-bed incineration technology from a technological perspective, and present an outlook on the potential of future fluidized-bed incineration facilities utilizing that performance and features.

2. Features of Ebara’s Fluidized-bed Incineration Technology

Fluidized-bed incinerators are designed to form a fluidized bed by supplying air (fluidizing air) from the...
lower side of the fluidizing medium (silica sand, etc.) filled at the bottom of the furnace and incinerate the substance to be treated within the bed. Note that in general, the combustion reaction of the treated substance is not completed in the fluidized bed, and the unburned combustible content thereof is completely combusted by supplying secondary air into the free board section, which is provided in the furnace upper area above the fluidized bed.

One of the features of the fluidized-bed incinerator is that it is possible to incinerate diverse substances in a single furnace, i.e. substances ranging in calorific value from low, such as sludge, to high, such as waste oils or plastics, because of the uniform temperature distribution and remarkable heat transfer characteristic peculiar to the fluidized bed. For this reason, we first released a fluidized-bed incinerator for industrial waste that was designed to treat diverse substances. The TIF (Figure 1), which is one of our current main equipment models, was subsequently developed when making inroads into the field of municipal solid waste incineration to meet demand for large-scale treatment.

The TIF produces an interchanging flow of fluidizing medium particles within the fluidized bed by causing a different superficial velocity of fluidized air between the central and surrounding areas of the fluidized bed. This interchanging flow enhances the effect of breaking and shredding waste and the effect of taking waste into the inner part of the fluidized bed and, at the same time, ensures the stable discharge of noncombustibles. Another significant advantage of the TIF is its capabilities to sufficiently mix even diverse substances to be treated and to form a uniform combustion reaction field thanks to the powerful particle stirring effect within the fluidized bed.

3. Low Excess Air Ratio Combustion of the Fluidized-bed Incinerator

Recently, there have been rising expectations for waste-to-energy facilities as locally distributed energy resources, and therefore there has been an increase in the importance of the development of element technology conducive to high-efficiency power generation, such as low excess air ratio combustion, high-temperature high-pressure boilers, and dry type advanced exhaust gas treatment. In particular, the adoption of low excess air ratio combustion directly contributes to the maximization of net power output through the increase of generated power output achieved by improved boiler efficiency, as well as the reduction of power consumption by fans etc. on the premises. In addition, the adoption of low excess air ratio combustion is very beneficial because reducing the amount of exhaust gas results in decreased capital costs of components for waste heat recovery, such as boilers, and also components for exhaust gas treatment.

The fluidized-bed incinerator offers such advantages as compact incinerator design and easy control of the amount of electricity generated. On the other hand, fluctuations of the quality and quantity of waste supplied are apt to directly cause combustion to fluctuate due to the fast combustion reaction. For this reason, there was a tendency for the peak of CO (carbon monoxide) to appear in low excess air ratio operation.

Thus, to realize low excess air ratio combustion in the fluidized-bed incinerator, it is important to improve the steadiness of waste feed into the incinerator. To this end, at the latest facilities adopting the aforementioned next-generation type fluidized-bed incinerator, a system for coarse shredding of waste and
a double pit process (separate storage of received waste and shredded waste) is implemented to achieve improved steadiness of waste feed, which is realized by homogenizing the waste by coarse shredding in advance to be fed into the incinerator.

The reason why the combustion reaction is fast in fluidized-bed incinerators is that the temperature of the supplied waste rises rapidly after the waste comes into contact with the fluid medium, due to the high heat transfer characteristic peculiar to the fluidized bed, and the thermal decomposition and combustion reaction of waste swiftly follows. In general, the temperature of the fluidized bed tends to rise as the primary air ratio (the ratio of the amount of fluidizing air to the theoretical amount of air required for waste combustion) approaches 1. Therefore, by reducing the primary air ratio from conventional range and controlling the fluidization speed to the minimum extent possible, the thermal decomposition and combustion reaction of waste can be slowed and hence combustion fluctuations can be suppressed. As a result, the appearance of the CO peak can be prevented and now the incinerator can be operated stably, even if at a low air ratio. This is the slow combustion process.

The slow combustion process is effective particularly for equipment improvement work (life extension work) of existing facilities for which reduction of CO2 emissions is required by means of e.g. reducing power consumption because the implement of the slow combustion process contributes directly to the reduction of power consumption by forced draft fans. We have, therefore, adopted this slow combustion process for life extension work of several existing fluidized-bed incineration facilities and confirmed a remarkable improvement effect of combustion stability4. Specifically, even at a relatively small-scale facility (with a treatment capacity of approximately 40 tons/24 hours) that treats non-shredded waste, approximately 20 to 30% reduction of power consumption was achieved while preventing the appearance of the CO peak and ensuring stable operation by maintaining the appropriate combustion air ratio and thereby satisfactorily reducing the temperature of the incinerator bed.

In our experience, the fluctuation rate of the amount of waste supplied (the ratio of the fluctuation range to the average value of the amount of waste supplied) decreases in inverse proportion to the increase of the treatment capacity per furnace, in the case of the fluidized bed incinerator which treats non-shredded waste. Thus, it is expected that larger-scale facilities can achieve more stable operation at a low air ratio by adopting the slow combustion process even if waste is not shredded.

Note, however, that in operation at a low air ratio, simply reducing the amount of air supplied may cause such problems as excessive rises of the temperature at the outlet of the incinerator, the generation of thermal NOx, the adhesion of clinker to the incinerator wall, and the adhesion of ash to the heat transfer surface of the boiler. In addition, there is the possibility that the reduction of the amount of secondary air resulting from the low air ratio combustion will weaken the mixing and stirring effect in the free board section and hamper complete combustion. An effective solution to these issues is exhaust gas recirculation in the free board, which is also expected to significantly reduce CO and NOx concentrations because it can maintain the appropriate, homogeneous temperature field necessary for complete combustion of the unburned combustible content and also selective non-catalytic reduction reactions, as described later.

4. Latest Project of Equipment Improvement Work of a Non-shredding Type Fluidized-bed Incinerator

This section introduces the latest project of equipment improvement work (life extension work) of a non-shredding type fluidized-bed incinerator based on the concept described in the preceding section. In this project, we achieved stable operation with a lower air ratio and reduced CO and NOx concentrations compared to conventional fluidized-bed incinerators by adopting the slow combustion process and exhaust gas recirculation for the free board section, and retrofit major components for the purpose of reducing power consumption and increasing the amount of electricity generated.

A comparison of operation performance before and
after the equipment improvement work in this project is shown in the Table. The amount of waste treated and the calorific value of the waste did not show a significant change before and after the improvement work, but the overall air ratio decreased from approximately 1.8 to 1.4, and the steam output of the boiler increased from 13.4 to 14.7 tons/h.

The relationship between the air ratio at the boiler outlet and the CO and NOx concentrations of exhaust gas before and after the equipment improvement work is shown in Figure 2. The CO concentration [Fig. 2 (a)] before the improvement work tends to considerably increase at an air ratio below approximately 1.8 but after the improvement work, it remains low even when the incinerator is operated at an air ratio of approximately 1.25 to 1.5. On the other hand, the NOx concentration [Fig. 2 (b)] has a tendency to decrease linearly in proportion to reduction of the air ratio. It should be noted that, neither a selective catalytic reduction tower nor a spraying system for the denitration agent, such as urea or ammonia, into the free board section of the incinerator is installed at this facility. However, [Fig. 2 (b)] shows that after the improvement work, the incinerator can be operated with the NOx concentration in the order of 20 ppm by reducing the air ratio to approximately 1.25 to 1.3.

The trends of the air ratio at the boiler outlet and the CO and NOx concentrations (for 12 hours) after the equipment improvement work are shown in Figure 3. The average air ratio during this period is 1.27, which is equal to or lower than the level of the latest incinerators and the lowest value ever as a non-shredding type fluidized-bed incinerator, while the appearance of the peak of the CO concentration is prevented at an average of 2.4 ppm. Moreover, the NOx concentration remains as low as approximately 20 to 25 ppm.

Figure 4 shows a comparison of the gross power output, the power consumption, and the net power output before and after the improvement work. Please note that these values are the average values during operation of the two incinerators, and the power consumption includes that of the building facilities, the lighting, and the recycling plant. The gross power output increased from approximately 3040 kWh/h before the improvement work to approximately 3690 kWh/h after, whereas the power consumption decreased from
approximately 2090 kWh/h to approximately 1730 kWh/h. As a result, the net power output almost doubled, from approximately 950 kWh/h before the improvement work to approximately 1960 kWh/h after. The amount of annual CO₂ emissions was reduced by approximately 46.3% after the improvement work.

Note that in this project, the steam condition [2.65 MPa (abs) × 290 °C] of the waste heat boiler remained unchanged from before the improvement work. If the waste heat boiler and related auxiliary equipment are also updated to apply the steam conditions [4.0 MPa (abs) × 400 °C] generally applied at the latest facilities, the gross power output can be increased to approximately 5260 kWh/h. In this case, the net power output will increase to approximately 3630 kWh/h, and the reduction rate of the amount of annual CO₂ emissions is estimated to be increased by approximately 120% because the reduction of the amount of CO₂ emissions due to the increase of net power output will exceed the amount of CO₂ emissions before the improvement work.

5. Considerations for Design and Operation

As already mentioned, in the fluidized-bed incinerator, the combustion reaction of waste is not completed within the fluidized bed and the unburned combustible content is completely combusted by supplying secondary air into the free board section. In this process, the denitration reaction is accelerated because the CO, NH₃, etc. produced in the reduction atmosphere in the fluidized bed area act as reducers. Thus, the adoption of exhaust gas recirculation for the operation of the fluidized-bed incinerator at a low air ratio plays an important role in enhancing the mixing stirring effect in the free board section and thereby accelerating the abovementioned combustion and denitration reaction. It is therefore desirable to keep the reaction field with an appropriate temperature range for these combustion and denitration reactions as homogeneous as possible when newly adopting exhaust gas recirculation for existing fluidized-bed incinerators. To achieve this, the arrangement of recirculation nozzles and balance of the flow rates from each recirculation nozzle should be optimized as an important consideration in design and operation.

As an example of a design assessment, the results of a preliminary assessment based on combustion simulations of the abovementioned project are shown in Figure 5. In this calculation, which was performed only for the free board section, temperature distribution of the incinerator [Fig. 5 (a)] and unburned gas distribution [Fig. 5 (b)] were evaluated assuming the unburned gas produced at the fluidized bed was combusted according to the overall single-stage
reaction. In Fig. 5 (a) and Fig. 5 (b), simulation results corresponding to the situations before the improvement work (air ratio approximately 1.8, without exhaust gas recirculation) and after (air ratio: approximately 1.4, with exhaust gas recirculation) are shown on the left and right, respectively.

Each cross section of the combustion gas passage shows that the unburned combustible content passes through the local high-temperature field (marked with the red circle) for the situation before the improvement work. For the situation after the improvement work, on the other hand, it is evident that the temperature distribution at each cross section is uniform and the unburned combustible content homogeneously decreases along the direction of the flow of exhaust gas (upward from below) as a result of the optimization of the arrangement of the recirculation nozzles and of the balance of the flow rates.

**Figure 6** shows the CO and NOx concentrations actually measured at different locations of the free board section after the improvement work. Both of the CO and NOx concentrations gradually decrease from the lower stage to the middle and upper stages of the free board, corroborating the results of the combustion simulations shown in Fig. 5. Judging from the fact that the actually measured temperature of the free board in the project was approximately 900 °C in the lower stage and approximately 870 °C at the outlet, it is
important to secure a sufficient retention time for the temperature region where the combustion reaction of the unburned combustible content (850 °C or higher) and the selective non-catalytic reduction reaction (850 to 950 °C) are positively accelerated in order to reduce both CO and NOx at the same time. We also found that appropriate control of the amount of recirculated exhaust gas is effective in preventing the appearance of the NOx peak to keep the temperature of the free board section from fluctuating even if the quality (calorific value) of the waste changes.

Note that the overall single-stage reaction model used for the abovementioned simulations was simple and relatively easy to calculate, but detailed analysis using an elementary reaction model can contribute to further reduction of CO and NOx. In some improvement work projects currently under design assessment (which are not explained in this paper due to space limitations), we are considering the optimization of secondary air and recirculated exhaust gas supply into incinerators through combustion analysis using the elementary reaction model.

6. Future Outlook on Fluidized-bed Incineration Technology

In this paper, we explained that existing non-shredding type fluidized-bed incineration facilities for treating municipal solid waste can be operated with an air ratio and the emission of CO and NOx equal to or lower than those of the latest incinerators by adopting the slow combustion process and low air ratio combustion technology combined with exhaust gas recirculation.

In the early stages of adopting fluidized-bed incinerators in the field of municipal solid waste incineration, waste shredding was an indispensable pretreatment for stable waste combustion in the fluidized bed. This was a disadvantage compared to grate-type incinerators for which waste shredding is not required in general. Therefore, acting ahead of other manufacturers, we developed the non-shredding type fluidized-bed incinerator and introduced it to the market. Through the project of equipment improvement work mentioned in this paper, we achieved remarkable combustion stability at the non-shredding type fluidized-bed incineration facility, which is equal to or higher than that of the latest grate-type incineration facilities. We are aware that this achievement has great significance in terms of future outlook on the fluidized-bed incineration technology.

Concerning municipal solid waste treatment in Japan, the necessity of seeking a method combining economic rationality and high energy recovery efficiency is increasing in terms of future changes in the social environment, such as depopulation and municipal financial difficulties, and the furthering of measures against global warming. In fact, cases of mixed treatment of diverse wastes produced in local communities, such as high calorific industrial waste like waste plastics and low calorific waste-like night soil sludge or sewage sludge, are on the increase at municipal solid waste incineration facilities owned and operated by municipalities. Fluidized-bed incinerators are appropriate for mixed treatment of diverse substances with different calorific values or properties, and will be promising solutions in preparation for future changes in the quality or properties of substances to be treated.

In addition, for medium and small-scale municipalities, operating only waste sorting facilities or mechanical/biological treatment (MBT) processes without constructing incineration facilities will be an option to realize economical, wide-area treatment of garbage in the future, as already introduced in Europe and other regions. In this case, medium and small-scale municipalities will only sort circulative resources, such as metals, or ferment organic waste, and after sorting, the combustible residues will be transported to and treated by large-scale waste-to-energy facilities as waste-derived fuels. Ebara has delivered many units of fluidized-bed incineration equipment, including facilities fueled by such waste-derived fuels, to Europe and other countries. These facilities are still in operation in some countries, and the largest-scale facility is operating with a heat input of 90 MW (equivalent to 650 tons/day for 12 MJ/kg of waste-derived fuel calorific value, or 820 tons/day for 9.5 MJ/kg of calorific value equivalent to typical municipal solid waste), which is far in excess of incinerators operating in...
Japan. This facility is a good example of making the most of the distinguished advantages of the fluidized-bed incinerator, which is capable of efficient energy recovery from waste with relatively high calorific value increased as a result of sorting and flexibly achieving mixed treatment with wastes of significantly different properties, such as sludge.

Furthermore, there is an increasingly active movement toward operating waste-to-energy facilities as local power plant for local production and local consumption. The primary function required for these facilities to meet these needs is the capability to stably transmit the planned amount of electricity. Additionally, it will also be expected in near future that these facilities have superior load responsiveness enabling the transmitted power output to respond to fluctuations of electricity demand and/or power output of other renewable energy sources (photovoltaic power generation, wind power generation, etc.) within the regional area, which may also enhance economical operation of the facilities. When specially required, a coarse shredding system should be implemented to maximize the steadiness of waste feed and combustion stability (as is the case with a facility we delivered), which will be an effective approach for elaborate control of the power output.

Waste-to-energy facilities with an excess capacity may be able to increase their operating rates by utilizing biomass resources, such as forest remaining wood (which is a renewable energy resource in regional areas), in ordinary operation. In this case, the excess capacity may be allocated to the treatment of disaster waste in the event of a disaster. The features of fluidized-bed incinerators, which are fit for mixed treatment of various substances, will contribute to the realization of such flexible operation.

With regard to selecting the type of incineration facility, it is frequently discussed whether to select a grate-type incinerator or a fluidized-bed incinerator, and whether or not waste should be shredded in the case that a fluidized-bed incinerator is selected. In the future, however, depopulated societies will be required to secure and maintain an appropriate social overhead capital stock without waste. To realize this, it is important in the planning phase to select such technology that will be capable of achieving the required functions economically and efficiently throughout its life cycle. One of the feasible solutions to this issue is the construction of plural types of incineration equipment with different features, such as a grate-type incinerator and a fluidized-bed incinerator, within the same facility or the same region, as has been done in the EU. That is, facilities will be required to flexibly assume roles by using different types of incineration equipment according to the properties of the substances to be treated so that economical operation will continue for many years to come.

References