Automatic Plant Operation Utilizing AI and Big Data Analysis in Waste-to-Energy Plants

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Abstract:

Construction of a Waste-to-Energy (WtE) facility is the core business of JFE Engineering. And in this field, our clients in Japan (e.g., local authorities) are more interested in medium- and long-term management and operation contract, in addition to simple EPC contract. Numerous numbers of such a management and operation contract are ongoing currently, but efficient operation with a small number of operators is required in order to reduce operational cost. In addition, due to "declining birth rate / aging population" and "labor shortage", we are facing a shortage of experienced operators. To solve the situation, JFE Engineering has opened a remote support facility in Yokohama headquarters in September 2014, and has been providing remotely assisted plant operation to experienced operators from this facility. Furthermore, in order to support WtE facilities which increase every year, "fully automated operation" of such facilities is necessary.

In this paper, we will report how we have achieved "automatic operation" of incinerators, and the result of the demonstration operation at a fully automated operation facility.

1. Introduction

The main trend in the construction and operation of waste-to-energy (WtE) plants in Japan, is now DBO (Design, Build, Operate) or PFI (Private Finance Initiative) projects, in which a private-sector company undertakes a long-term operation and maintenance contract after construction in addition to the original EPC (Engineering, Procurement, and Construction) contract for construction of the facility. An increasing number of facilities which are already in operation have also been changed to long-term comprehensive operation contracts. To respond to these changes in the business environment, JFE Engineering strengthened the remote maintenance service which it had provided to the customer since 2003 and established the Remote Service Center (hereinafter, RSC) as a remote operation support facility for plants in September 2014. The RSC is equipped with the "JFE Hyper Remote™" system* to support operation plants by utilizing the internet-of-things (IoT) to provide remote support for plants throughout Japan. The RSC was expanded in March 2018 and transitioned to the Global Remote Center (hereinafter, GRC) with strengthening security functions, and now provides an expanded range of support.

This article introduces the remote support by the GRC, together with the status of development of fully automated operation of incinerators using IoT, AI and data analysis technologies.

2. Overview of Remote Support System

2.1 Global Remote Center (GRC)

The RSC was a dedicated remote support facility for WtE facilities. In the GRC, the RSC was expanded as a remote support facility that also supports other types of plants constructed by JFE Engineering, and its remote support functions for overseas plants and cybersecurity countermeasures were enhanced.

In the remote support for WtE plants at the GRC,

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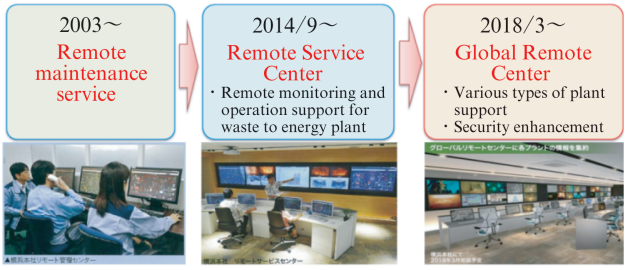

Fig. 1 Background to Global Remote Center establishment[1)]

veteran operators mainly monitor the incinerator and perform actual operation when necessary by the same type of 24-hour system as in each facility in order to support stable and safe operation of the plants.

In addition to operation monitoring and actual operation from a remote location, the GRC also utilizes various types of data collected and accumulated using the IoT to strengthen support by the state-of-the-art "JFE Hyper Remote" system by applying data analysis techniques and AI. **Figure 1** shows the background up to the establishment of the GRC.

2.2 JFE Hyper Remote™

"JFE Hyper Remote" consists of equipment and systems for remote support of WtE facilities, and was put into operation in September 2014. Although the "JFE Hyper Remote" system originally supported two WtE facilities, that number has now been expanded to 10, and support of five additional facilities has already been decided. Including those supported facilities, the system will support a total of 15 facilities in the near future.

The "JFE Hyper Remote" system has three broad functions, as follows.

1) Function that enables the same monitoring and operation as that performed by operators in the central control room of the supported facility.
2) Collection of a large volume of diverse data such as operational data and combustion images, and their use in data analysis and AI.
3) Function for optimizing electric power sold to power companies and PPS (Power Producer and Supplier), as many supported facilities are power generating facilities.

The main work of the operators in the GRC is the first item, i.e., monitoring and operation. JFE Engineering formulated the concept shown in **Fig. 2** several years ago and is promoting R&D activities to realize unmanned operation in the central control room, as illustrated in **Fig. 3**, by utilizing accumulated data and state-of-the-art AI.

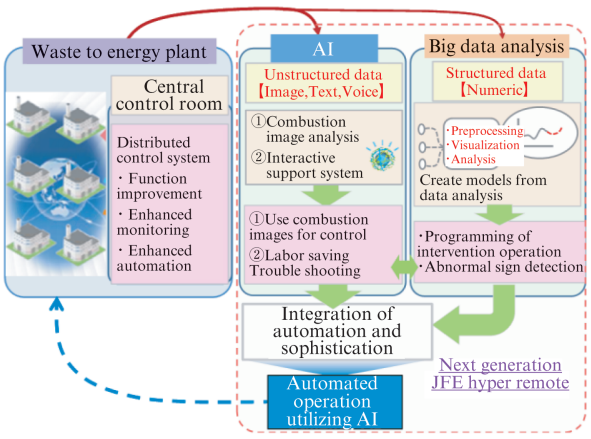

Fig. 2 System overview of data analysis and AI

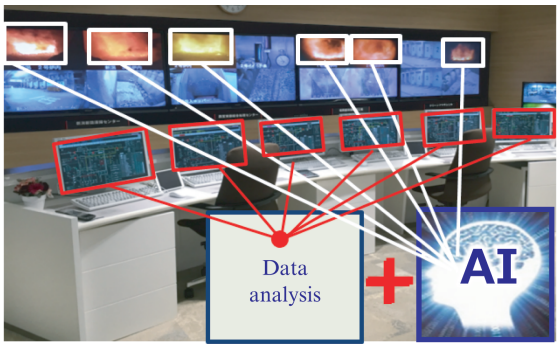

Fig. 3 Image of automatic operation to incinerator utilizing AI

3. Remote Support Utilizing IoT and AI

3.1 Support Region Utilizing AI

Accompanying the privatization of WtE plant operation, shortages of skilled operators have gradually occurred, and this trend will also continue in the future. Since the establishment of the GRC, JFE Engineering has collected various types of data by utilizing the IoT in order to cope with this situation. Primary purpose of utilizing these data is automation of manual operation to enable stable secure operation of incinerators by skilled operators, and a second purpose is to collect and utilize the know-how of skilled operators.

To achieve these purposes, JFE Engineering started AI utilization with leading AI makers from 2015 and began operation of the following two systems in 2018, one being an interactive support system, and the other, a combustion condition image analysis system.

3.2 Interactive Support System

In the interactive support system, the know-how of skilled operators and various kinds of documents are stored in a database, and appropriate answers can be obtained instantaneously by voice or drawings when a

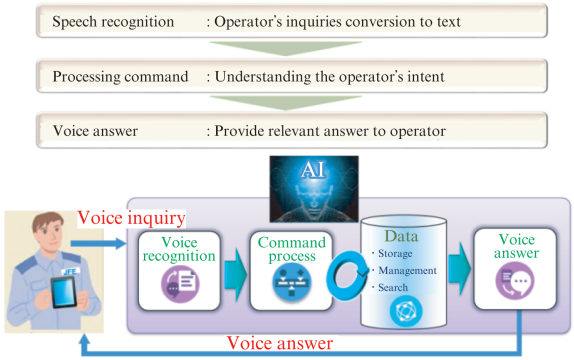

Fig. 4 Outline of interactive support system[1, 2)]

Fig. 5 Inquiry screen for interactive support system

new employee or young operator makes an inquiry by using AI speech recognition, command processing and voice answer technologies. This system has two functions, 1) an inquiry function for operational techniques and troubles and 2) a document (drawing) search function for design drawing, user's manuals, procedures and examples of trouble, etc. **Figure 4** shows an overview of the interactive support system, and **Fig. 5** shows an example of an inquiry screen actually used.

Trial operation of this system started in May 2018, and actual operation in the GRC and two operation facilities began in October. When the system was put into operation, there were cases when it did not understand the meaning of inquiries and could not give a correct answer, and correct answers and documents were not obtained.

In this system, all voice and command processing results and reply results are stored as log data when an inquiry is made. The system operation manager checks these logs and makes continuous efforts to improve accuracy by additional registration of terminology to enhance the accuracy of technical terms and dictionaries and text conversion of the content of inquiries and command processing, together with learning to strengthen command processing.

3.3 Combustion Condition Image Analysis System

In the GRC and the central control room of WtE facilities, operators monitor the combustion condition inside the furnace by means of process data on DCS (Distributed Control System) screens and ITV (Industrial Television) monitors in order to confirm stable, secure operation. The combustion condition image analysis system digitizes the quality of combustion in images monitored by ITV monitors.

An Automatic Combustion Controller (hereinafter, ACC) is used in operation of an incinerator, and alarms are set to ensure that critical process data do not deviate from the control values so that the operator can check the DCS alarms and judge whether a response to improve combustion is necessary or not. However, as there was no alarm notification function for the combustion condition, it was necessary for the operator to monitor combustion images and judge the quality of the combustion condition based on operating experience. JFE Engineering implemented the combustion condition image analysis system utilizing AI to judge the combustion condition from ITV monitored images and started actual operation of the system in October 2018. In this system, as in the interactive support system, the system operation manager utilizes additional learning to improve the level of combustion condition judgments to the same level as those of skilled operators.

In this system, combustion images are processed in the DCS on the WtE facility side, and imaging data generated from those images is input here. The quality of the combustion condition in these image data is digitized by a classifier, in which accuracy is enhanced by learning using past image data. The DSC on the facility side can monitor these numerical values in the same way as process data, and notify the operator by an alarm when a condition that requires improvement occurs.

Figure 6 shows the outline of the combustion condition image analysis system, and **Fig. 7** shows a combustion visualization monitoring screen used in operation. **Figure 8** is an example of digitization of the combustion condition by the combustion condition image analysis system.

4. Efforts Toward Fully Automated Incinerator Operation

4.1 Overview of Issues and Efforts for Fully Automated Operation

As mentioned above, automatic control by an ACC

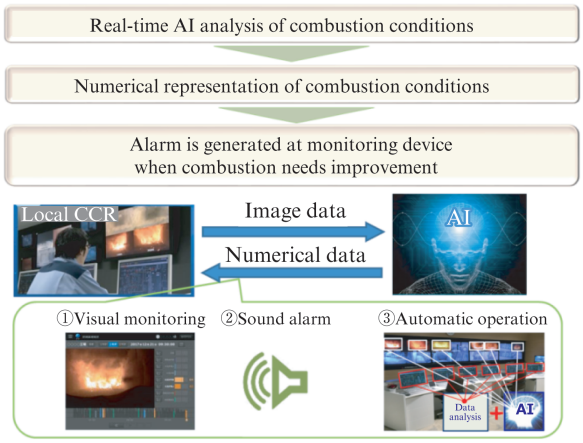

Fig. 6 Outline of combustion condition analysis system[2, 3)]

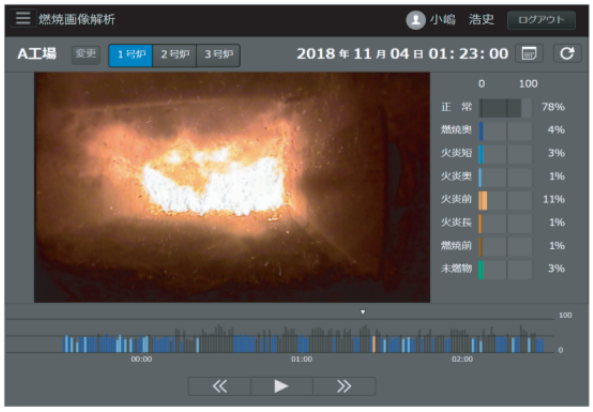

Fig. 7 Visualization monitoring screen of combustion condition analysis system[2, 3)]

Condition	Percentage
Good	5
Weak	91
Strong	4

Condition	Percentage
Good	86
Weak	6
Strong	7

Condition	Percentage
Good	23
Weak	7
Strong	70

Fig. 8 Example of digitization of real images by combustion condition analysis system

is used in operation control of incinerators. However, the -LVH of the waste supplied to incinerators changes constantly, and if the range of fluctuations becomes excessive, this will result in a poor combustion condition if only automatic control by the ACC is used, as operation control values that require strict control, such as the combustion control temperature and flue gas composition, will become unstable. In this case, the operator judges the necessity of improvement, and if necessary, performs manual operation of combustion control by the ACC to improve combustion condition.

Here, the aim is to realize even more secure and stable fully automated operation of incinerators by programming the manual operations performed by operators and strengthening combustion control by the ACC. To achieve this, JFE Engineering collected various data in connection with manual operation and promoted automation of manual operation. In promoting these efforts, there were mainly three points that should be considered:

1) Operators judge that manual operation is necessary based on various process data and the combustion condition.
2) Standards for judgment of manual operation differ depending on the individual.
3) The operational items in manual intervention can differ, even under the same conditions.

Based on these three considerations, the judgment standards for manual intervention when operators check various data, the amount of operation in manual intervention, and the timing of recovery of normal operation were modeled and incorporated in combustion control as a control program, and demonstration operation was conducted at an actual facility.

Figure 9 shows an example of an analysis of the process data at the time of a grate speed increase, and **Fig. 10** shows an analysis of the process data during grate deceleration.

4.2 Status of Demonstration Operation

The control function for fully automated operation was introduced in an actual facility beginning in October 2018, and the demonstration operation is ongoing. Here, the process data that were judged to be effective for fully automated operation based on an analysis of data on manual operation by operators, and combustion condition data obtained from the combustion condition image analysis system were integrated in a comprehensive manner, and the content of operation by skilled operators to achieve stable combustion was added to the conventional ACC control.

Because manual intervention by operators involves multiple items, a fully automated operation function was introduced in the waste feeding system in October

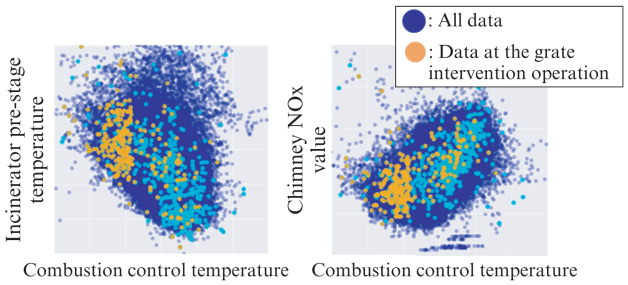

Fig. 9 Process data at the time of grate increase[3)]

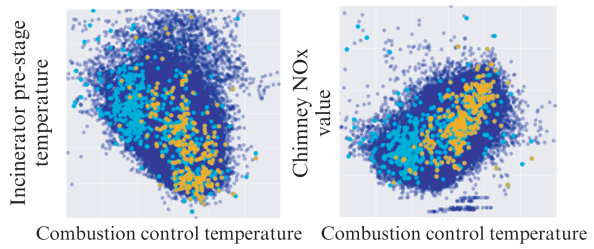

Fig. 10 Process data at the time of grate deceleration[3)]

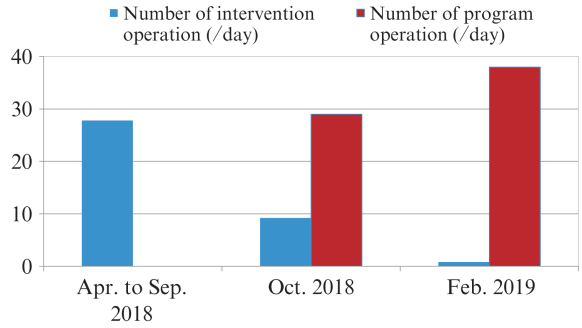

Fig. 11 Operation intervention status in demonstration operation

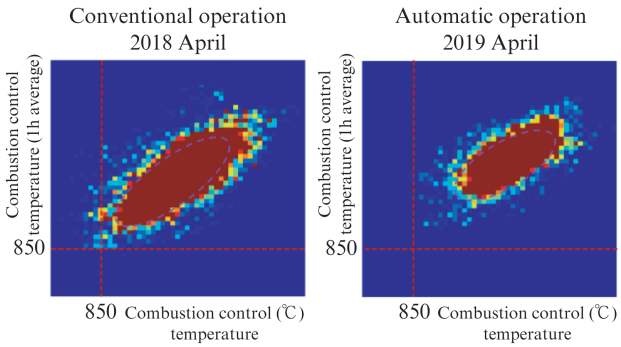

Fig. 12 Distribution of combustion control temperature between conventional operation and automatic operation

2018, as this is the most important part of this company's grate type incinerators and also requires the most frequent manual intervention. Subsequently, the fully automated operation function was also expanded to the combustion air blowing system in February 2019.

Prior to introduction of this automatic control function in the waste feeding system, skilled operators had intervened manually from several times/day to several 10s of times/day at each incinerator. However, intervention was reduced to about 30 % of this level in January 2019 by introduction of this function. Following this, operation was stabilized further by adding automatic control to the combustion air blowing system, and as a result, intervention by skilled operators decreased to zero, confirming the possibility of long-term fully automated operation. **Figure 11** shows the condition of manual intervention during the demonstration operation period.

In February 2019, manual intervention by operators become almost zero, and instead, the number of program interventions by the control function for fully automated operation increased by approximately 40 % in comparison with the number before introduction.

A comparative evaluation of conventional operation and fully automated operation was carried out to determine whether fully automated operation leads to improved combustion stability. As a period when the quality of the waste is the same, conventional operation in April 2018 and fully automated operation in April 2019 were compared. Here, the distributions of the instantaneous value of the incinerator combustion control temperature and its 1 hour moving average temperature were arranged, as shown in the example in **Fig. 12**.

As the combustion control temperature for stable combustion, it is necessary to secure a temperature of 850 ˚C or higher. As shown in Fig. 12, the distribution region of the combustion control temperature was smaller with fully automatic operation than with conventional operation, showing that the combustion control temperature is more stable under fully automated operation.

In waste incineration plants that include power generation facilities, there is a high correlation between the combustion control temperature and the amount of steam generated by the boiler. Therefore, the stability of the combustion control temperature leads to stability of the amount of steam generation, and finally results in stable power generation by the steam turbine generator which uses that steam. In addition, thermal fluctuations inside the furnace are also reduced when the combustion control temperature is stable, and this contributes to a decrease in refractory abrasion and consumption.

This demonstration operation is ongoing at present, and is confirming the stability of combustion by fully

automated operation of the incinerator over the long term.

5. Conclusion

In addition to remote support by skilled operators, JFE Engineering has been working to enhance fully automated operation of incinerators by utilizing data analysis and AI since FY 2018 in support by the "JFE Hyper Remote" system. Fully automated operation of incinerators was introduced in the form of strengthening of the ACC of actual facilities, and had been in operation for almost one year as of this writing. Satisfactory results were obtained, as perfect fully automated operation of an incinerator was achieved over a period of more than 2 weeks in February 2019, and fully automated operation was also continued thereafter. Secure fully automated operation by stable optimal combustion control based on enhanced use of AI has been confirmed, and at present, this function has been introduced at four facilities and work to commercialize this system is underway.

JFE Engineering will continue to contribute to society by expanding and strengthening its secure, stable environmental plant operation business, beginning with waste-to-energy plants, which are a key part of the social infrastructure.

* "JFE Hyper Remote" is a registered trademark of JFE Holdings, Inc.

References

1) Kojima, H.; Seno, M.; Hashimoto, T. Efforts of data analysis and IoT in Waste to Energy Plants. The Proceedings of the Symposium on Environmental Engineering 2018, 28. p. 160–163.
2) Kojima, H. Sangyouhaikibutsushisetsu ni okeru IoT, AI katsuyourei. INDUST. 2018, no. 367, p. 38–41.
3) Kojima, H.; Seno, M.; Kawano, T.; Tamagawa, K. Plant automatic operation utilizing AI and big data analysis in Waste to Energy Plants. The Proceedings of the Symposium on Environmental Engineering 2019, 29. p. 132–135.