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Discussion on CFD Technology of Mechanical Stoker-type Waste Incinerator in Japan

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Abstract: *In recent years, to reduce the design cost, improve the economic benefits and shorten the research cycle, the leading waste incinerator manufacturers in Japan have developed high-precision three-dimensional CFD (Computational Fluid Dynamics) models and software based on the actual measured data. Since CFD technology can simulate the combustion state of the incinerator under various conditions, it can help Japanese manufacturers understand and explain the phenomena observed in reality, optimize the design of various equipment, and improve the operating conditions and efficiency of the incinerator. Based on their most advanced mechanical stoker-type waste incinerators, Japanese manufacturers study the impact of various parameters on the combustion in the incinerator based on CFD technology. Only by controlling the combustion parameters such as the excess air coefficient, Japanese manufacturers can maintain the stable and complete combustion in the incinerator, reduce the emission of pollutants and improve the waste heat recovery efficiency of the incinerator.*

Keywords: *Waste Incinerator, Combustion, CFD, Simulation, Automatic Combustion Control*

1. Introduction

In the process of design, manufacture, and optimization of municipal solid waste (MSW) incinerator, the rationality of gas flow in the incinerator is an important consideration [1]. It is because the flow of gas in the furnace not only has a significant impact on the performance of the incinerator and the emission of nitrogen oxides (NOx), but also affects the emission concentration of harmful gas carbon monoxide (CO) and the generation of dioxin, and affects the corrosion of heat transfer tubes [2]. Since the flow of gas in the incinerator is related to the basic performance requirements and service life of the incinerator, the rationality of gas flow in the incinerator needs to be considered in the design of the incinerator [3].

In the mechanical stoker-type waste incinerator, the main design contents are the furnace volume; furnace shape; primary air volume for combustion; secondary air volume for cooling and mixing; air temperature of each part; air distribution ratio of each section of the grate; position, quantity, diameter and injection direction of secondary air nozzles; etc. [4]. At the same time, for the design of waste heat boiler, it is also necessary to consider the heat exchange area, the configuration of heat exchange surface, the shape of airflow path, etc. [5]. The specification parameters of incinerator and boiler are usually designed based on previous experience or actual plant measurement results. This design method is effective, but it is challenging to solve practical problems such as reducing dioxin emission based on experience, and there are also some problems such as cost in the experiment [6].

Recently, the new research method of heat transfer and fluid flow analysis using computer has attracted extensive attention. In the past, computer analysis was mainly used to study structure and strength, while fluid flow analysis was only used in limited fields such as aerospace engineering. In recent years, with the continuous improvement of computer hardware performance and the continuous progress of computer simulation technology, general heat exchange devices, waste incinerators, and other equipment can be simulated by computer to a certain extent [7].

This paper introduces advanced and effective technologies to design and develop waste incinerators of leading waste incinerator manufacturers in Japan based on heat transfer and fluid flow analysis software.

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2. CFD research background of Japanese manufacturers

Japanese manufacturers mainly use CFD numerical calculation method to design, develop and optimize waste incinerators and boilers based on heat transfer and fluid flow analysis. In order to ensure the equipment performance, essentially all Japanese manufacturers have special R&D teams to develop CFD software.

Japanese manufacturers began to use CFD technology for research and development very early. In the 1990s, CFD technology was used to simulate the temperature distribution in the furnace, velocity field, and concentration field of flue gas of the Automatic Combustion Control (ACC) system. Around 2000, CFD technology has made significant progress, which can predict the material change, temperature rise, and flow velocity change in the combustion chamber when chemical reactions are considered. When new technologies and products are developed, Japanese manufacturers have done many fluid flow and temperature distribution analyses with CFD technology before actual machine experiments. Japanese manufacturers basically have CFD basic R&D departments and have invested much money in CFD basic research to ensure the leading and reliable incinerator technology and reduce the R&D cost.

Taking Hitachi Zosen Corporation as an example, the company believes that CFD simulation research has the following advantages: (1) because there is no need to make samples, it can be simply studied under various conditions; (2) it can visualize the invisible flue gas flow field, which is easy to understand visually; (3) it can simulate situations that have not been encountered in the past (for example, more stringent emission standards than the general situation, newly added equipment, etc.); (4) It can be used as the general goal of design. Hitachi Zosen Corporation determines the general goal of design, masters the general design direction based on CFD simulation research, and takes the CFD simulation results as the reference of the actual design. Hitachi Zosen Corporation has done the following research using CFD technology: (1) incinerator: analyzes the flue gas flow field, CO distribution, NOx distribution, temperature distribution, etc. in the incinerator; studies and optimizes the shape of the incinerator and the setting position of the secondary air nozzles; (2) Flue gas purification system: temperature regulating tower, cooling tower, bag filter, pipe shape, and piping structure. When it studies the setting position of the secondary air nozzles, Hitachi Zosen Corporation uses CFD simulation technology to change the nozzle position, fluid flow, and other parameters; studies various situations; masters the design direction; and takes the simulation results as the reference data of the actual project. For Hitachi Zosen Corporation, CFD technology has the advantages of visualization, low cost, and high efficiency. It can be used in the following R&D directions: (1) used to analyze the combustion characteristics of incinerator; (2) used for design and optimization of incinerator; (3) used to analyze the relevant characteristics of flue gas purification system; (4) used for the design optimization of the system. Since CFD technology provides a reference basis for the design and optimization of incinerator and flue gas purification system, Hitachi Zosen Corporation applies CFD technology to the design of incinerator.

However, CFD is a simulation study, which has the following uncertain factors: (1) CFD is modeling (Simplified) simulation, which always has errors with the actual situation; (2) CFD can only deal with steady state (cannot deal with emergencies such as unsteady combustion). Therefore, Japanese manufacturers take the CFD simulation results as the design reference and do not directly use the results in the design.

3. CFD research methods of Japanese manufacturers

3.1. Hitachi Zosen Corporation

The heat fluid analysis software used in the CFD Research of Hitachi Zosen is "FLUENT". The company uses FLUENT software to solve the numerical solution of the simultaneous equations composed of mass conservation equation, momentum conservation equation, energy conservation equation, chemical matter conservation equation, and other equations. In FLUENT, the finite volume method is used for discretization, the SIMPLE algorithm is used to solve the pressure-velocity coupling equations, the k-ε two-equation model or Reynolds stress model is used for the turbulence model, the ray tracing model is used for radiation, the vortex dissipation model is used for combustion, etc. In terms of accuracy and generality, the CFD research of Hitachi Zosen uses some standard models, and it is relatively easy to simulate some equipment with complex shapes [8].

In the CFD study of mechanical stoker-type waste incinerator, only the simulation of gas phase is often considered, and the solid waste fuel on the grate is simplified. Therefore, Hitachi Zosen has

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developed a software called "3d-MSW" to simulate the combustion of waste bed on the grate. The software takes the grate feeding speed as a parameter, and it can analyze the influence of the parameter on the flue gas temperature and carbon monoxide concentration in the incinerator. Because the simulation results of 3d-MSW are consistent with the test data of the experimental incinerator, and the software can simulate not only the combustion of waste bed under normal air condition, but also the combustion of waste bed under oxygen-enriched air condition, the software is suitable to simulate the combustion of waste bed in mechanical stoker-type waste incinerator under various conditions.

The 3d-MSW software uses a CFD model called "MSW-Bed", which simulates the state change of waste combustion on the grate by tracking the motion of discrete particles. Because municipal solid waste is composed of various substances with different properties, and the waste distribution on the grate is not uniform, MSW-Bed regards the waste bed as a discontinuous dispersion system. The principle of the MSW-Bed model is as follows: (1) the waste bed is composed of waste particles with various properties, and waste particles are tracked by Lagrange method to simulate the overall situation of the waste bed; (2) the moving speed of waste particles is consistent with that of the grate. In the moving process, waste particles undergo preheating, drying, pyrolysis, rapid combustion, and cooling, and the effects of grate structure and waste bed shape are considered; (3) waste particles exchange heat and matter with the gas phase. Based on the MSW-Bed model, the 3d-MSW software considers the interaction between waste bed and gas phase, and the influence of grate moving speed on combustion in the incinerator. It can simulate the characteristics of combustion, heat transfer, and fluid flow in the incinerator to simulate the overall situation of the incinerator.

With the 3d-MSW software, Hitachi Zosen can effectively simulate the ordinary air combustion and oxygen-enriched air combustion in the waste incinerator and the combustion in the experimental incinerator. Therefore, the simulation results can be applied to the development of the real machine. 3d-MSW considers the influence of grate speed on gas phase temperature and CO concentration, so it is an effective method to simulate gas and solid phases combustion in the incinerator [9].

3.2. Taguma Industries

Taguma applies CFD technology to the design and development of waste incinerator, boiler, cooling tower, grate, and other equipment of waste incineration power plant, so as to ensure the best performance of the equipment and maintain the best operation state of waste incineration power plant. In order to optimize the design and operation conditions of various equipment and avoid strenuous or expensive experiments, Taguma studies the impact of different parameters on the incinerator with CFD technology to predict and judge the state of the incinerator under various conditions, and provide reference and help for explaining and understanding the phenomena observed in practice. Using the fluid analysis software CFX and according to the CFD simulation results, Taguma has developed a new mechanical stoker-type incinerator, which realizes the stable combustion of the incinerator under the condition of excess air coefficient of 1.3, reduces the toxic substances generated in the combustion process and improves the residual heat recovery efficiency of the incinerator.

The new waste incinerator of Taguma adopts an exhaust gas recirculation (EGR) system. The combustion gas below the ignition point (containing high concentration O2 and low concentration corrosive gases such as HCl and SOx) is led out from the rear arch tail of the incinerator. Cooled by the heat exchanger, it is injected into the secondary combustion chamber from the throat of the incinerator. It is mixed and stirred with the combustion gas in the primary combustion chamber. The secondary air is injected to ensure the complete combustion of unburned gas. In this way, the combustion gas in the primary combustion chamber can be effectively utilized, and a uniform high-temperature reduction atmosphere with an excess air coefficient of about 1.9 can be formed in the furnace to inhibit the generation of NOx effectively. Since air equivalent to an excess air coefficient of about 0.4 is fed into the secondary combustion chamber, the unburned substances such as CO and dioxin in the incinerator are completely burned under the condition that the excess air coefficient is 1.3.

Taguma uses CFD technology to analyze the combustion state in the incinerator and develops the new mechanical stoker-type waste incinerator by optimizing the structure and combustion conditions of the incinerator. Compared with the previous incinerators with excess air coefficient of 1.7~2.0, the new incinerators can realize stable and complete combustion under the condition of excess air coefficient of 1.3, inhibit the generation of toxic substances such as NOx, CO, and dioxin, reduce the environmental burden and improve the energy recovery efficiency [10].

3.3. JFE Corporation

JFE mainly develops waste incinerators with experimental methods. JFE also uses numerical analysis methods, but because the three-dimensional model requires a lot of calculation time, JFE mainly uses one-dimensional and two-dimensional models. In order to calculate the three-dimensional model of the size of the actual machine with high precision, JFE adopts the most advanced two-way gas flow incinerator as the simulation object (as shown in Fig. 1). The incinerator divides the flue gas in the furnace into two parts: the primary flue gas and the sub flue gas. The main flue gas with high concentration oxygen and the sub flue gas containing unburned components are effectively mixed and stirred in the flue gas mixing chamber.

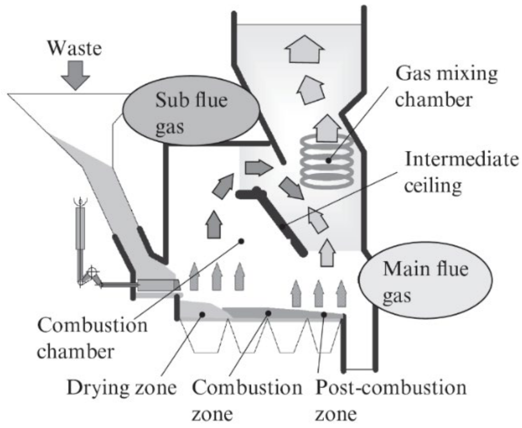

Figure 1: Two-way gas flow incinerator of JFE.

JFE selects the combustion reaction mechanism that can simplify and accurately simulate the gas combustion in the furnace in the two-dimensional model with FLUENT software. Then, according to the size of the actual machine, the three-dimensional model of the incinerator is established, and the combustion reaction mechanism is extended to the three-dimensional model for calculation. The simulation results show that the calculation results of temperature distribution and CO concentration distribution in the incinerator agree with the actual measurement results, which confirms the effectiveness and practicability of numerical simulation technology of JFE.

Therefore, JFE has CFD numerical simulation technology that can accurately predict the combustion state in the furnace and takes this technology as a research, development, and design tool to further improve the performance of waste incinerator [11].

3.4. Kawasaki Heavy Industries

Based on its unique parallel flow waste incinerator, Kawasaki Heavy Industries. has developed its unique three-dimensional CFD numerical analysis model, which can predict NOx emission of incinerator. When the waste fuel moves with the grate, the model can carry out three-dimensional CFD analysis of the combustion of waste bed and its thermal decomposition gas. According to the results of CFD numerical simulation, Kawasaki Heavy Industries makes the temperature in the incinerator evenly distributed and reduces NOx emission by increasing the EGR recirculation gas volume and reducing the excess air coefficient of the incinerator. With the help of CFD analysis technology, Kawasaki Heavy Industries can realize low NOx combustion only by controlling the recirculation gas volume of EGR and the excess air coefficient of the incinerator, which reduces the life cycle costs (LCC) of waste incineration power plant, improves economy, reduces the environmental burden and improves the efficiency of residual heat recovery [12].

4. Conclusions

When they design and develop waste incinerators, based on the experimental data of actual incinerators, the leading waste incinerator manufacturers in Japan develop high-precision three-dimensional CFD numerical simulation technology to simulate the combustion state of solid and gas phases in the incinerators. Since the CFD calculation results are consistent with the actual measurement results, Japanese manufacturers can optimize the structure and combustion conditions of the incinerator

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with CFD technology, so as to reduce the excess air coefficient required for stable and complete combustion of the incinerator, reduce the emission of NOx, CO, dioxin and other harmful substances, reduce the operation cost of the waste incinerator power plant, reduce the environmental burden, improve the energy recovery efficiency, and improve the economic benefits of the waste incineration power plant.

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