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Development of New Engineering Technology Based on Computer Analysis of Dust Diffusion

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Abstract:

Nippon Steel has completed the development of a technology for dust-diffusion analysis that can predict and control "airflow" and "dust movement" in a plant building accomodating an electric arc furnace. This endeavor has culminated in a collection of working-environment design technologies that can adequately address problems ranging from ventilation in steel plants to the handling of turbulent flow in semiconductor plants in numerous and varied plant spaces. The basic aim of establishing this new dust-diffusion-analysis technology and the solution of associated problems were concretely tackled, and airflow and dust movement were predicted. Equipment costs were successfully lowered by creating new airflow and dust movement which meet specific requirements. Based on these results, a new engineering technology incorporating the concepts of measurement and control was used to innovate problem-solving methods. This process is described in detail.

1. Introduction

Nippon Steel has implemented various studies and measures focusing on the large amounts of heat and dust generated in steel production processes in order to dispel the notoriety of jobs in production fields for being "dirty, difficult and dangerous," as well as to meet the mounting social need for environmental control in areas surrounding steel plants. These studies and measures incorporate a technology introduced in 1985 for the analysis of airflow with a large computer, and target the establishment of working-environment design technology, an advanced form of engineering technology[1)].

With respect to the issue of heat, Nippon Steel pushed forth the development and application of an innovative ventilation design technology to create a comfortable thermal environment by inducing an effective airflow in the plant building instead of relying on the conventional ventilation design method of adjusting temperature in the plant building by changing the air of the entire building.

Though the importance of the issue of dust in environmental improvement was fully recognized, many technical problems such as the movement of dust particles in air remained to be solved. The issue of dust was addressed by discharging the dust out of the plant building by changing the air of the entire plant building, as envisaged under the conventional ventilation design method.

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Dust-diffusion-analysis technology was developed for predicting the movement or diffusion path of airborne dust by applying advanced airflow-analysis technology to the model of an electric arc furnace plant building. Engineering technology was established from a new point of view by making good use of the dust-diffusion-analysis technology. These technology developments are reported here.

2. Focus of Technology Development for Dust-Emission Control

We can clarify the focus of technology development for dust-emission control by taking as an example the innovative ventilation design technology described in the previous chapter.

The layout of equipment and building shape for a typical rolling mill are shown in **Fig. 1**. The rolling mill is divided into three main areas. The high central building area houses equipment that generates a large amount of heat. The low entry-end and delivery-end building areas have overhead cranes to handle raw materials and products. The mill building formerly adopted the design method of providing each area with openings for the supply and exhaust of air and changing the air in each space through these openings. When it rained, the raindrops entered through the exhaust openings in the roof of the entry-end and delivery-end building areas, gathering on the coils and rusting them. This frequently occurring problem was long attributed to the construction of the exhaust openings. When airflow was analyzed by computer to pinpoint the cause of the problem, it was found that the amount of heat generated in the central area was so large that the air-supply louvers in the walls of the central area were unable to provide a sufficient air-supply capacity, and as a result air was supplied through the exhaust openings in the entry-end and delivery-end areas of the mill building.

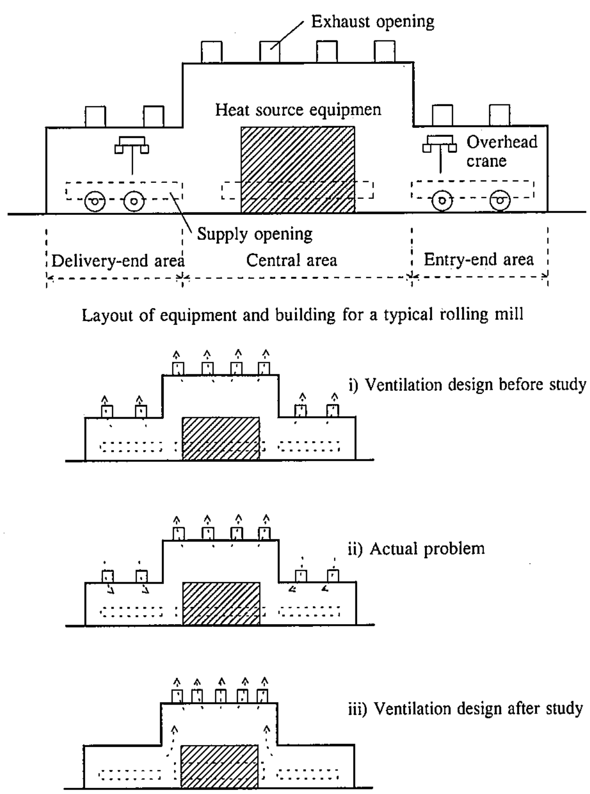


Fig. 1 New concept of ventilation design in rolling mill

One idea conceived to solve the problem involved closing all exhaust openings in the entry-end and delivery-end areas through which the raindrops entered and concentrating the supply and exhaust openings in the central area where the large amount of heat was generated. The validity of this idea was verified by airflow analysis. The airflow analysis confirmed the formation of a more powerful airstream for ventilation in the central area and the maintenance of a thermal environment equivalent to the former one, despite the closing of all exhaust openings in the entry-end and delivery-end areas.

This is the core idea of the innovative ventilation analysis technology that accurately clarifies (predicts) airflow and intentionally creates (controls) the most efficient airflow. We thought that if we could predict dust movement with high accuracy and intentionally control dust movement by applying this idea, we could solve all of the problems left unsolved due to our inability to predict dust-diffusion paths.

3. Characteristics and Equipment Problems in Plant Building for Electric Arc Furnace, and Basic Considerations for Development of Dust-Diffusion-Analysis Technology

3.1 Characteristics and equipment problems to be studied in plant building for electric arc furnace

Fig. 2 shows a schematic illustration of the plant building for an electric arc furnace adopted as the subject of the present study, and the modifications planned for its ventilation system. Two electric arc furnaces, A and B, are operated through the four steps of charging, preheating, melting and tapping, as shown in **Fig. 3**. The dust emissions from the furnaces are handled by two systems working in combination: a direct collection system that directly captures the dust emissions around the furnaces and another system which discharges fugitive dust emissions out of the plant building through the use of natural ventilation.

The plan for modification of the ventilation system is designed to make a complete switch from the present combination of the direct collection system and the natural ventilation system to the building-dust-collection system shown in **Fig. 4**. Specifically, the plant building is completely sealed, and the dust generated together with the hot gases from the electric arc furnaces is stored by ascending currents of air in the roof area. The dust-laden air collected near the roof area is gradually drawn by mechanical exhaust equipment. The largest concern with the building-dust-collection system is the deterioration of the working environment in the building due to the temporary storage of dust in the roof area arising from the sealing of the building. The equipment problems to be studied before the implementation of the modification plan are the prediction of dust movement as well as the prediction of airflow, the clarification of the dust-diffusion path, and the determination of the position and capacity of the mechanical exhaust equipment to create a more comfortable working environment in the building.

3.2 Basic considerations for development of dust-diffusion-analysis technology

The above-noted equipment problems are studied in the following two stages by referring to the basic considerations of ventilation previously described. The dust-emission control targeted in this study is carried out in these stages.

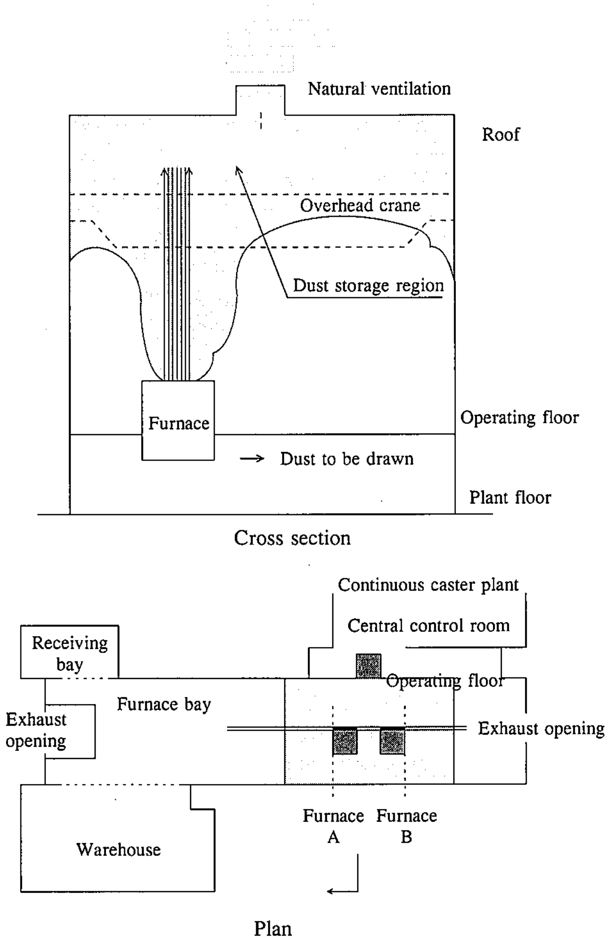


Fig. 2 Electric arc furnace plant to be studied

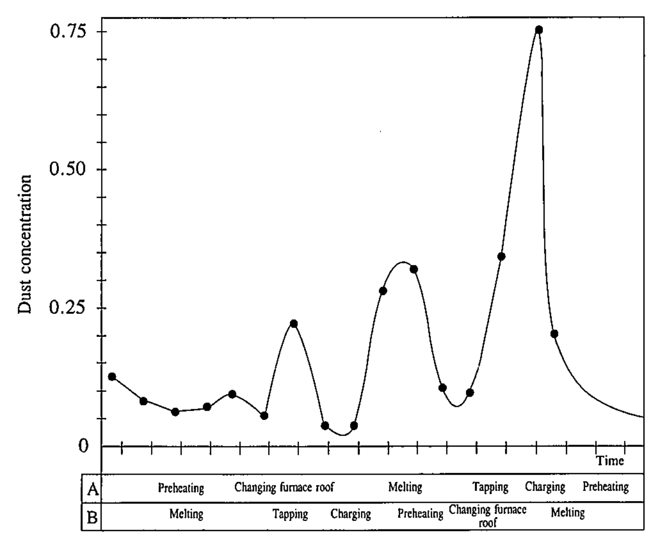


Fig. 3 Operating pattern and change of dust concentration at exhaust opening of electric arc furnace on a given day

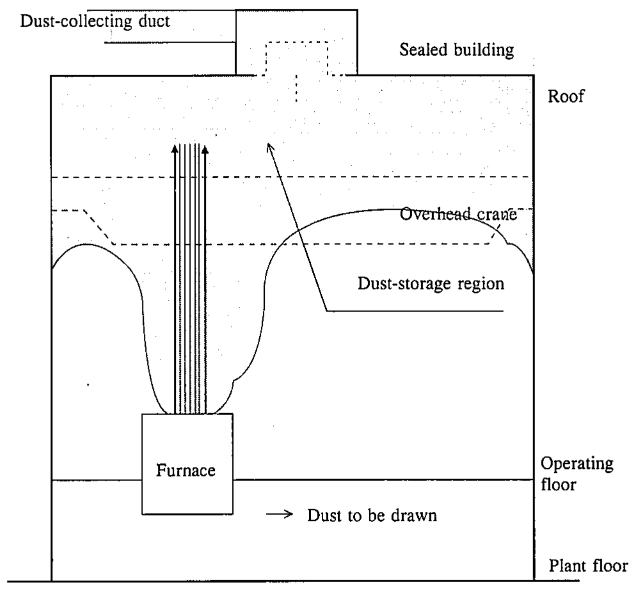


Fig. 4 Building-dust-collection system

Stage 1

Establish airflow and dust movement as basic conditions for dust-emission control, and develop a dust-diffusion-analysis technology for accurately predicting the airflow and dust movement.

Stage 2

Develop a technology for predicting (controlling) airflow and dust movement that can create a comfortable working environment in the plant building with a minimum of cost by applying the dust-diffusion-analysis technology established in stage 1.

Since verification of analytical results by experimentation and measurement is as indispensable as sophisticated analysis for the dust-diffusion-analysis technology, stage 1 is subdivided into the five steps shown in the flow chart of **Fig. 5**.

4. Development of Dust-Diffusion-Analysis Technology for Simultaneous Clarification of Airflow and Dust Movement

4.1 Theoretical development of dust-diffusion analysis

To establish the technology for predicting and controlling dust diffusion, it is necessary to theoretically clarify the movement of dust particles.

The Lagrangian method, which clarifies the motion of individual dust particles by solving the equation of motion, is a commonly known technique for theoretically elucidating the motion of dust particles. This method can be used to clarify the motion of individual dust particles one by one. When handling highly concentrated dust such as that observed in a plant building for an electric arc furnace, the number of dust particles is enormous. Thus, the Lagrangian method takes an impractically long time for numerical analysis due to the number of dust particles involved. In the technology development under study, it is important to gain a comprehensive understanding of airflow and dust movement in the plant building space. There remains the question of whether the microscopic method of tracking dust particles one by one can adequately determine the diffusion of dust throughout the plant building.

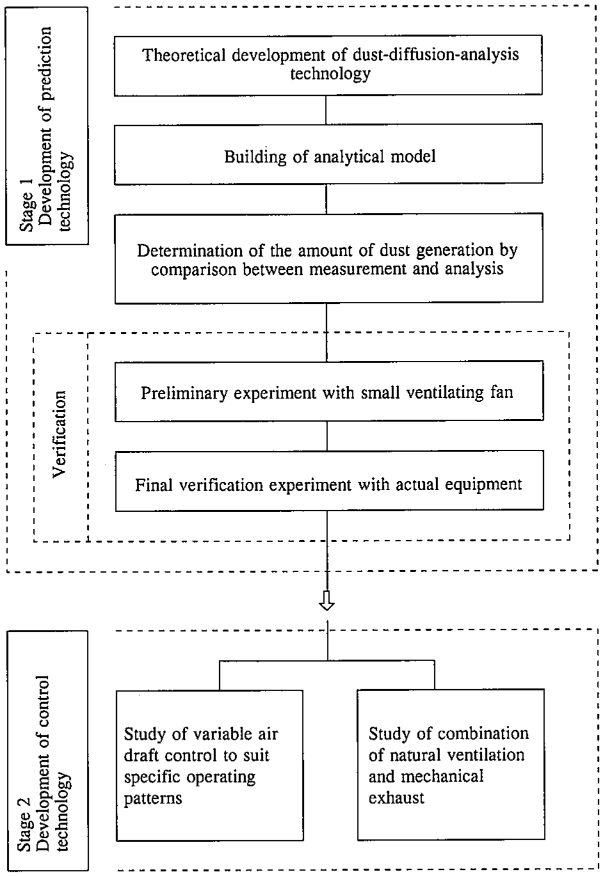


Fig. 5 Flow chart for establishment of technology

When the distribution of particle size and the density of dust generated from the electric arc furnaces were measured to ascertain the actual movement of dust particles from a macroscopic point of view, the dust particles were found to range from 1 to 100μm in size (**Table 1**). According to conventional findings[2,3], dust particles in this size range are strongly influenced by the viscous force (frictional force) of air. When the ascending velocity of the air is higher than the terminal settling velocity of the dust expressed by the Stokes equation of settlement, the motion of the air continues to diffuse the dust particles. When the ascending velocity of the air is lower than the terminal settling velocity of the dust, the dust particles settle at a constant velocity in balance with gravity.

Table 1 Particle size distribution of dust generated from furnaces

Particle size (μm)	Characteristic particle size (μm)	Weight ratio (%)
75-	75.0	37.5
50-75	62.5	12.3
25-50	37.5	19.3
20-25	22.5	6.8
15-20	17.5	22.9
10-15	12.5	0.6
5-10	7.5	0.2
2-5	3.5	0.2
-2	2.0	0.2

$$W_s = \frac{g \cdot d_s}{18\nu_g}(\rho_s - \rho_g)$$

where W_s = gravitational settling velocity (cm/s); g = gravitational acceleration (cm/s^2); d_s = diameter of dust particles (cm); ρ_s = density of dust particles (g/cm^3); ρ_g = density of air (g/cm^3); ν_g = viscosity of air (g/cm/s).

With dust particles in the size range from 1 to 100 μm in diameter, there is no change in the kinetic energy of the dust diffusion in the air. The state of dust diffusion can be very simply understood if, first, the dust and surrounding air are handled together as dust-laden air, and second, the concentration of the dust-laden air is calculated by basic equations of fluid dynamics together with the equation of diffusion (without relying on equations of motion for individual dust particles). This was our reasoning.

The state of dust diffusion can be analytically clarified by incorporating the Stokes equation of settlement into the equation of diffusion, an equation which satisfies the law of conservation of chemical species. The law of conservation of chemical species states that the inflow of substances into a space is equal to the outflow of substances from the space, as shown in **Fig. 6**. In the powder engineering field, the analytical method which applies the equation of diffusion is known as the Euler method. This series of numerical analysis methods is based on "PHOENICS", a three-dimensional heat transfer and fluid flow analysis program developed by the CHAM of Britain which discretizes the advection-diffusion equations by the finite volume method and solves the flow and temperature of air. The diffusion equation that incorporates the Stokes equation of settlement is coupled to the last step of the airflow-analysis routine shown in **Fig. 7**. For reference, the turbulence model adopted is the 0 equation model, and the temperature distribution is represented by a Boussinesq approximation model.

4.2 Establishment and concept of analytical model

4.2.1 Establishment of equipment and building model

The plant building for an electric arc furnace houses many items of equipment, including overhead cranes to carry scrap steel and molten steel ladles, burner cars to preheat the scrap, and a central control room to monitor and control the operation of the furnaces and auxiliaries. Other plant buildings such as a warehouse,

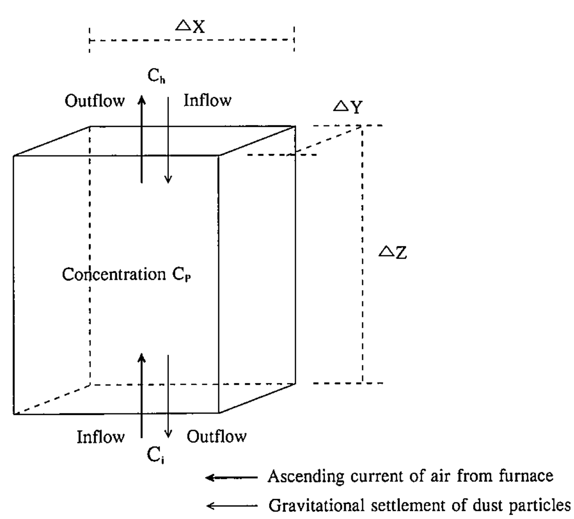


Fig. 6 Concept of dust-diffusion model in unit space

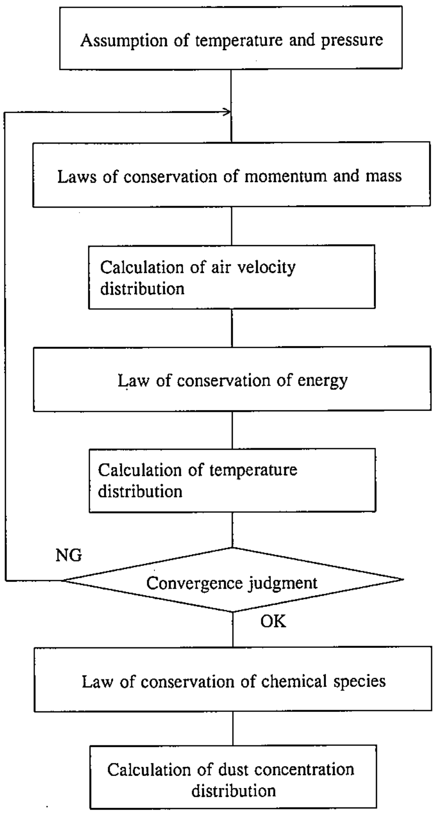


Fig. 7 Flow chart of dust diffusion analysis

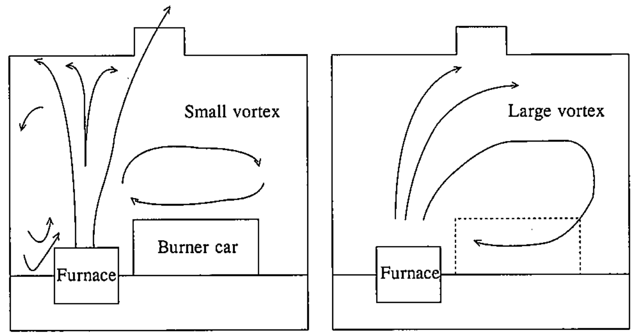


Fig. 8 Effect of plant equipment on airflow characteristics

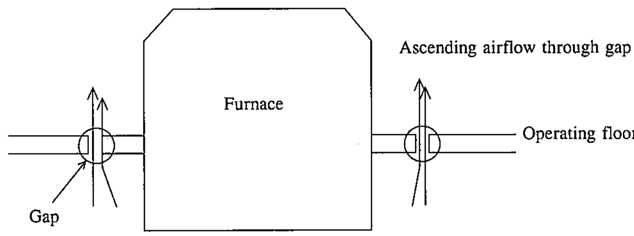


Fig. 9 Ascending currents of air through gaps in operating floor

receiving yard, and continuous caster bay are laid out alongside the plant building for the electric arc furnace. Of the items within the plant building, the ladles and the burner cars shown in **Fig. 8,** for example, approach the furnace proper, occupy a large space, and have a great effect on airflow such as draft. As a result of trial and error, it was clarified that ascending airflow through gaps in the operating floor and the openings in the plant floor (**Fig. 9**) also affect the characteristics of the airflow in the plant building. These auxiliary units, gaps, and openings must be incorporated into the analytical model to simulate real conditions in detail.

There are a total of 8 doorways to move the raw materials and products in and out of the plant building, as shown in **Fig. 10**. The doorways are open and closed to meet specific requirements, and air freely moves through them according to outdoor weather conditions and plant operating conditions. Thus, on a windy day, for example, the dust-laden air from the furnaces is carried by wind. The air direction, velocity, and temperature at each doorway are measured and used as boundary conditions for analytical purposes.

The number of the elements into which the mesh of the analytical model is to be divided for the appropriate modeling of the plant equipment and building is $42 \times 26 \times 19 = 20,748$ (**Fig. 11**).

4.2.2 Establishment of amount of heat generation

Two large heat sources in the plant building for an electric arc furnace have to be considered. One is the heat generated from the furnace surface, and the other is the hot gas that blows out of the furnace roof during melting and out of the tap hole during tapping. The amount of heat output in the production process (about 95% of the total amount of heat output), i.e., the sensible heat of the molten steel and slag and the heat lost to the furnace cooling water, is subtracted from the total amount of heat input, i.e., the preheat of scrap, electric power consumption, and heat generated by chemical reactions in the furnace. The two heat sources mentioned above are then added. The amount of heat generated from the furnace surface is calculated from convection-radiation equations by taking the furnace surface area, surface temperature, and emissivity as principal parameters. The rest is estimated as the amount of heat possessed by the hot gas. The study results are summarized in **Table 2**.

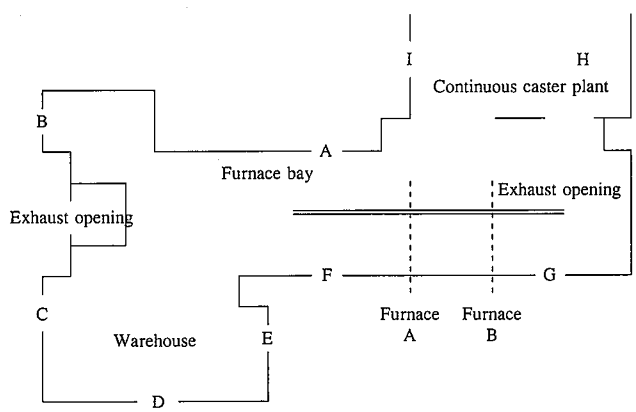


Fig. 10 Arrangement of doorways A to H with an area of 15 to 20 m^2

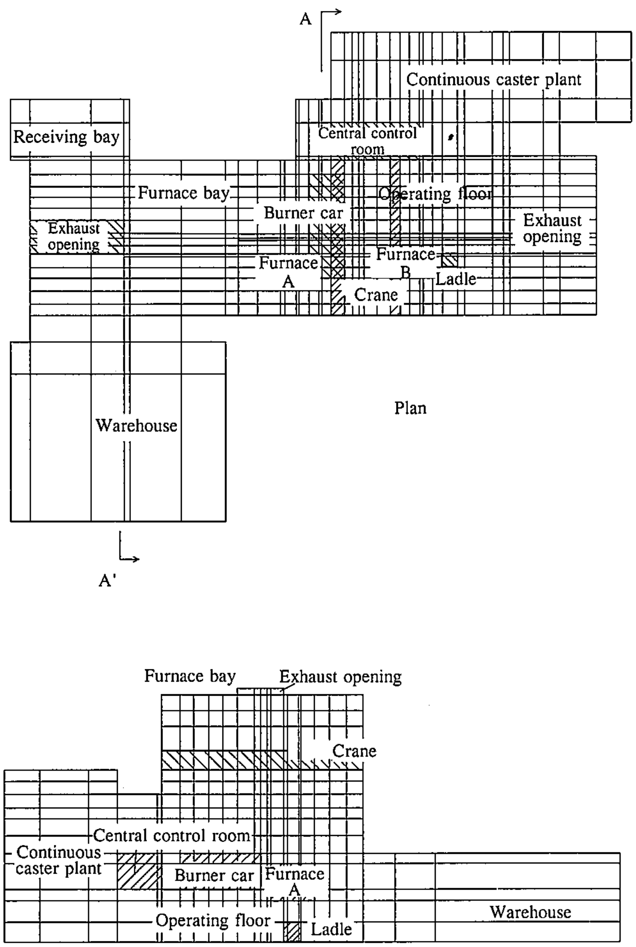


Fig. 11 Analytical model

Table 2 Breakdown of estimated heat input and output for molten steel

Breakdown			Ratio
Heat input			100%
Heat output	Sensible heat of molten steel and heat loss to equipment		95%
	Heat radiation in building	Heat radiation from furnace surface	4%
		Gas generated from furnace	1%
	Total		100%

4.2.3 Determination of the distribution of the dust particle size

The particle-size distribution of the dust generated in the plant building is listed in **Table 1**. For analytical purposes, the dust particles are represented by the four typical particle sizes shown in **Table 3**. Dust diffusion is analyzed for each characteristic particle size, and the results of the four analyses are all added and then indicated and evaluated as the ultimate dust-particle-size distribution.

Table 3 Analytical model for dust

Particle size (μm)	Typical particle size (μm)	Weight ratio (%)	Settling velocity (cm/s)
75-	75.0	37.5	41.7
50-75	62.5	12.3	29.0
25-50	37.5	19.3	10.4
15-20	17.5	30.9	2.3

4.3 Basic considerations on the determination of the amount of dust generation and accuracy verification of dust-diffusion-analysis technology

When the analytical model is built on the basis of what has been discussed above and is used for a computer simulation of the diffusion of dust in an actual plant building for an electric arc furnace, an important issue calling for extensive know-how is how to set the amount of dust generated from the electric arc furnace.

Though the amount of dust generation should be correctly set using calculated or measured values, it actually varies to a great extent. On top of that, it is practically impossible to calculate or measure the amount of dust generation because it is very large and because the hot atmosphere constitutes an obstacle. When the dust concentration is measured in the monitor plane right above the fur-

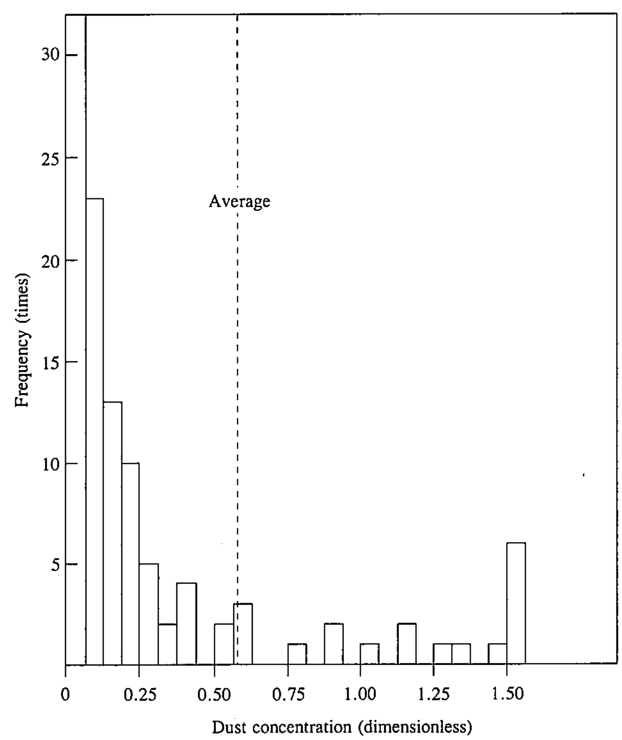


Fig. 12 Dust concentration and measurement frequency at exhaust opening during melting

Table 4 Dust concentration (dimensionless) measured in monitor plane under different operating conditions

Operating condition		Dust concentration	
Furnace A	Furnace B	Furnace A	Furnace B
Preheating	Melting	0.51	0.58
Tapping	Preheating	0.24	0.59
Charging	Preheating	0.36	0.43

nace, the amount of dust generation is found to vary greatly from a small fraction to several times the average level (**Fig. 12**). For reference, **Table 4** shows the average amount of dust generated from the electric arc furnaces A and B obtained using measurements taken in each step and averaging.

An inverse analysis method that uses the amount of dust generation as a parameter was devised as a means for solving this technical problem. Some appropriate reference points are established, calculated results are matched with measured results while changing the amount of dust generation, and the value with the highest approximation is taken as the amount of dust generation. The monitor plane and overhead crane plane right above the furnaces where the dust movement is the most regular and stable are adopted as the reference points.

The state of dust diffusion in the plant building is measured, and the measured data are analyzed to verify the accuracy of the analysis by the proposed method. The three cases shown in **Table 5** are selected as main operating conditions. Points (1) and (4) right above the furnaces A and B (**Fig. 13**) are established as reference points, and 10 points are established in the overhead crane plane and the building roof plane as points for evaluating analytical accuracy. Dust diffusion in the building is measured at these points. As measuring instruments, digital dust meters capable of measuring the dust concentration in a time series are used at the two reference points above the furnaces, and high-volume dust samplers capable of measuring the average dust concentration are used at the 10 evaluation points. Simultaneously, the airflow direction, velocity, and temperature are measured at the eight doorways in the building.

In the next step of the analytical procedure, the amount of dust generation is set so that the calculated dust concentrations at the reference points practically agree with the measured dust concentrations at the reference points. At the same time, the calculated and measured values are compared at the 10 evaluation points. The results are shown in **Fig. 13**. Despite differences at some points like the evaluation point (12), the validity of setting the amount of dust generation is verified, and the analytical model is found to be capable of highly accurate simulation of the airflow and dust movement in a conventional plant building for an electric arc furnace mainly ventilated by natural ventilation.

Table 5 Experimental cases

	Furnace A	Furnace B
Case 1	Preheating	Melting
Case 2	Tapping	Preheating
Case 3	Charging	Preheating

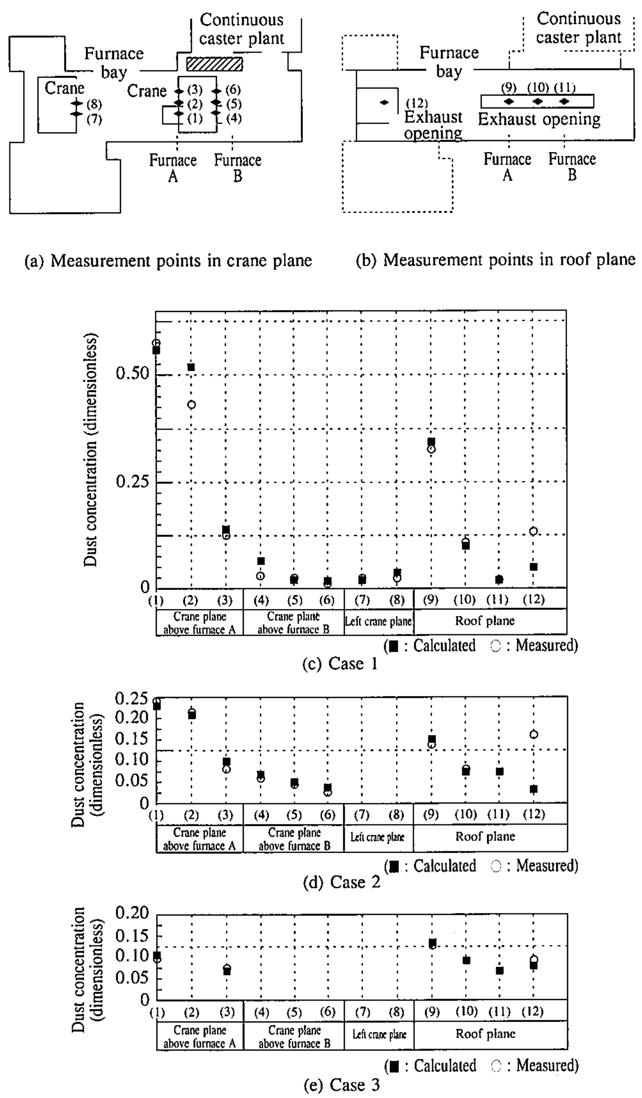


Fig. 13 Measurement and calculation of dust concentration under conventional operating conditions

4.4 Preliminary verification with small ventilating fan in plant building for an electric arc furnace before modification

To verify whether dust would be collected as reliably as analytically predicted after the modification of the plant building for an electric arc furnace to the building-dust-collection system, a small ventilating fan of about one-tenth the capacity of the planned mechanical exhaust equipment was installed in the roof right above the furnace A, as shown in **Fig. 14**. The values calculated by the analytical model discussed above were compared with the measured values to verify the accuracy of the analytical model. As described in the previous section, four evaluation points, (a) to (d),

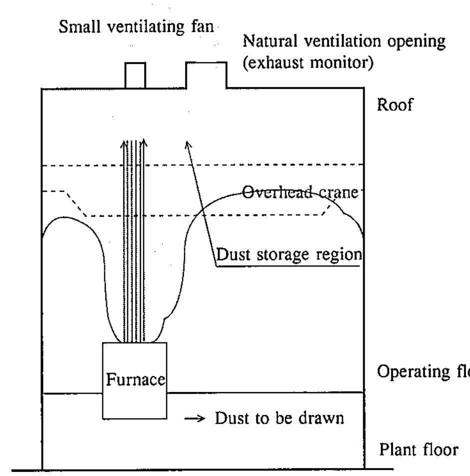


Fig. 14 Location of small ventilating fan

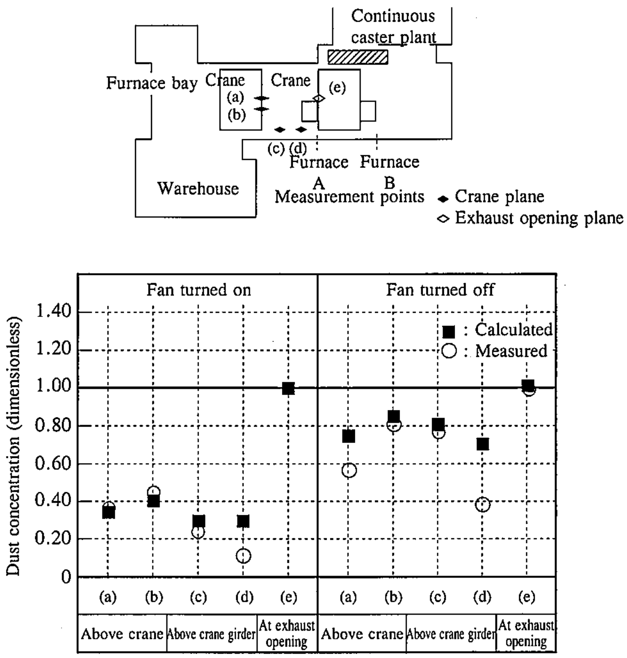


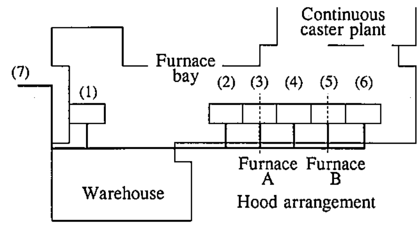
Fig. 15 Experimentation and analysis with small ventilating fan

were established in the crane plane, and one reference point, (e), was established above the furnace. The direction and velocity of the airflow in the doorways were also measured. Given the balance between the ventilating fan capacity and the amount of dust generation, furnace A alone was operated to produce dust, and furnace B was shut down.

The results are shown in **Fig. 15**. When the ventilating fan is turned on, the suction effect of the ventilating fan and the draft effect of the furnace result in a high concentration of dust-laden air with a high dust concentration at the reference point (e), and a relatively low dust concentration at the evaluation points (a) to (d). When the ventilating fan is turned off, the dust concentration at the reference point approaches the dust concentration at the evaluation points, meaning that the dust is uniformly diffused in the plant building. These data show that the analytical model simulates the change in the dust concentration in the building produced by the operation of the ventilating fan with sufficiently high accuracy. Thus, the analytical model can be considered practically applicable to plant spaces where the building-dust-collection system is installed.

4.5 Actual verification in electric arc furnace plant building after modification

As the final phase of development of the dust-diffusion-analysis technology, dust-collecting equipment was installed in the plant building for an electric arc furnace, and dust concentrations calculated by the analytical model were compared with measured dust concentrations to verify the validity of the analytical model. The arrangement and air volume distribution of six dust-collecting hoods are shown in **Fig. 16**. Cases 1 and 2 are selected from **Table 6** as operating conditions under which the validity of the analytical model is to be verified. As measurement points, reference points (b) and (e) are established above the furnaces for setting the amount of dust generation from the furnaces, and evaluation points (a), (c), (d), (f), (g) and (h) are established above the overhead cranes and on the operating floor, as shown in **Fig. 17**.



	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Air volume	0.20	0.16	0.13	0.20	0.19	0.12	1.00

Fig. 16 Hood arrangement and air volume distribution

Table 6 Experimental cases

	Furnace A	Furnace B
Case 1	Melting	Tapping
Case 2	Preheating	Melting

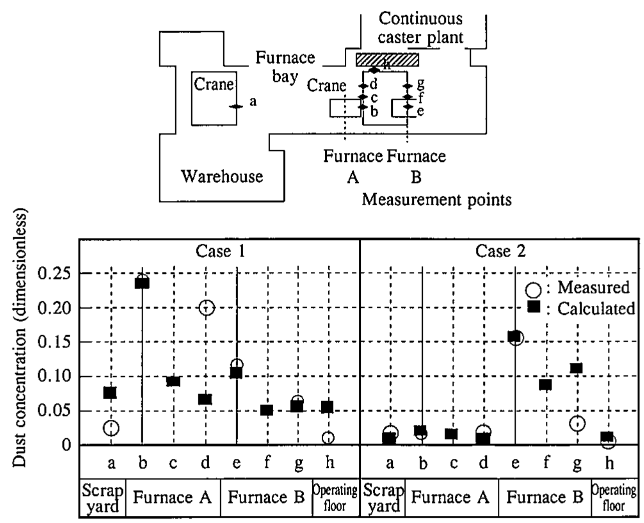


Fig. 17 Comparison of measured and calculated dust concentrations

The calculated and measured dust concentrations are compared in **Fig. 17**. The two sets of values agree very well in all instances except at the evaluation point (d) in case 1 and the evaluation point (g) in case 2. Although detailed data are omitted here, the new dust-collection system improved the environment in the plant building more effectively than the conventional system.

4.6 Summary

The results of the analytical model discussed above may be summarized as follows:

(1) The analytical model can accurately track the dust-diffusion process characterized by movement of dust together with airflow at a given velocity and then separation of dust from the airflow and settling of dust at lower velocities.

(2) The analytical model can simulate with practical accuracy air and dust flow in building spaces where many items like electric arc furnaces are arranged in a complex manner and operated under conditions varying moment by moment.

(3) The analytical model can predict with high accuracy the benefits of the building-dust-collection system in improving the dust-diffusion process, the dust concentration, and hence the overall working environment in the plant building.

5. Creation of New Airflow and Dust Movement by Dust-Diffusion-Analysis Technology

As our final goal we established the technology for creating airflow and dust movement to ensure a comfortable working environment in the plant building at minimum cost through the study of two concrete cases.

5.1 Study of further reduction in mechanical exhaust capacity in building-dust-collection system after modification

We studied the further reduction in the mechanical exhaust capacity while maintaining a comfortable working environment in the plant building after modification. One of the most important requirements in this study was the prediction of airflow and dust movement capable of degrading the working environment in the plant building.

When dust diffusion in the plant building retrofitted with the building-dust-collection system was analyzed by the proposed model, it was found that dust leaking from the dust-collecting ducts right above the electric arc furnaces diffuses together with airflow in the plant building, that the dust diffusion is the cause for the deterioration of the working environment in the plant building, and that the working environment in the plant building can be improved by minimizing the amount of dust leaking from the dust-collecting hoods.

For the purpose of further reduction in the mechanical exhaust capacity, we analyzed the case in which the total air volume is decreased by 20% despite an approximately 40% increase in the air volume of hoods (3) and (5) right above the furnaces (**Table 7**). The results are shown in **Fig. 18**. The flow of dust leaking from the dust-collecting hoods right above the furnaces can be controlled by concentrating the suction air volume right above the furnaces. The working environment in the plant building can be thus maintained at almost the same level as now, even when the total mechanical exhaust air volume is reduced by 20%.

To summarize, this series of study results show that the original purposes of the project, including the reduction in the total mechanical exhaust air volume, can be achieved by clarifying airflow and dust movement as causes for the deterioration of the working environment in the plant building for an electric arc furnace, and by increasing the suction air volume right above the furnaces to minimize this airflow and dust movement.

5.2 Study of minimization of mechanical exhaust capacity by combination of natural ventilation and mechanical exhaust equipment

It is considered possible to reduce the mechanical exhaust capacity and conserve energy by making effective use of air and dust flow by natural ventilation in combination with mechanical exhaust equipment. Here, we refer to the combined use of natural ventilation and mechanical exhaust equipment as a "hybrid ventilation system". The hybrid ventilation system is generally considered to be more efficient than the sealed building-dust-collection system discussed up to now.

Table 7 Air volume distribution (dimensionless)

Hood	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Before change	0.20	0.16	0.13	0.20	0.19	0.12	1.00
After change	0.15	0.07	0.22	0.07	0.22	0.07	0.80

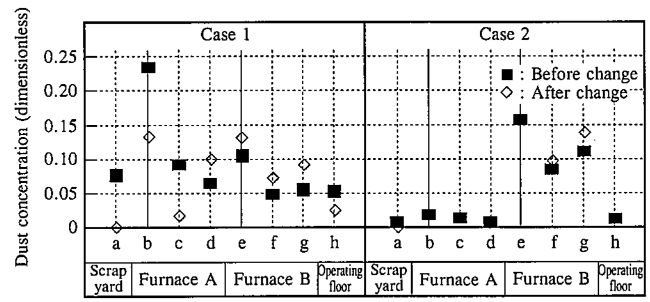


Fig. 18 Analytical results of air volume distribution and total air volume before and after change (for a to h, see **Fig. 17**)

The hybrid ventilation system is based on the discharge of heat by natural ventilation and the discharge of dust by mechanical exhaust equipment, as shown in **Fig. 19**. When heat is moved out of the building by natural ventilation, dust leaking from the mechanical exhaust equipment can also be carried out of the plant building by the natural ventilation air. To realize the hybrid ventilation system, the capacity of the mechanical exhaust equipment has to be increased in order to limit the amount of dust carried out of the building. Although the benefits of the hybrid ventilation system are widely recognized, technical difficulties have limited its practical application to only a few plants.

Fig. 20 shows analyses of the dust concentration distributions of the sealed building-dust-collection system and the hybrid ventilation system for the same mechanical exhaust capacity. When the capacity of the mechanical exhaust equipment is controlled to limit

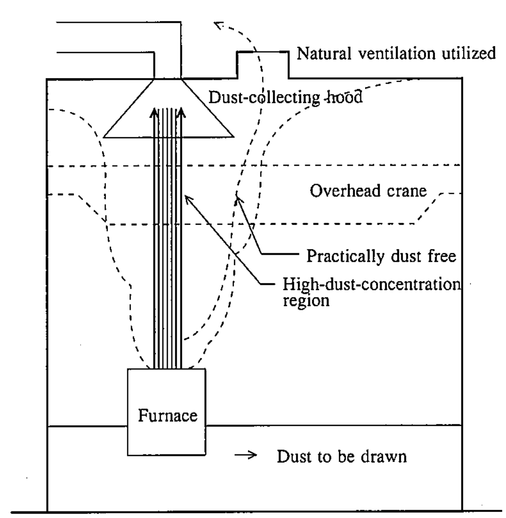


Fig. 19 Combined use of mechanical exhaust and natural ventilation

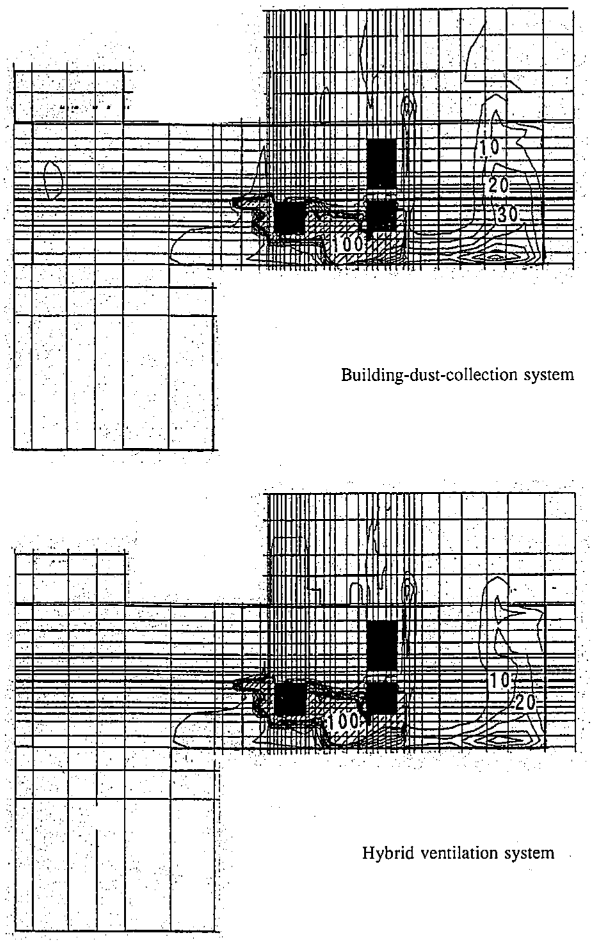


Fig. 20 Dust concentration distribution determined by dust-diffusion analysis (dust concentration around furnace = 100)

the concentration of dust leaking from the mechanical exhaust equipment to very low voluntary dust concentration requirements, the concentration of dust diffusing into areas around the furnaces is substantially lower with the use of the hybrid ventilation system, clearly indicating that the hybrid ventilation system provides a cleaner environment.

Now that the awareness of environmental issues is enhanced, the building-dust-collection system is generally recognized to have the following two problems:

(1) Increase in size of mechanical exhaust equipment

The optimal building air temperature and dust concentration to provide a comfortable working environment are two dominant factors that determine the specifications of mechanical exhaust equipment. To meet both conditions, the mechanical exhaust equipment must have the capability to completely change the air from several to several tens of times per hour. Thus, the resultant equipment cost is expected to be high.

(2) Sharp increase in running cost

Since a large amount of heat is continuously generated from the electric arc furnaces, the draft effect produced by the airflow degrades the dust-collection efficiency unless the generated heat is discharged out of the plant building by constant ventilation. The mechanical exhaust equipment must therefore be run continuously, generating enormous costs.

By freely creating airflow and dust movement to meet specific ventilation requirements, the hybrid ventilation system is expected as a final solution to the problems of increased size and the enormous cost of running the mechanical exhaust equipment.

6. Development into New Engineering Fields

The establishment of the dust-diffusion-analysis technology has led to the completion of the development of a series of working environment design technologies capable of solving problems ranging from ventilation at steel plants to turbulence at semiconductor plants in a wide spectrum of plant spaces (**Table 8**). The dust-diffusion-analysis technology is considered fully applicable to the solution of various environmental problems at and around steel plants. For example, it is expected to solve the problem of water vapor diffusion at a hot strip mill by predicting and controlling the flow of water vapor instead of dust, and the problem of dust dispersion from a coal yard into a surrounding area by predicting and controlling the flow of air.

The dust-diffusion-analysis technology has already been applied to solve the problem of ventilation at an aluminum refining plant and municipal solid waste incineration plant, and the problem of cooling efficiency at a shape mill cooling bed. In this way, it is widely applied with successful results to equipment and process problems which could not be quantitatively solved in the past. The dust-diffusion-analysis technology that can predict and control the flow of mainly air can meet the challenge of solving important equipment technology problems in new engineering fields.

Table 8 Description and development steps for working environment design technology

Step 1

Applicable space	Large natural ventilation space	Large-pressure space
Evaluation item	Airflow direction and temperature	Air pressure in building
Technology	Technology for predicting and controlling air temperature and flow at arbitrary points in space by taking air supply and exhaust areas and air supply and exhaust opening arrangement as parameters	Technology for predicting and controlling air pressure at arbitrary points in space by taking roof and wall gap area ratios as parameters
Basic equation	Conservation equations of air quantity, temperature, and velocity	
Applied equation	———	———

Step 2

Applicable space	Clean room space	Indoor dust diffusion space
Evaluation item	Completely vertical laminar flow	Dust diffusion characteristics
Technology	Technology for predicting and controlling vertical laminar flow through micro flow simulation by taking the floor-opening ratio as parameter	Technology for predicting and controlling dust concentration at arbitrary points in space by taking the mechanical dust collection capacity as a parameter
Basic equation	Conservation equations of air quantity, temperature, and velocity	
Applied equation	Basic equations for turbulence model	Basic equations for gas diffusion

7. Conclusions

The dust problem has been traditionally studied with respect to the one-to-one quantitative relationship between dust generation and collection points. The most advantageous feature of the dust-diffusion-analysis technology is that it incorporates an invisible dust-diffusion path between the dust generation and collection points and enables the quantitative prediction and control of dust at an arbitrary point in the space concerned. In addition to breaking the conventional concept that dust-collection equipment and building ventilation belong to mechanical engineering and architectural engineering, respectively, this initiative has created a common design environment as represented by the dust-diffusion-analysis technology, and has allowed the application of specific engineering know-how to appropriate uses. The dust-diffusion-analysis technology has thus allowed us to move forward into new engineering areas where we can derive more accurate solutions.

The authors will improve environments and realize low-cost equipment specifications by positively applying the dust-diffusion-analysis technology to a wide range of projects, and contribute to the solution of various working environmental problems by paying attention to unresolved environmental problems and new engineering fields.

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