Environment Control Technology for Electronic Equipment Manufacturing Facilities

Matsuo Kamitani
Ryusuke Gotoda
Yasuhiro Kashirajima
Makoto Tanaka

OVERVIEW: Control of environmental factors at production facilities has grown in importance as the performance of electronic devices has improved. Hitachi Plant Technologies, Ltd. is active in a variety of different environment control technologies, including: (1) Technologies that achieve a clean environment taking account of dynamic phenomena at LCD production plants that use large stacker cranes, (2) Technologies for precise temperature control able to keep variations in air temperature down to the 0.001°C range, (3) Pressure control technologies able to predict dynamic pressure changes in air conditioners, and (4) Super clean ultra-low dew-point air generator technology and other techniques for creating environments with a dew point of -100°C or less for organic EL and other production facilities.

INTRODUCTION

AS progress is made in areas like semiconductor miniaturization and performance or the adoption of larger LCD (liquid crystal display) substrates, the control of atmospheric environmental factors (cleanliness, temperature, and pressure, etc.) required in the production of these products is becoming increasingly important. Also, the production of devices such as organic EL (electroluminescence) displays and lithium-ion batteries requires an environment in which the small quantities of moisture, organic compounds, and other material present in the air are subject to control.

To meet this demand, Hitachi Plant Technologies, Ltd. supplies solutions for controlling environmental factors in the production process, primarily for industrial applications, and has established environment control technologies specifically for electronic devices.

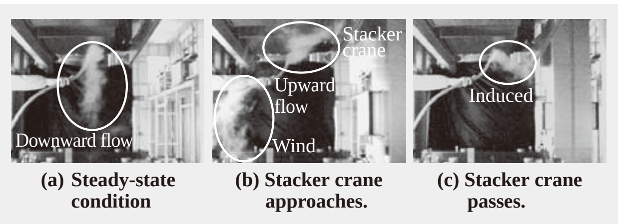


Fig. 1—Visual Representation of Airflow in Stocker during Stacker Crane Travel.
The images give a visual representation of the turbulent airflow that occurs when the stacker crane is in motion. Ensuring a clean environment requires the consideration of dynamic phenomena.

This article describes a technique for airborne particle analysis in LCD plants that takes account of dynamic phenomena (a clean environment technology)[1], precise temperature control technology for improving processing and measurement accuracy in the semiconductor production process[2], a pressure control simulator that can predict pressure changes in air conditioners (a form of pressure control technology)[3], and super clean ultra-low dew-point air generator technology suitable for use in organic EL production[4].

CLEAN ENVIRONMENT TECHNOLOGY FOR LCD PLANTS

Issues at LCD Plants

The automatic cassette stockers used to hold glass substrates in FPD (flat panel display) plants are increasing in size to handle the larger substrates being processed. In order to maintain a clean environment inside these large stockers, it is becoming necessary to consider not only cleanliness under static steady-state conditions as in the past but also to evaluate the effect on cleanliness of dynamic phenomena by considering the turbulent airflow caused by the movement of the high-speed stacker cranes used inside the stockers.

Fig. 1 shows examples of turbulent airflow inside a large stocker. Although a downward flow is present under static steady-state conditions, updrafts and wind flows occur when the crane approaches and induced drafts are evident after it has passed. It also seems likely that a combination of a number of different

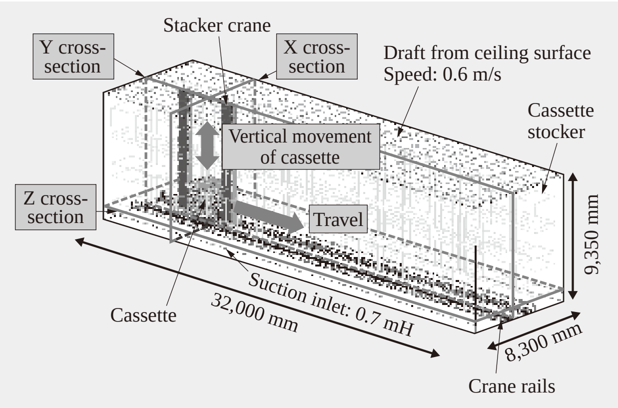


Fig. 2—Cassette Stocker Model.
An overview of the model used to analyze a cassette stocker used for temporary storage of LCD (liquid crystal display) substrates.

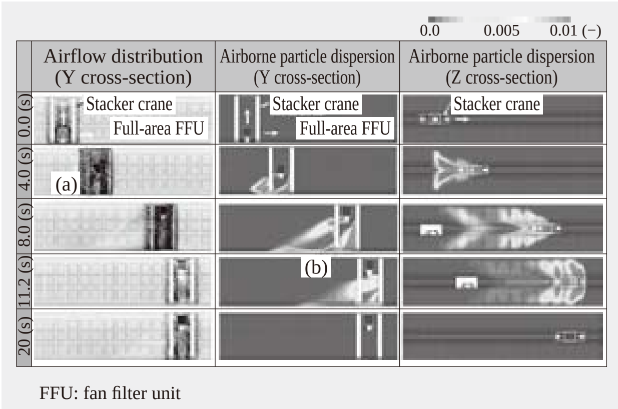


Fig. 3—Analysis Results for Airflow and Airborne Particle Dispersion in Cassette Stocker when Stacker Crane in Motion.
The analysis indicates how operation of the cassette stocker causes the dispersion of airborne particles inside the stocker chamber. This is due to the airflow and airborne particle dispersion that occur when the stacker crane lifts a cassette while in motion.

stacker crane movements will cause a major disruption in the airflow. The following sections describe an analytical investigation into the fundamental factors that determine how dynamic phenomena affect the inside of the stocker.

Airborne Particle Analysis Method

An analysis of airflow distribution and airborne particle dispersion characteristics was undertaken using a model of the cassette stocker (see Fig. 2). The operation of the stacker crane involves travel by the stacker crane at the same time as vertical movement of the cassette. The simulation uses a standard k-ε model and a feature of the modeling of the stacker crane was a preliminary investigation that combined a number of different sorts of dynamic mesh (moving mesh) at moving boundaries to obtain the optimum combination.

Analysis Results

Fig. 3 shows an analysis of combined movement in which the stacker crane is in motion at the same time as the cassette is rising. A downward flow is present prior to the stacker crane starting to move and the analysis shows how a diagonal airflow upward and to the right subsequently forms in the cassette due to the combined effects of the crane travel and the swirling flow caused by the vertical movement [see Fig. 3 (a)].

The airborne particle dispersion results show how the interaction between the crane travel and the airborne particles produced by the vertical movement tend to expand the effect into the stocker shelves. Also, the airborne particles are swept up in the wake on the underside of the stacker crane [see Fig. 3 (b)]. This is linked to the airflow in the wake of the stacker crane and suggests that, for the generation of airborne particles when crane travel is combined with vertical movement, the swirling flow in the wake of the stacker crane is likely to occur only in the downward flow region.

In response, a form of separation and removal using local air extraction in the vicinity of the airborne particle generation was considered as a way of improving cleanliness by minimizing the dispersion of airborne particles caused by stacker crane movements. Fig. 4 shows an example of the study into local air extraction in the vicinity of the assumed airborne

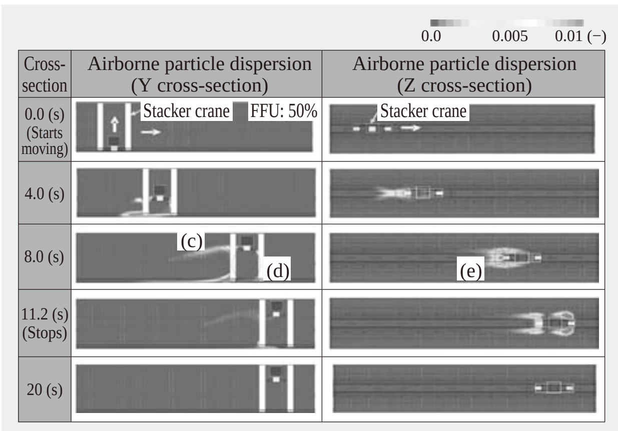


Fig. 4—Analysis Results for Airflow and Airborne Particle Dispersion when Local Ventilation Used to Improve Cleanliness.
The extent of airborne particle dispersion in the cassette stocker is reduced by the use of local ventilation.

particle generation [vertical movement (sliding contact between the stacker crane and lift) and stacker crane travel (sliding contact between the crane wheels and rails)].

Compared to Fig. 3, this shows a lower level of airborne particle dispersion due to vertical motion of the cassette in the rear of the stacker crane [see Fig. 4 (c)] and the underside of the rising cassette [see Fig. 4 (d)]. Also, the Z cross-section shows that the airborne particles are not dispersing further than the rail width due to the suction in the vicinity of the rails [see Fig. 4 (e)].

In this way, Hitachi Plant Technologies was able to obtain an analytic understanding of the effects that moving bodies have on large regions of air and create clean technologies that can predict in advance the effectiveness of measures to limit dispersion from sources of airborne particle generation.

PRECISE TEMPERATURE CONTROL TECHNOLOGY

Overview of Control Technology

The requirements for measurement accuracy in manufacturing processes such as semiconductor production equipment are becoming progressively more stringent each year and achieving this high accuracy requires that the environments in which these systems are installed be subject to strict temperature control. This section describes an air conditioning system able to control variations in air temperature with accuracy in the 0.001°C range.

Although this air conditioning system has a conventional configuration that combines a heater with a fan coil unit that uses cold water produced by a chiller as its heat source, it achieves precise temperature control through enhancements to the individual components. Key features include: (1) Use of a fast-acting heater and (2) Use of a heat storage medium to suppress temperature fluctuations (see Fig. 5).

Whereas temperature control typically deals with fluctuations with a period in the range of one hour to several tens of minutes, achieving ±0.001°C control requires the system to work for short-duration fluctuations in the range of several minutes to several tens of seconds. A special heater with a faster response than a conventional heater was developed to allow the system to cope with shorter duration fluctuations than in the past [see Fig. 6 (a)].

The heat storage medium is brought into contact with the air to perform heat exchange and suppress temperature fluctuations. Although the characteristics differ depending on factors such as shape and material, this method is able to minimize temperature fluctuations with a shorter duration than can be controlled using heater control. By using an appropriate combination of heat storage medium and heater control, temperature fluctuations across the entire range from long to short duration can be successfully minimized [see Fig. 6 (b)].

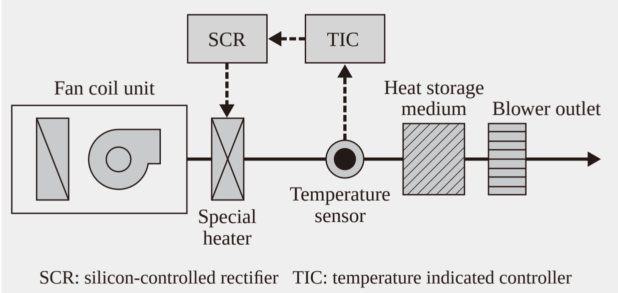


Fig. 5—Air Conditioning System with Precise Temperature Control.
Characteristics include a quick-acting heater, minimization of temperature fluctuations through use of heat storage medium, and other techniques.

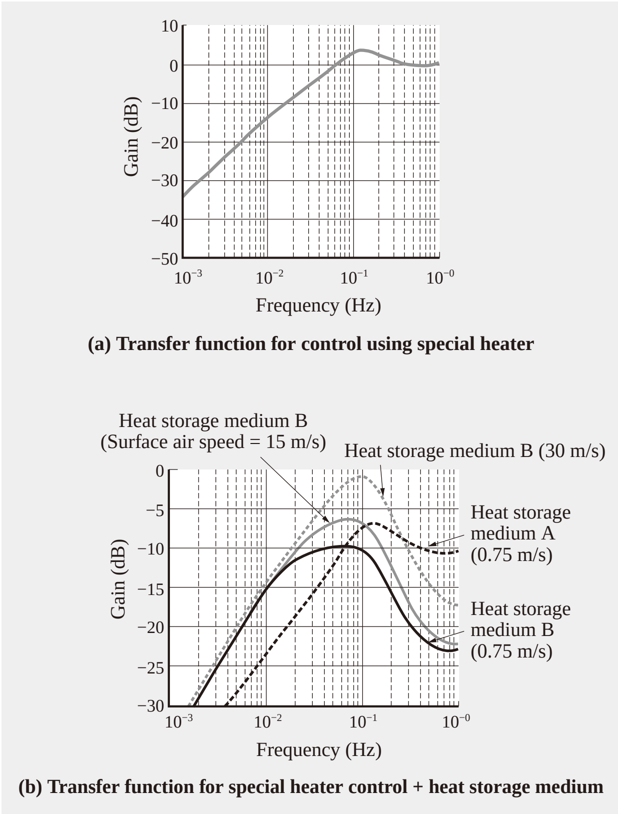


Fig. 6—Transfer Function for Special Heater and Heat Storage Medium Combination.
Temperature fluctuations across the entire range from long to short duration can be minimized by obtaining the transfer functions for the special heater and heat storage medium and combining these appropriately.

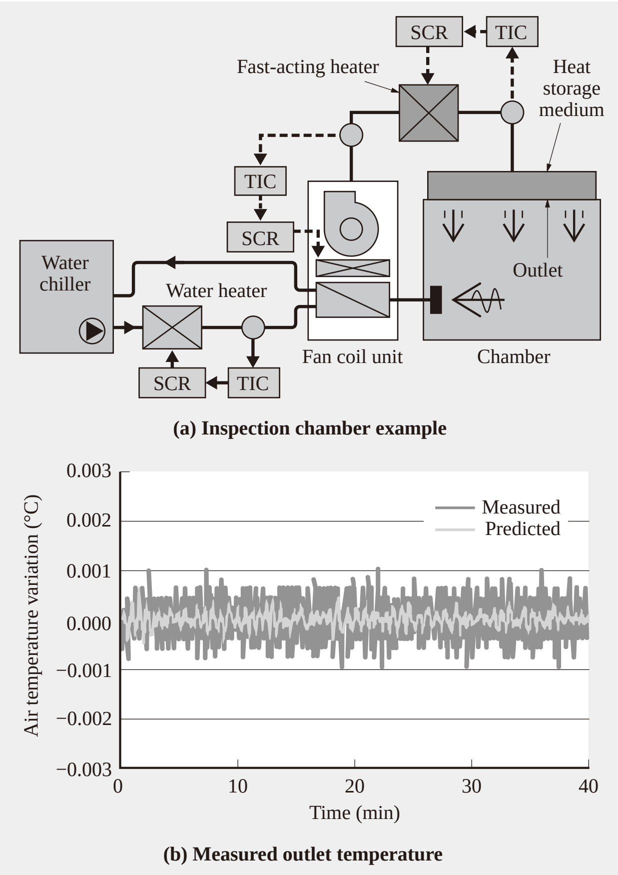


Fig. 7—Application of Air Conditioning System with Precise Temperature Control in Inspection Chamber.
The system was installed in a semiconductor component inspection chamber where it demonstrated its ability to control the outlet temperature in the ±0.001°C range.

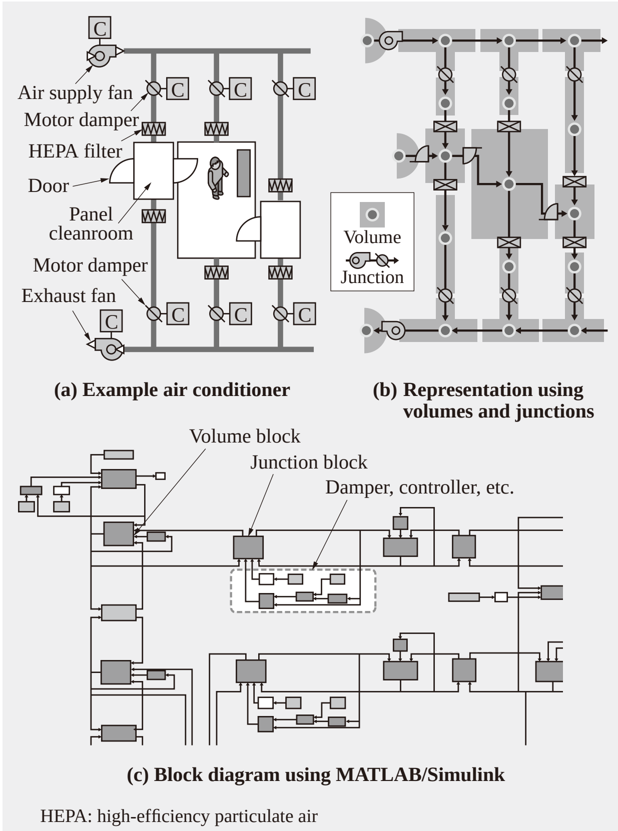


Fig. 8—Overview of Pressure Control Simulation for Air Conditioner.
An analysis system was configured using MATLAB/Simulink that used the volume-junction method to model the air conditioner, ducting, control unit, and other components.

Example Application of Air Conditioning System with Precise Temperature Control

Fig. 7 (a) shows an example of a semiconductor component inspection chamber in which this air conditioning system is used. Hitachi Plant Technologies successfully produced an air conditioning system able to keep the reference value for a small thermistor (time constant: 3 to 4 s) in the 0.001°C range by using the heat storage medium and fast-acting heater described above and also by combining thermal insulation with airflow design and control of cold water and cooling water [see Fig. 7 (b)].

PRESSURE CONTROL TECHNOLOGY

Pressure Control Simulation

The control of room pressure is an important factor in maintaining a clean environment in the rooms used to manufacture electronic devices. Unfortunately, during air conditioner design, it is difficult to predict air pressure variation based on various external factors. Accordingly, Hitachi Plant Technologies developed a pressure and control system simulator able to predict changes in pressure in air conditioning equipment.

The simulation uses the volume-junction method to analyze the pipeline network and other components. This method divides ducts and rooms into small "volumes" and represents the airflow between volumes as "junctions."

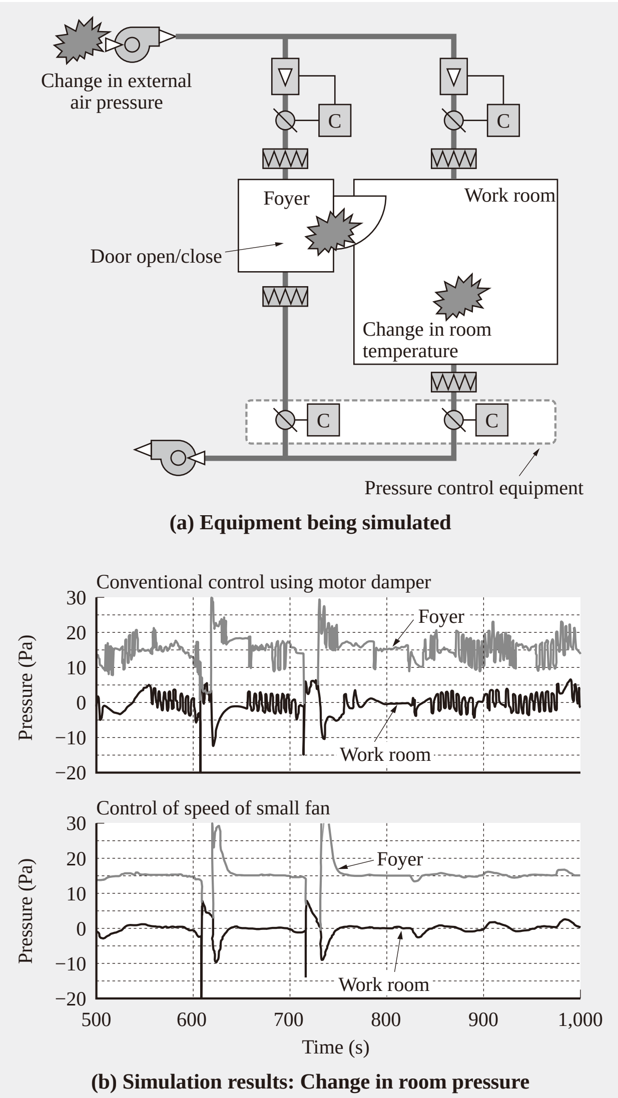
The simulation was implemented on the MATLAB/Simulink* numerical analysis software. It divides the volumes, junctions, fans, dampers and other elements into blocks and represents the complex air conditioning duct system (which contains loops and locations where the flows branch or merge) as a block diagram (see Fig. 8). Hitachi Plant Technologies developed this simulator so that it can be used to test the control system under a variety of different operating conditions. Features include the ease with which models can be configured and the ability to perform coupled analysis of the control system and airflow behavior.

* MATLAB and Simulink are registered trademarks of The MathWorks, Inc.

Pressure Control Method

The simulation described above was used to compare the control performance of a pressure control device located in the exhaust duct under the influence of different external conditions in the two-chamber equipment layout shown in Fig. 9 (a). Fig. 9 (b) shows an example of the room pressure changes predicted by the simulation which demonstrates that pressure control performed by controlling the speed of a small fan achieves excellent control performance and keeps the pressure more stable than when control is performed using a conventional motor damper.

This pressure control technique using a small fan also achieved excellent control performance when used in an actual plant. Hitachi Plant Technologies intends to continue using simulation-based studies to devise control methods for a wide range of different cleanroom operating conditions.



(a) Equipment being simulated

(b) Simulation results: Change in room pressure

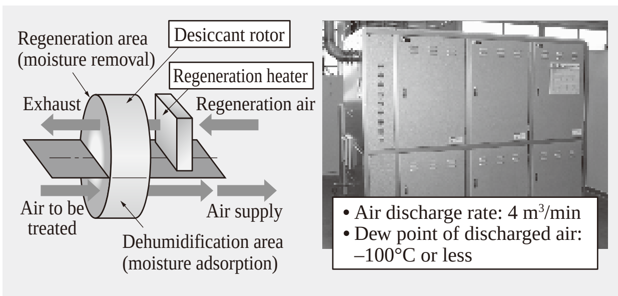
Fig. 9—Performance Comparison of Pressure Control Equipment Using Pressure Control Simulation.
A comparison was made of the performance of two different types of pressure control equipment in response to external influences (variations in external air, door opening and closing).

SUPER CLEAN ULTRA-LOW DEW-POINT AIR GENERATOR TECHNOLOGY

Principles of Dehumidification and Adsorption

Demand is growing for cleanrooms that keep the presence of airborne molecular contamination to an extremely low level. These are required for the production of products such as organic EL and organic semiconductors that use organic thin film. In response, Hitachi Plant Technologies has developed ultra-low dew-point and ultra low airborne molecular contamination air generator technology to minimize the presence of water and organic molecules in the atmosphere of manufacturing process of advanced devices.

Fig. 10 (a) shows the basic configuration of a dry dehumidification technique that uses heat to dehumidify air. The dry dehumidification technique consists of a dehumidification area that dehumidifies the incoming air and a regeneration area that regenerates the desiccant rotor, a desiccant rotor that uses adsorption to remove moisture from the air, and a regeneration heater that heats the air used for regeneration. The temperature rises due to the heat of adsorption generated when the moisture in the air being treated is absorbed by the desiccant as it passes over the desiccant rotor. Meanwhile, the air that enters the regeneration area is heated by the regeneration heater to the required desorption temperature (temperature needed to regenerate the desiccant) and then passes over the desiccant rotor to regenerate it by desorbing



(a) Basic configuration of dry dehumidification technique

(b) Super clean ultra-low dew-point air generator system

Fig. 10—Principles of Super Clean Ultra-low Dew-point Air Generator Technology and Equipment Photograph.
The system works on the principle of dry dehumidification and consists of three desiccant rotors connected in series.

the moisture it previously adsorbed. Unlike the previous dehumidification technique which produced low-temperature water to dehumidify the air by cooling it, this dry dehumidification technique produces air with low humidity using a desiccant which removes moisture from the air by adsorbing it.

Overview of Super Clean Ultra-low Dew-point Air Generator System

Fig. 10 (b) shows a photograph of the super clean ultra-low dew-point air generator system. To produce air with an ultra-low dew-point, three desiccant rotor stages are connected in series to eliminate even the very smallest amounts of moisture from the air by passing it over multiple desiccant rotors.

Equipment Performance

Dehumidification performance

After optimizing the operating parameters for the dehumidifier, testing was conducted to determine its performance at removing moisture and airborne molecular contamination. Fig. 11 shows example operating data for the dehumidifier at startup. The dew point of the discharged air gradually falls after the system starts and reaches –100°C after 20 hours. The moisture content continues its steady fall after that, reaching a dew point of –110°C after 6 days in operation. This demonstrates the excellent dehumidification performance of the system that uses multiple desiccant rotor stages.

Performance at removing organic contaminants

The system uses a desiccant to absorb moisture that works on the principle of physical adsorption. Assuming this process is not selective, organic compounds and other airborne molecular contamination can also be expected to be removed from the air. Accordingly, Hitachi Plant Technologies modified the operating conditions to investigate how the system's performance at removing airborne organic compounds varied with changes in the dew point temperature of the discharged air. Fig. 12 shows the performance for removing organic compounds which improves as the dew point of the discharged air falls. Specifically, the removal ratio exceeds 99% when the dew point is below –100°C that is better than the 90% removal ratio achieved by the chemical air filters commonly used to filter out organic compounds.

Accordingly, this technology provides a super clean ultra-low dew-point air generator system capable of removing more than 99% of the organic compounds present in the environment while supplying air with a dew point below –100°C.

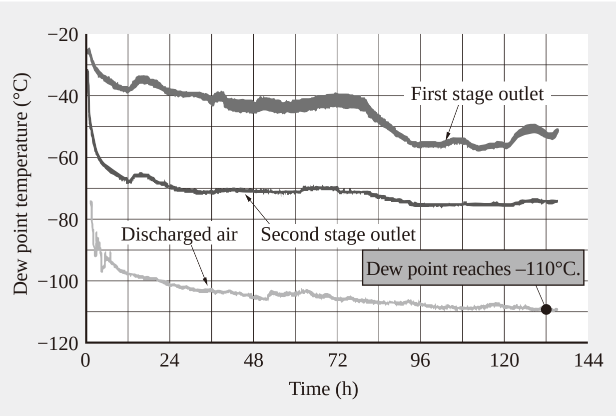


Fig. 11—Change in Air Dew Point Temperature over Time.
The graph shows operating data for the super clean ultra-low dew-point air generator system at startup. The results demonstrate the excellent dehumidification performance of the system, with the dew point of the discharged air reaching –100°C after 20 hours and –110°C after 6 days.

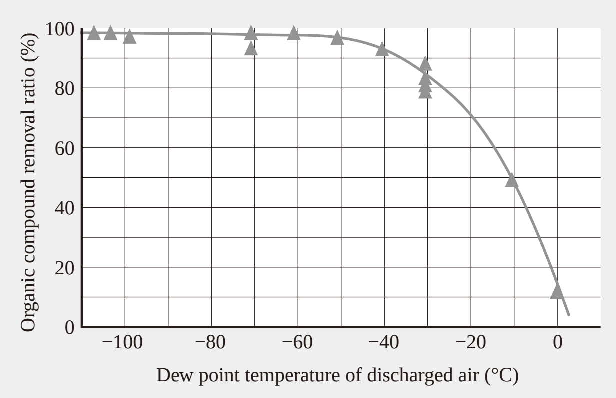


Fig. 12—Relationship between Dew Point Temperature and Organic Compound Removal Performance.
The performance at removing organic compounds improves as the dew point falls, reaching better than 99% removal when the dew point is below –100°C.

CONCLUSIONS

This article has described a range of environment control technologies for electronic device manufacturing, namely Hitachi Plant Technologies's cleanroom technology, precise temperature control technology, pressure control technology, and super clean ultra-low dew-point air generator technology.

Hitachi Plant Technologies, Ltd. intends to continue the development of environment control technologies that help build electronic device manufacturing facilities able to achieve even higher levels of precision in future.

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ABOUT THE AUTHORS

Matsuo Kamitani

Joined Hitachi Plant Engineering & Construction Co., Ltd. (currently Hitachi Plant Technologies, Ltd.) in 1994, and now works at the Air Conditioning & Plant Engineering Systems Department, Matsudo Research Laboratory. He is currently engaged in the development of an AC facilities system. Mr. Kamitani is a member of The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE).

Ryusuke Gotoda

Joined Hitachi Plant Engineering & Construction Co., Ltd. (currently Hitachi Plant Technologies, Ltd.) in 1988, and now works at the Air Conditioning & Plant Engineering Systems Department, Matsudo Research Laboratory. He is currently engaged in the development of an AC facilities system. Mr. Gotoda is a member of the SHASE.

Yasuhiro Kashirajima

Joined Hitachi Plant Engineering & Construction Co., Ltd. (currently Hitachi Plant Technologies, Ltd.) in 1996, and now works at the Air Conditioning & Plant Engineering Systems Department, Matsudo Research Laboratory. He is currently engaged in the development of an AC facilities system. Mr. Kashirajima is a member of the SHASE.

Makoto Tanaka

Joined Hitachi Plant Engineering & Construction Co., Ltd. (currently Hitachi Plant Technologies, Ltd.) in 1997, and now works at the Air Conditioning & Plant Engineering Systems Department, Matsudo Research Laboratory. He is currently engaged in the development of an AC facilities system. Mr. Tanaka is a member of The Japan Society of Mechanical Engineers (JSME).