Favorable Design Parameter to Control Contamination Associated in FPD Fabrication Cleanrooms

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ABSTRACT

The design criteria for the Flat Panel Display (FPD) fields are now expanded to the fabrication environment. This is due to the fast growth of the FPD market. Especially in the FPD fabrication cleanrooms, the defect rate of final products becomes significantly affected by airborne contamination. We focus our attention on the reduction of airborne contamination. The evaluation of design parameters capable of contamination control is undertaken. The substantiated profile for the most favorable design parameter is devised. The systematic approach to carry out the fluid dynamics simulation of huge and complex FPD cleanrooms is proposed. To verify the appointed design parameter, devised profile, and proposed approach, flow simulations of actual FPD cleanrooms are performed and the specified design parameter is implemented into the actual FPD cleanroom fabrication. The overall results verify that the strategy is proper and reliable.

Keywords: Cleanroom Design, Cleanroom Simulation, Flat Panel Display.

1. INTRODUCTION

Conventionally, the design criterion for productivity in the mechanical field was focused on reducing manufacturing time/cost and increasing reliability. Nowadays, the design criterion for productivity in cleanroom manufacturing is focused on a clean fabrication environment. This is due to the fast growth of the Flat Panel Display (FPD) market. Especially in the FPD fabrication field, the defect rate of final products becomes significantly affected by airborne contamination, even if the whole process is carried out in the cleanroom [1].

The designs of cleanrooms have evolved over several years, but only one design has been popular for a number of years in semiconductor industries [2,3]. This type of cleanroom, the unidirectional airflow cleanroom, is widely used wherever the very best cleanroom conditions, such as ISO 5 (Class 100) and lower, are required. Recently, FPD industries started building unidirectional airflow cleanrooms in large dimensions for the fabrication of Liquid Crystal Displays (LCD), Plasma Display Panels (PDP), Electro Luminescent Displays (ELD), and Field Emission Displays (FED) [1].

Ideally in a unidirectional airflow cleanroom, the air is expected to flow in a unidirectional way. The air flows vertically from the ceiling through the perforated floor, down to the basement, then horizontally to the outlet allocated at the side of the room. Special care is given to the cleanroom: the air is supplied through high efficiency filters to prevent contamination by relatively larger particles flowing with the air, and the workers and the equipment entering into the room are inspected very carefully in order not to allow particles along with them.

However, in reality, the flow starts turning horizontally before it passes through the perforated floor due to the weighted outlet location in the FPD cleanrooms. Moreover, there exists the possibility of particle production due to machine wear and the potential of particle growth by collisions/agglomerations of tiny particles [4]. Thus, there still may be relatively large unexpected particles in the cleanroom. The problems of imperfection caused by particle deposition on the products may still not be solved completely.

On the other hand, due to the fast growth of the FPD market, the cleanroom dimensions increase with an increase of product size as large as 2 m by 2.2 m for the 7th generation LCD. As the cleanroom dimensions increase, the flow inclination phenomenon results more seriously in imperfection of the product due to airborne contamination by the particles striking against working machines and/or products. In FPD cleanrooms, an allowable angle of flow inclination is considered to be 15 degrees. However, in reality, the angle of flow inclination at task height where products are placed is much larger. The contamination problem may still not be a minor one.

Based on our experience associated with FPD cleanrooms, the flow field is considered to be the major factor to control contamination and to be affected significantly by the increase of the cleanroom dimensions [1,4,5]. Unfortunately, not enough attention has been paid to this matter and there is no practical or experimental method to accurately and completely determine flow patterns in cleanrooms. We realized that the Computational Fluid Dynamics (CFD) technology had advanced to the point where it could be used to solve design problems focused on airborne contamination. These facts led us to adopt CFD into the FPD cleanroom design to solve airborne contamination problems.

However, the exact modeling of an actual three-dimensional cleanroom is crucial to produce accurate CFD results. Moreover, the amount of work needed for the representation of a cleanroom and simulation of the flow field is magnificent. Every step needs to be done over and over in designing new facilities or upgrading existing ones. This propelled us to search out a systematic approach to carry out the CFD simulation of huge and complex FPD cleanrooms.

We accomplish our aim by interlinking the modeling task upon a mechanical design tool with the simulation task upon a CFD tool. Furthermore, we try to find a way to feedback simulation results directly to the conceptual design criteria for FPD fabrication cleanrooms focusing on airborne contamination control. To provide designers with the concepts for the flow-based integration of the cleanroom layout, we had developed a mathematical model that interprets the airflow inclination at various cleanroom dimensions into a unified representation [1]. The results had adopted into further layout design to prevent airborne contamination by flow inclination under geometric constraints of the cleanroom.

This study begins with the evaluation and verification of favorable design parameters to control product contamination. The cleanroom design parameters capable of increasing the unidirectional down flow region in the fabrication floor are selected. The effectiveness of each parameter on cleanroom flow is analyzed based upon the CFD simulation. Then, the most favorable design parameter enabling the flow to move in a more unidirectional way is appointed. The substantiated profile of the parameter is devised and evaluated under geometric constraints.

To verify the capability of the parameter increasing the unidirectional down flow region, the CFD simulations of actual FPD cleanrooms are performed without and with the prescribed parameter. Finally, the specific profile of the parameter is implemented into the actual FPD cleanroom fabrication. The results show that the prescription of the parameter is proper and the parameter itself is robust enough to reduce FPD product contamination by airborne particles.

2. EVALUATION OF FPD CLEANROOM DESIGN PARAMETERS

In the FPD fabrication field, there are many design parameters that affect cleanroom flow. Those may be enumerated as inlet geometry and velocity profile, outlet geometry and pressure profile, access floor geometry and perforation profile, partitions, eyelids, add-on suction or injection ducts, and so forth. However, some are troublesome to install, some are high cost, and some are hard to operate or control. Moreover, predicting the flow field variation upon geometry alteration and/or profile modification is often impossible due to the complicated configuration of the cleanroom associated with FPD fabrication process and equipment.

In the present study, we focused our attention on the reduction of product defect rate by increasing the unidirectional down flow region in the fabrication floor. The increase of the unidirectional down flow region surely results in lesser contamination. Thus, the design parameter being sought should be capable of controlling the flow precisely. To be a favorable design parameter, it better be one that could be applied for all FPD cleanrooms under various geometries and situations even including pre-existing ones. Also, it needs to be popular, common, and handy. Thus, the extent of the design parameters being sought is narrowed based on the experiences with FPD cleanroom flow.

The geometry of inlet, outlet, and access floor is excluded, since it is hard to be changed by being confirmed at the beginning of the cleanroom construction. The partitions and eyelids are dropped, because those are too specific and not welcomed in the actual FPD fabrication field. The adjustment on the outlet pressure profile is restricted and avoided due to air re-circulation. Thus, the fundamental cleanroom design parameters helpful for increasing steady state unidirectional down flow and controllable with less time/cost/work may be confined to the inlet velocity profile and the access floor perforation profile. In addition to these two, add-on suction or injection ducts in the basement are evaluated for significantly contaminated cleanrooms, but those are also put aside comparing the expense versus the effect.

Figure 1 shows the inclined flow angle in the middle section of an actual FPD cleanroom. The dimension of the actual cleanroom is 100m wide, 200m long, and 9m high. In order to obtain unidirectional down flow, the cleanroom is built in two stories with the first story 5m in height. The middle one-third portion in longitudinal direction is shown in Fig.1. The flow angle in the cleanroom is obtained by the CFD simulation. The change in absolute angle from zero to 90 degree is represented by the change in color from blue to red. The air flows from the ceiling, through the perforated

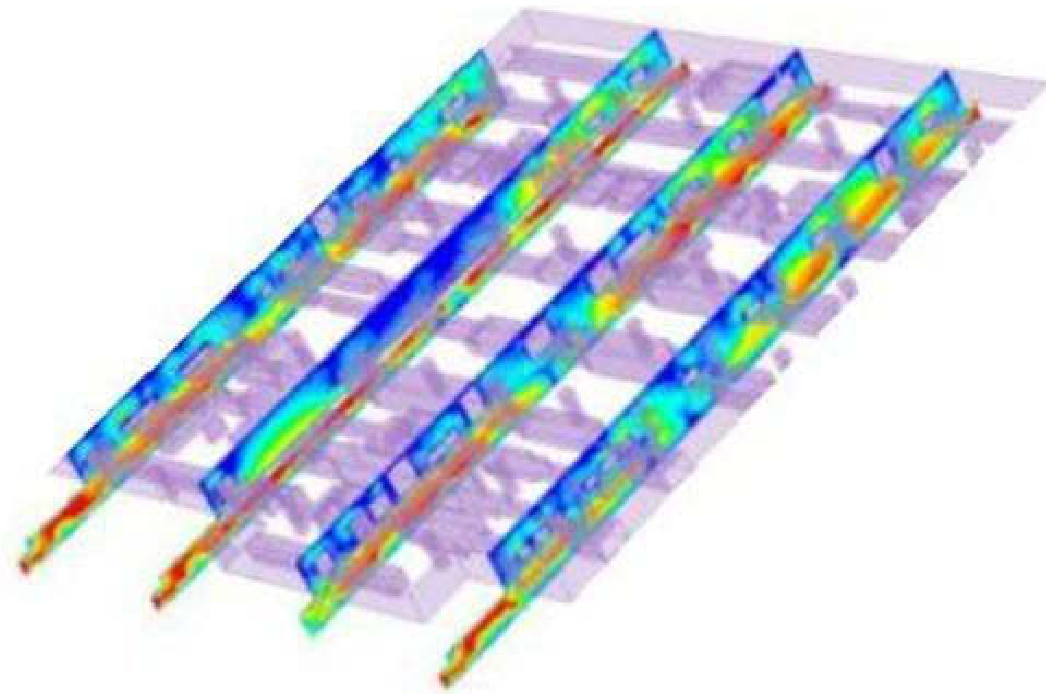


Fig. 1. Inclined flow angle in actual FPD fabrication cleanroom

floor, down to the basement, then, to the outlet located at the side of the cleanroom. Since outlets are allocated widthwise at the side only, the flow starts turning horizontally before it passes the perforated floor due to the weighted outlet location. Thus, the angle appears as the greenish and yellowish colors at the upper floor. This phenomenon, the flow inclination especially at task height, usually causes the imperfection of products due to particle deposition on the product during fabrication process.

In the FPD fabrication field, the most popular treatment for the flow inclination phenomena may be the adjustment on the access floor perforation profile. However, in reality, it does not work as planned. This is probably due to the flow angle passing through the panel, and the limited panel selection. Perforated panels are available only at three open ratios, 9%, 18%, and 51% for FPD cleanrooms. Moreover, the mass flow rate passing through the perforated panel is affected not only by the open ratio but also by the flow angle significantly. This fact is well known but not realized much in the actual field, so the perforated panels are being placed neglecting the flow angle.

To verify the significance of the flow angle effect, two-dimensional CFD simulations are performed using 20% and 50% perforation ratios by changing the flow directions. Figure 2 shows the simulation models with assigned perforation ratios and flow directions. Figure 3 shows the normalized mass flow rate passing through the perforated panel at various flow directions. By taking a glance at Fig.3, we easily notice that the information on the flow field is crucial for proper prescription of perforation ratio.

On the other hand, to judge the effectiveness of the access floor perforation profile on the flow in comparison with the inlet velocity profile, two-dimensional CFD simulations are performed using without or with specified inlet velocity profile and access floor perforation profiles. Figure 4 shows the particle path predicted from the simulation results. The path with uniform inlet velocity profile and uniform access floor perforation profile is shown in Fig.4(a). The one with parabolic inlet velocity profile conserving total incoming flow rate and uniform access floor perforation profile is shown in Fig.4(b). Figures 4(c) and Fig.4(d) are the ones with uniform inlet velocity profile and specified access floor perforation ratio. The open ratio is assigned, 50% for the first half from the axis of symmetry and 20% for the rest in Fig.4(c), and 50% for first three-forth and 20% for the rest in Fig.4(d). Figure 5 shows the inclined flow angle at task height calculated from the simulation results. With the uniform and parabolic inlet velocity profile, the inclined angle starts increasing from the axis of symmetry up to its maximum value, and then decreases down to zero at the outlet sidewall. With the non-uniform perforation profile, the angle variation deviates from the one with uniform profile, representing the flow instability due to the improper jump in perforation.

By comparing the case names in Fig.5 with those in Fig.4, we can see that adjustment on the open ratio with available perforated panels is less effective for increasing the unidirectional down flow region, and may even initiate the flow instability by sudden changes. Therefore, flow adjustment using access floor perforation ratio may be proper for the minor control. It should be performed locally around the equipment, after the overall flow field is settled down.

At this point, we may conclude that the most favorable design parameter that is stable and robust enough to increase the unidirectional down flow region in the fabrication floor is the inlet velocity profile.

3. SUBSTANTIATION OF FPD CLEANROOM DESIGN PARAMETER

In order to substantiate the appointed design parameter, i.e., inlet velocity profile, two-dimensional CFD simulations of the FPD cleanroom using various inlet velocity profiles under geometric constraints are carried in advance of actual three-dimensional FPD cleanroom simulations. To increase unidirectional down flow on the fabrication floor, the inlet velocity profiles from the 0^{th} up to 6^{th} order are devised and those effects on the flow are evaluated. The typical form of the N^{th} order inlet velocity profile conserving the total incoming flow rate and keeping the minimum velocity at the symmetry line may be written as:

$$V(x^N) = V_{\min} + \ (N+1)\ (V_{avg} - V_{\min}) \left(\frac{x}{0.5\ W} \right)^N \tag{1}$$

where, V_{avg} is the average velocity equals to the total inlet flow rate over the total inlet area, $V_{\min}$ is the minimum velocity acceptable for the actual FPD cleanroom fabrication, W is the cleanroom width, x is the distance from the axis of symmetry, and N is the order of polynomial.

Figure 6 shows the inclined flow angle at task height predicted by two-dimensional CFD simulations using the 0^{th} to 6^{th} order inlet velocity profiles, and Fig.7 shows the predicted angle at different height using the 2^{nd} order inlet velocity profile. The proper order of the inlet velocity profile for the specific cleanroom geometry concerned in this study is found to be the 2^{nd} through 4^{th}. As shown in Fig.7 for the 2^{nd} order, the flow angles at other heights are compared for the rest of orders. The results with the 3^{rd} to 4^{th} order are appeared with less flow inclination.

However, it is questionable if those will still be appropriate when the equipment is placed. To be sure, two-dimensional CFD simulations for the cleanroom with three rows of equipment are performed using the 0^{th} to 6^{th} order inlet velocity profiles and using the modified version of the 0^{th} to 6^{th} order velocity profile. The cleanroom width is divided into three sections having the equipment at the center. The modified sectional profile is set with the maximum velocity at the symmetry side of the equipment edge, conserving the sectional incoming flow rate at each polynomial order and keeping the minimum velocity at the section boundary.

The geometry of equipment placed in divided sections and the predicted angle at task height are shown in Fig. 8. The effect of equipment placement and velocity profile modification on the inclined flow angle at task height is shown in Fig.9. The angle without equipment using the 2^{nd} order profile is shown in solid line with the last index *0*. The one with equipment using the 2^{nd} order profile is shown in blacked out circle marks with the last index *1*. The one with equipment using the modified sectional profile is shown in triangular marks with the last index *2*. The 2^{nd} order profile is appeared to be better than the modified one and ones with the rest of orders.

In addition to the inclined flow angle, the mass flow rate transferring the sections is investigated and the results are shown in Fig.10. The mass transfer rate across the boundary of the first and second sections counting from the symmetry line is shown with indexes *S10, S11, S12*, and that for the second and third is shown with indexes *S20, S21, S22*. The last indexes *0,1,2* stand for the cases without the equipment, with the equipment, with the modified profile, respectively as same as those explained for Fig. 9.

Regardless of the order of inlet velocity profile, overall mass flow rate across the boundary of the first and second section increases and that of the second and third decreases when the equipment is placed. This is anticipated, since the air near the symmetry line needs to travel longer. It is affected more by the decreases of the room for the air to travel. Thus, the flow is more pressurized towards the outlet when the equipment is placed under fixed inlet flow rate and fixed outlet area. On the other hand, when the 2nd and 3rd order inlet velocity profile is assigned, the increase of mass flow rate across the boundary of the first and second section appears to be less than 0.5% even if the total room for the flow to travel is decreased by 28% upon equipment placement. This shows that the flow in FPD fabrication cleanroom may not be affected significantly by the equipment with 28% or less in volume fraction.

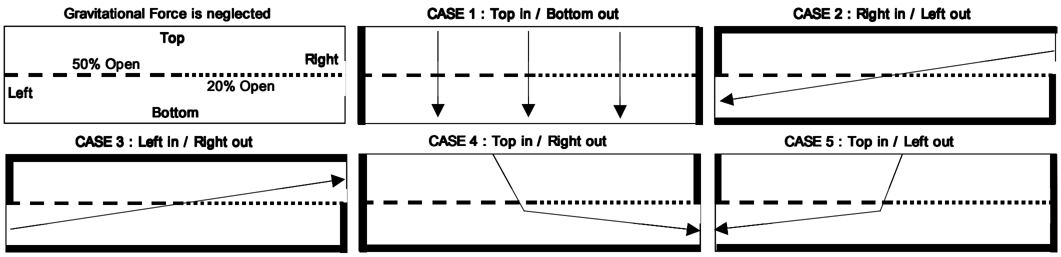


Fig. 2. Geometry and assigned conditions for perforation tests

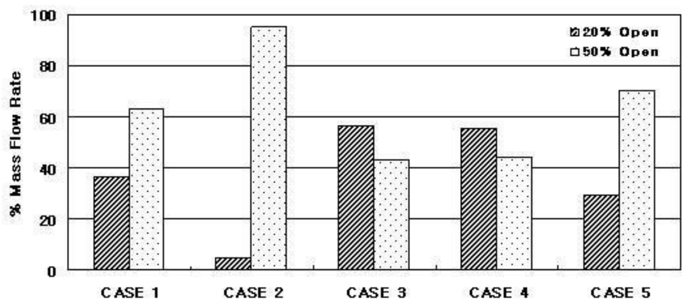


Fig. 3. Normalized mass flow rate through perforated panel at various flow directions

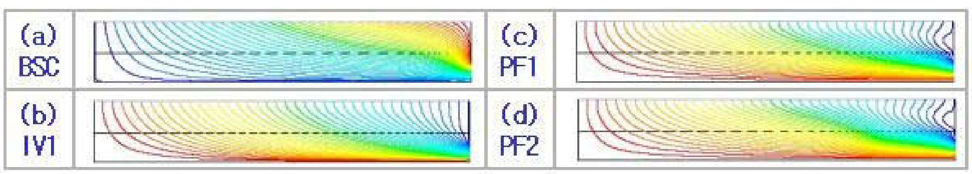


Fig. 4. Particle path obtained by CFD simulations upon various boundary conditions

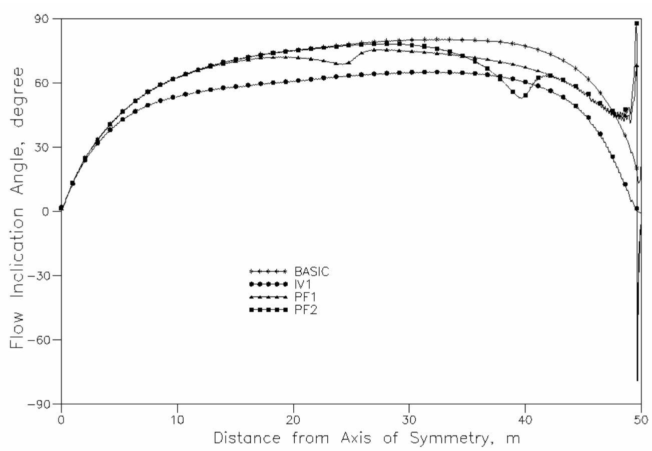


Fig. 5. Flow angle predicted by CFD simulations upon various boundary conditions

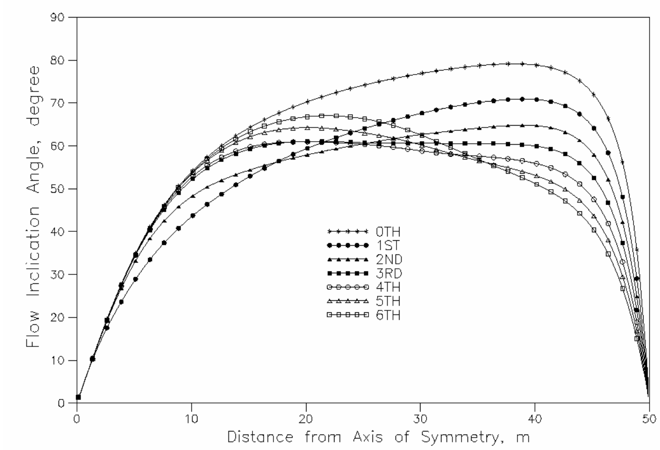


Fig. 6. Flow angle predicted by CFD simulations upon various velocity profiles

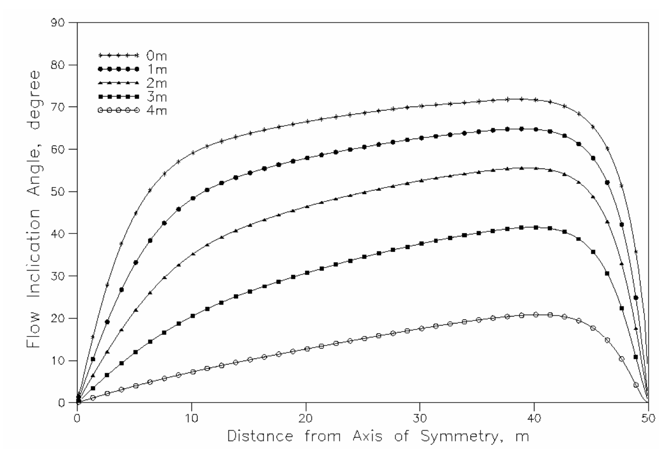


Fig. 7. Flow angle at different height predicted by CFD simulation

At this point, it is assured that the prescription of the 2^{nd} order inlet velocity profile is proper, even upon equipment placement, under fixed inlet flow rate and outlet area. Therefore, the 2^{nd} order profile is picked up as the most appropriate inlet velocity profile for the specific cleanroom geometry concerned in this study.

4. APPLICATION TO ACTUAL FPD FABRICATION CLEANROOM

As the last but the most important step, the substantiated 2^{nd} order inlet velocity profile is applied to the three-dimensional CFD simulation of an actual FPD cleanroom. Generally, it is neither easy nor simple to model a three-dimensional FPD cleanroom that is as huge as 100m wide, 200m long, and 9m high. Especially when the geometry is so complicated because of the equipment lay out, it is even harder. Moreover, the exact modeling of an actual three-dimensional cleanroom is crucial to obtain accurate CFD simulation results. Thus, the amount of work needed for the representation of the cleanroom and for the simulation of the flow field becomes magnificent. In order to solve these problems, the systematic approach to carry out CFD simulations of huge and complex FPD cleanrooms is initiated.

By interlinking the modeling task upon a mechanical design tool with the simulation task upon a CFD tool, our aim is attained. The three-dimensional modeling of the FPD cleanroom and the equipment is done using the commercial modeling software CATIA V.4. The three-dimensional mesh generation on the flow volume is carried upon the same

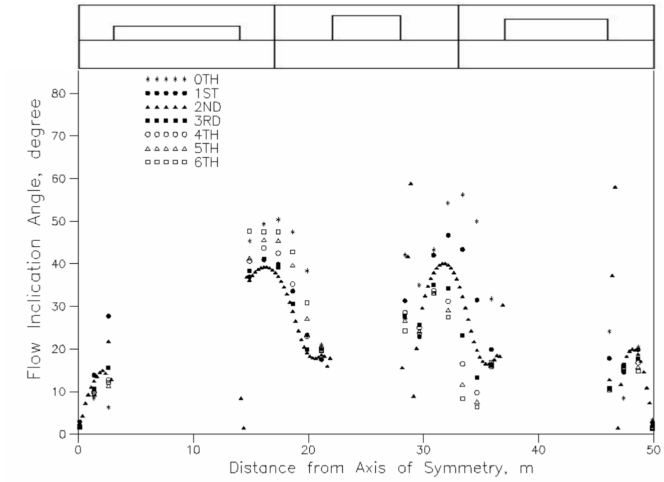


Fig. 8. Flow angle with equipment layout upon various velocity profiles

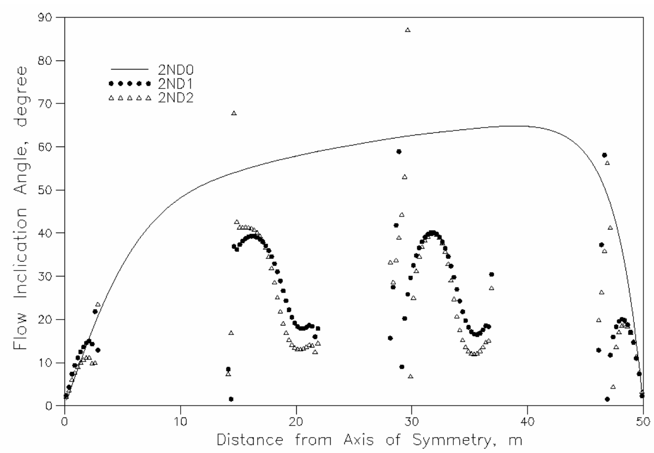


Fig. 9. Flow angle upon equipment layout and velocity profile

modeling software. Then, the meshed flow volume is transferred to the commercial CFD software Fluent V.6. The three-dimensional CFD simulation of the FPD cleanroom is performed upon the same CFD software.

Figure 11 shows the pressure and the inclined flow angle distributions in the middle section of the actual FPD cleanroom at task height. The flow field is obtained by the three-dimensional CFD simulation following the approach proposed in this study. The predicted distributions upon assigned uniform inlet velocity are shown in Fig.11 (a), and ones upon devised 2nd order inlet velocity are shown in Fig.11(b). The pressure and inclined flow angle variations towards the outlet are both decreased and evened in Fig.11(b) in comparison with Fig.11(a).

The results prove that our prescription to the inlet velocity is proper for the specific cleanroom geometry concerned in this study. Furthermore, the substantiated inlet velocity profile is implemented into the actual FPD cleanroom fabrication. The effectiveness is verified by the reduction of the product defect rate.

5. CONCLUSIONS

In this study, we point out the most favorable design parameter to control airborne contamination associated in the FPD fabrication cleanroom as the inlet velocity profile. Then, we devise the substantiated profile of the parameter. Furthermore, we proposed a systematic approach to carry out CFD simulations of huge and complex FPD cleanrooms.

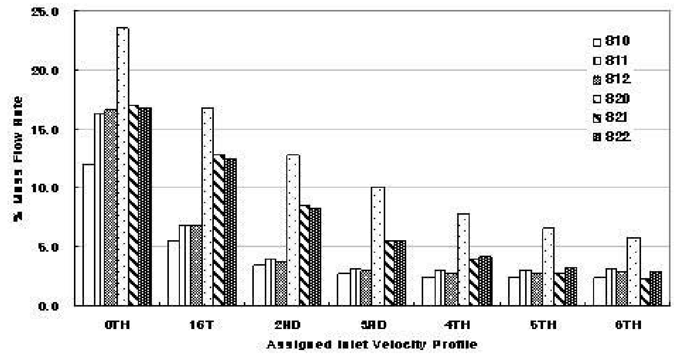
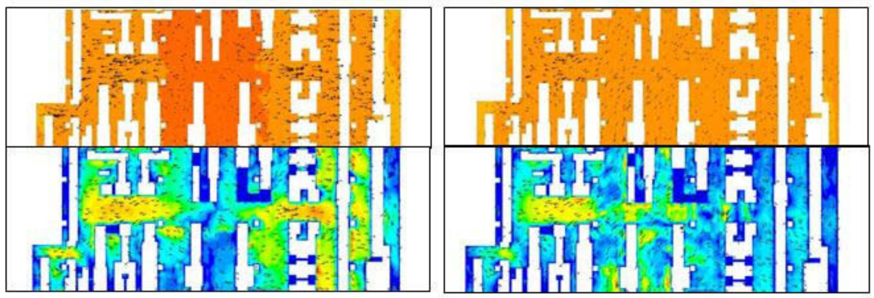


Fig. 10. Normalized mass transfer rate across section boundary



(a) (b)

Fig. 11. Predicted pressure and angle distribution in actual FPD fabrication cleanroom

In this study, the CFD simulations of FPD cleanrooms are accomplished by interlinking the modeling task upon a mechanical design tool with the simulation task upon a CFD tool.

To verify the appointed design parameter, devised profile, and proposed approach, the CFD simulations of actual FPD cleanrooms are performed and the devised profile is applied to the actual FPD cleanroom fabrication. Overall, the results show that our strategy is proper and reliable, and even robust enough to reduce FPD product contamination.

6. ACKNOWLEDGEMENTS

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