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Simultaneous control of particle contamination and VOC pollution under different operating conditions of a mini-environment that contains a coating process

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Abstract

Improvement in contamination control for a LCD color filter coater was studied by using a mini-environment design. Different operating conditions of the door and the exhaust of the mini-environment were studied. Measurements of particle concentration, flow field, and VOC concentration were performed. Both the particle contamination to the coating process and the VOC contamination to the outside cleanroom environment were considered in this study. It was found that a mini-environment could be designed to significantly reduce the particle concentration. Also, the exhaust of the mini-environment was found to affect the flow field in the mini-environment and result in an increase of particle contamination at a level close to the coating process. The design of the mini-environment requires optimal operating conditions.

1. Introduction

In the liquid crystal display (LCD) color filter manufacturing process, the color filter resin must be uniformly coated on a glass substrate (for example, 300 × 300 mm). To maintain the quality of the color filter coating a clean environment is necessary. The experiments were carried out in the LCD laboratory of the Electronics Research and Service Organization (ERSO). The color filter spin coater was originally located in a class 100 cleanroom. Occasional high levels of particle contamination affected the coating process. Particle concentration counts in the hundreds had been detected around the color filter spin coater.

In addition, the color filter resin and the coating process released odorous vapors and VOC's that would cause discomfort and health hazards to the personnel working in the area. Besides the contamination control for the manufacturing process, containment of the VOC pollution was also of prime concern. These were the two objectives that prompted the research work.

The concept of mini-environment has been successfully applied for contamination control. Generally, a mini-environment means an enclosed space within a somewhat clean environment and contains a manufacturing process that requires an especially clean environment. Cleaned air is supplied directly to the manufacturing process for the removal of particles. There have been several studies [1–3] that discussed design methods for ensuring a clean space inside a mini-environment. VOC pollution caused by the manufacturing process, however, was not well addressed.

Specifically for the resist spin-coater, Carpenter et al. [4] had studied the effects of using a mini-environment on the product performance for 150 mm wafers. However, the focus of the study was on the defects of the wafer caused by particle contamination. Factors that might have caused the defects were only analyzed

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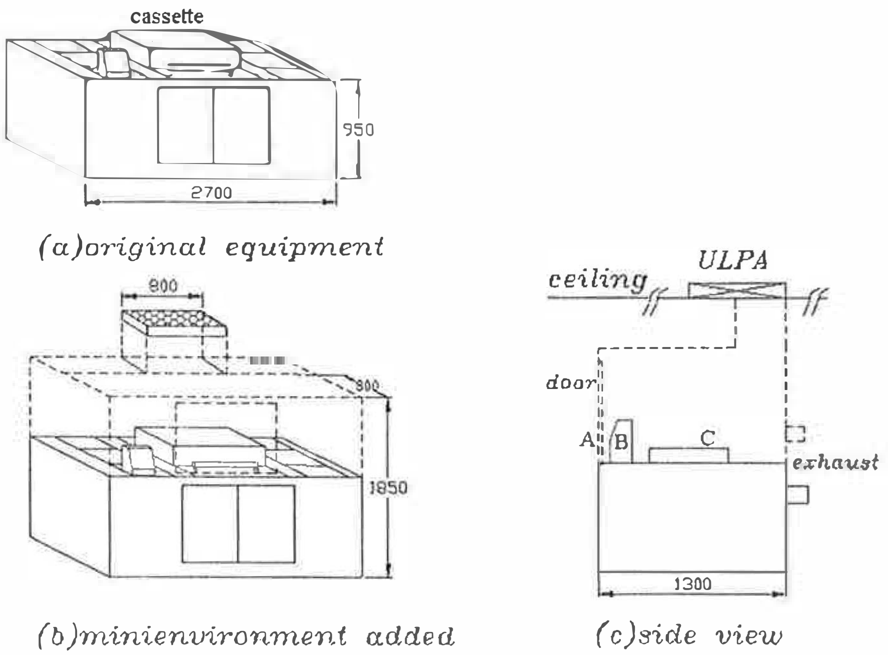


Fig. 1. The spin coater and the mini-environment experimental design, dimensions given in millimeters.

statistically, and the detailed analysis of the effects of airflow patterns and also particle dispersion mechanisms were absent in the study. Moreover, VOC pollution to the working environment was not considered.

Controls of particle contamination to the manufacturing process and also the VOC pollution were considered together in this research. A mini-environment with a single door and an exhaust was fabricated for the color filter spin coater at the ERSO LCD laboratory. The coater was originally equipped with an exhaust that was connected to the general exhaust system of the laboratory. This additional exhaust was required in order to balance the airflow and keep the mini-environment at slightly negative pressure so as to contain the VOC.

The door has to be opened for the ingress of substrates and also some handling processes. Therefore, the two operating variables in the experiments were the exhaust fan operation and the condition of the door. The particle concentration and the airflow path in the mini-environment are important subjects in this study. Measurements were conducted to determine the effects of different operating conditions on the particle contamination problem. For the study of the VOC pollution, an artificial VOC source was applied inside the mini-environment, Measurements of VOC concentration inside and outside of the mini-environment for different operating conditions were used to determine the effects on the containment of VOC pollution.

2. The experimental design

Fig. 1(a) shows the original setup of the color filter spin coater. The color filter spin coater under study was model CHUO RIKKEN A-8118 and the dimensions of the glass substrate used were $300 \times 300 \times 1.1$ mm. The color filter spin coater was originally located in a class 100 cleanroom. The cleanroom was of a turbulent flow type with air change rate of 230 per h. Figs. 1(b) and 1(c) show the addition of a mini-environment in order to enclose the spin coater. Important dimensions of the mini-environment are as shown in Fig. 1.

The mini-environment was extended to the ceiling and covered part of a ULPA filter. Cleaned air was supplied through the ULPA filter. Therefore, the area of the ULPA filter covered was determined by the mass balance of airflow in the mini-environment. The material of the wall of the mini-environment was soft plastic and was supported by stainless steel frames.

As shown in Fig. 1, air was supplied from the centrally located ULPA filter. The door of the mini-environment was centrally located and had dimensions of 100 cm wide and 80 cm in height. The exhaust of the mini-environment was on the opposite side of the door and was centrally located. The exhaust of the coater was located on the two sides of the cassette as viewed from the door.

The flow field was studied experimentally using a

3D ultrasonic anemometer (KAIJO FA600). The ultrasonic anemometer had three pairs of alternating emitter/receiver heads that were used to measure the three components of the air velocity. The velocity components were calculated by measuring the time period of the sonic pulse propagating from the emitter to the receiver heads. The sampling rate of the measurement was 20 Hz and therefore fluctuation of air velocity could be measured. For the anemometer used, the span between a pair of emitter/receiver heads of the measuring probe was 5 cm. The measuring time for each position was 50 s.

As the anemometer probe was of finite size, measurements were taken in the central plane that intersects the door and the exhaust of the mini-environment as in Fig. 1. This cross-sectional plane was also used in all other measurement.

The particle concentration in the mini-environment was measured by a particle counter (PMS, μLPC-110). The particle counter used a light source that was a 2 mW He–Ne Laser. The detection range of the particle size was 0.1–0.5 μm for the particle counter used.

The VOC concentration was measured using a trace gas detector (COSMOS XP-329). The VOC concentration was measured at the level above the coater cassette that contained the processed substrates. Three locations were measured, (a) just out of the door, (b) inside the mini-environment and close to the door, and (c) close to the cassette. In order to simulate the dispersion of the VOC's, an artificial acetone source was used, and was located at the cassette. VOC concentration near the source was measured to be 1900 on a relative scale.

3. Experimental conditions

Although the whole coating process was isolated in the mini-environment, the door had to be opened for the transport of the substrate. Therefore, two operating conditions of the door were experimented, with the door opened and with the door closed. Also, it was considered that the exhaust of the mini-environment might have a significant impact on the contamination control. Therefore, the ON/OFF conditions of the exhaust were also experimented. In considering the above variables, there were all together four experimental conditions as listed in Table 1.

Measurements of VOC concentration, particle concentration, and flow field were conducted for each of the experimental conditions. For each set of measurements, effects of the different experimental conditions can therefore be compared. Supply of cleaned air was controlled in all the experiments. The total amount of the exhaust was approximately 15.5 m^3/min.

4. Results of flow pattern measurement

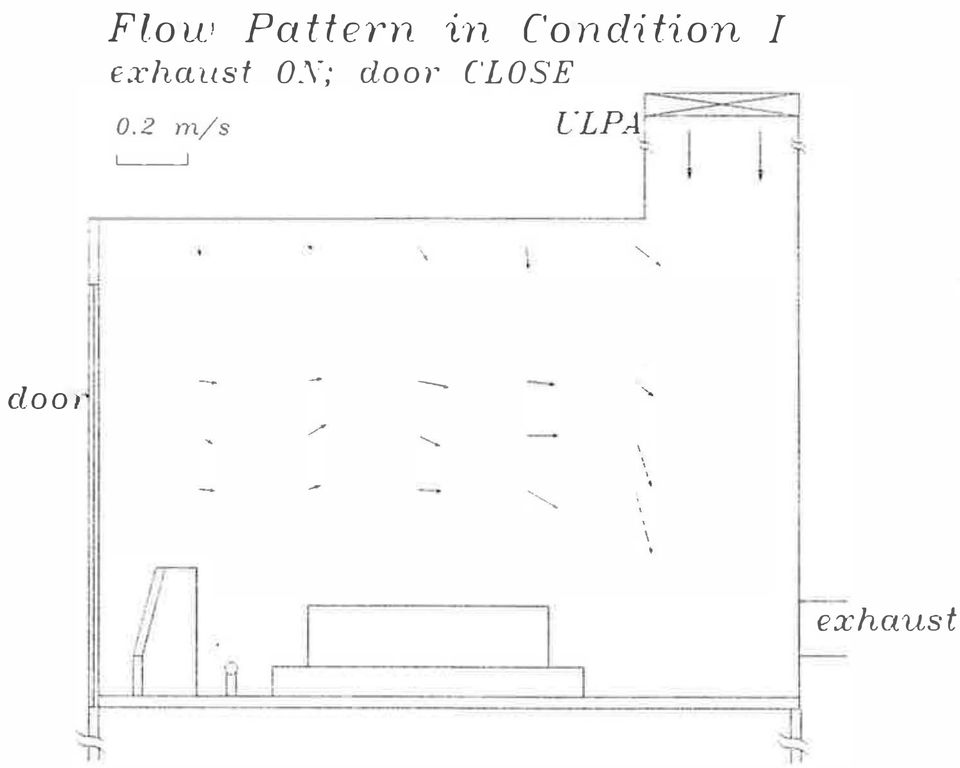
Results of the flow measurement are shown in Fig. 2 for all the four experimental conditions. The flow patterns in the central plane are shown as velocity vectors in Fig. 2. The exhaust of the spin coater drew air from the two sides of the cassette. When the exhaust fan was off as for conditions II and III, only weak flow fields were obtained. Moreover, in Fig. 2, the flow fields in this plane indicate the induction effects of the incoming airflow from the ULPA filter.

When the exhaust fan was on as in conditions I and IV, stronger velocity vectors are observed (Fig. 2). Also, it is observed that the inflow from the ULPA filter turns to the direction of the exhaust on approaching the level of the cassette. The exhaust of the mini-environment appears to be the dominating driving force of the horizontal transportation. Strong horizontal flows above the cassette are noted when the exhaust is on. This horizontal transportation may not be beneficial to the control of contamination to the coating process.

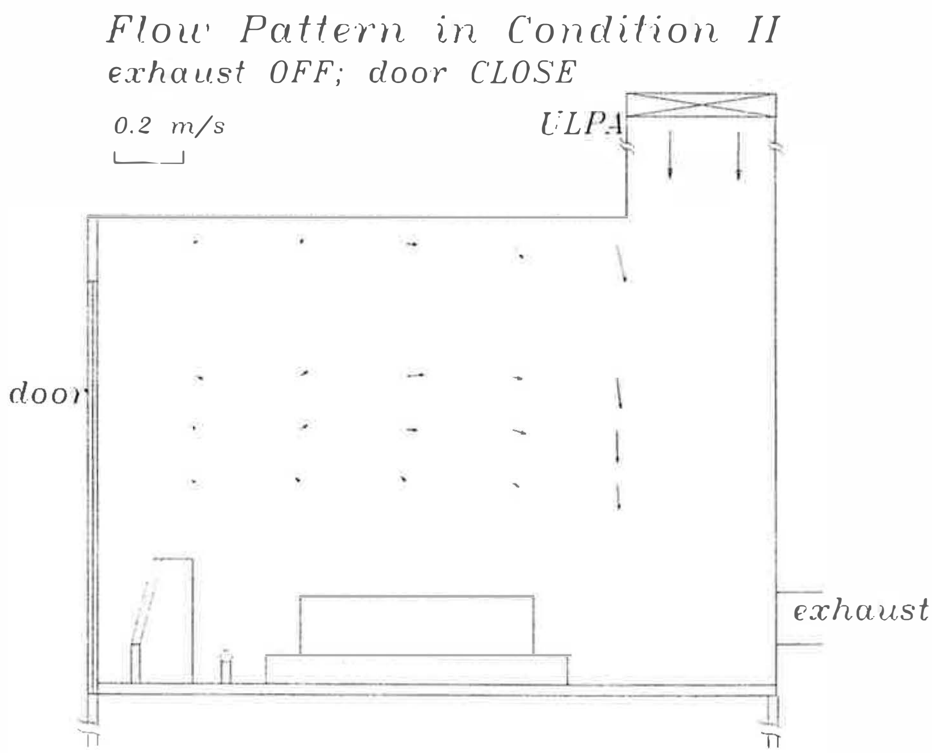
Table 1
Contamination level in the mini-environment, by particle counts[a]

Conditions Particle size (μm)	I (N/ft^3)	II (N/ft^3)	III (N/ft^3)	IV (N/ft^3)	Outside
0.1	13.7	2.7	6.3	21.7	40.8
0.2	14.3	2.3	3.7	37.7	57.7
0.3	10.3	4.7	2.0	26.7	27.8
0.5	14.0	3.0	4.0	24.4	18.9
1.0	13.0	2.0	1.0	18.0	7.6
2.0	2.0	0.3	1.0	8.3	5.3
3.0	2.0	0	0.3	3.0	3.0
5.0	0	0	0	1.0	2.7
Total	69.3	15	18.3	140.8	160.8

[a] I = door closed, exhaust ON; II = door closed, exhaust OFF; III = door open, exhaust OFF; IV = door open, exhaust ON.

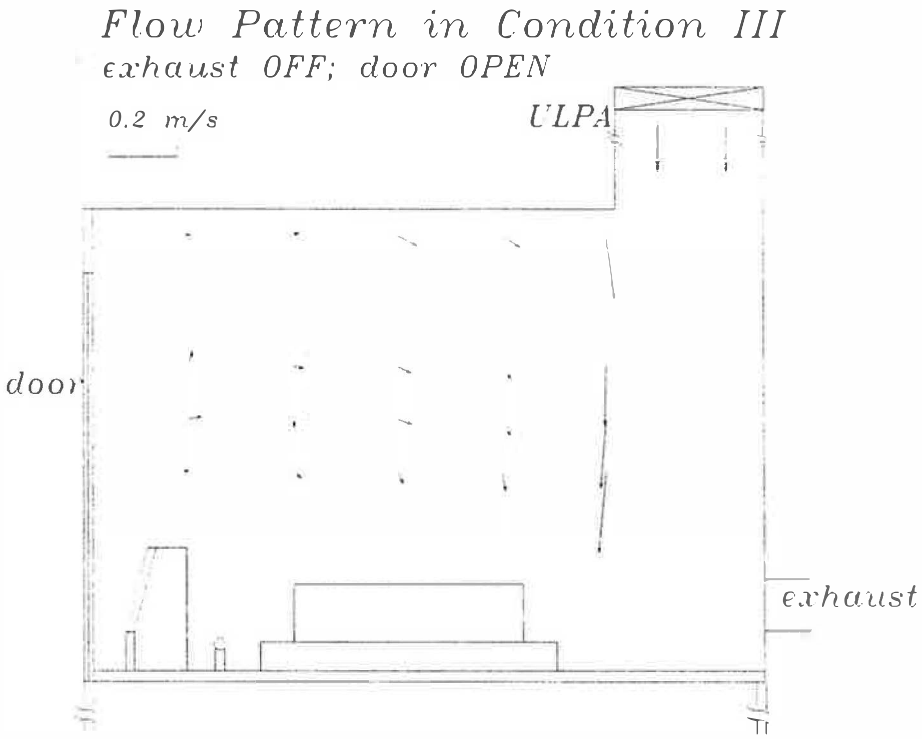


(a)

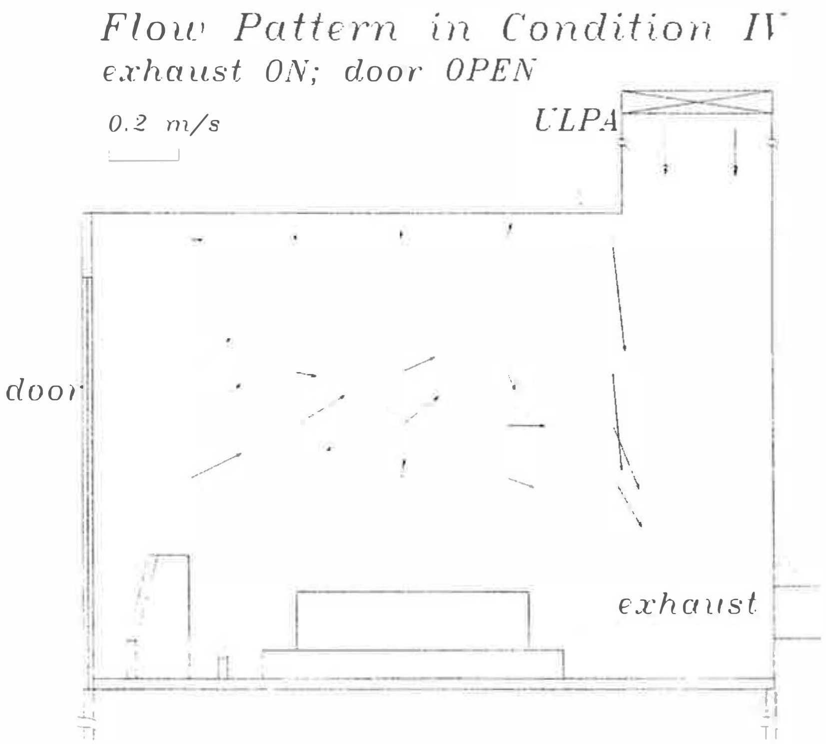


(b)

Fig. 2. The flow pattern within the mini-environment of the spin coater.



(c)



(d)

Fig. 2 (*continued*)

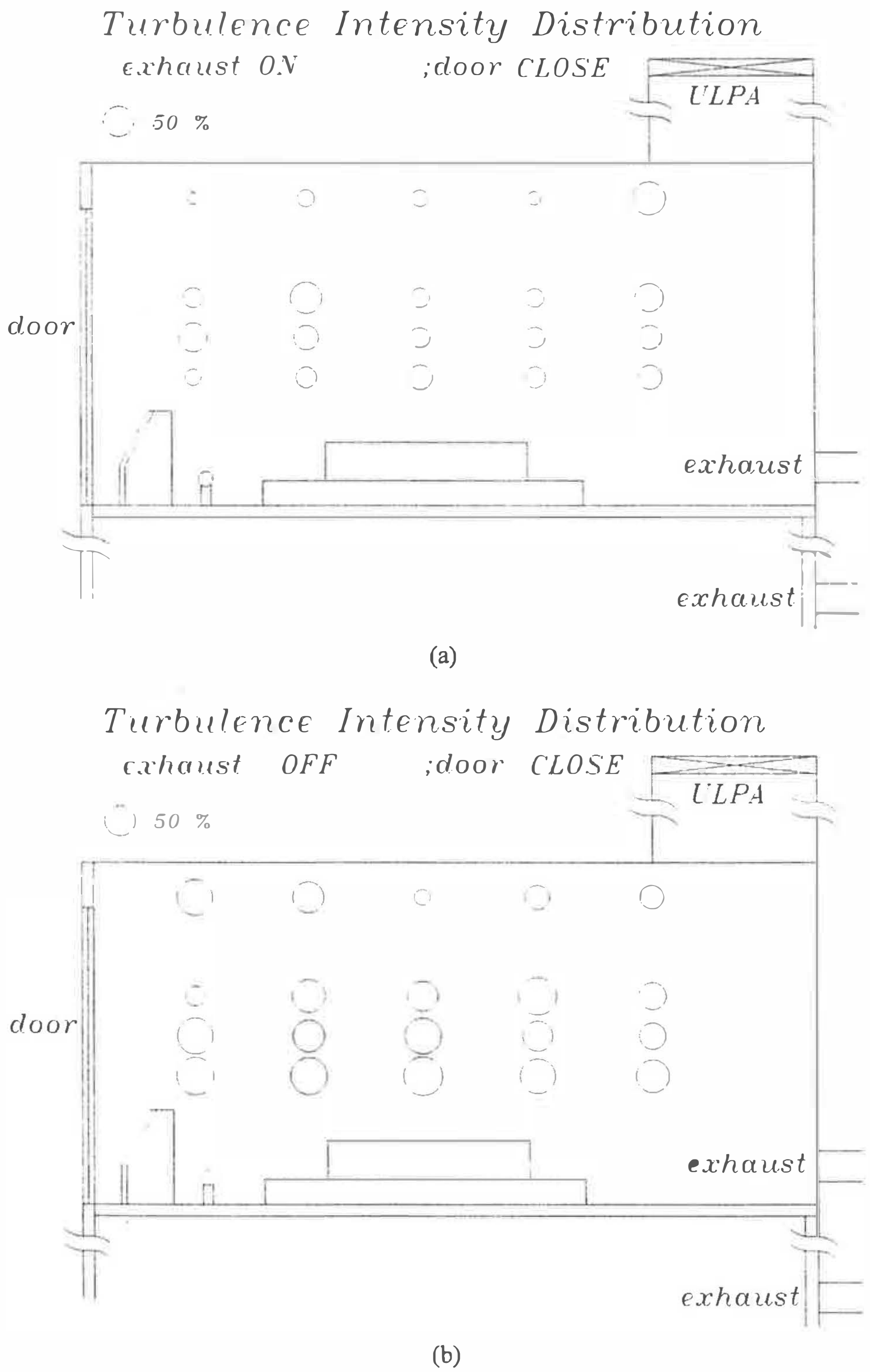
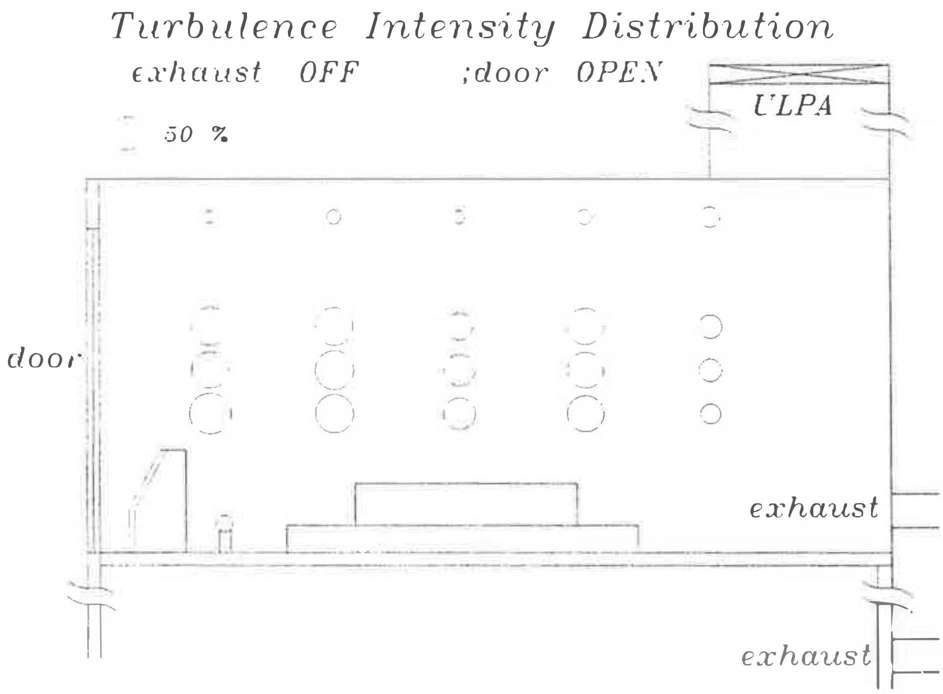


Fig. 3. The turbulence intensity within the mini-environment.



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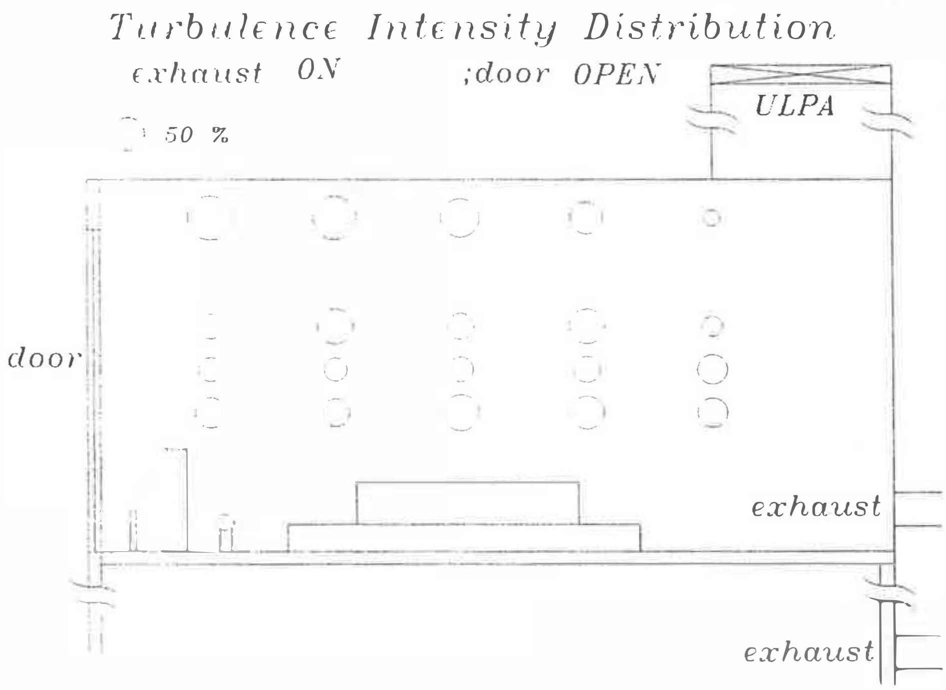

(d)

Fig 3 (*continued*)

5. Results of turbulence intensity measurement

Turbulence intensity is an index of mixing effectiveness of the airflow. Higher level of turbulence intensity indicates higher contamination transportation. The definition of turbulence intensity is [5]

$$TI = \frac{1}{\bar{U}}\sqrt{\frac{\bar{u}'^2 + \bar{v}'^2 + \bar{w}'^2}{3}} \quad (1)$$

where U is the time mean velocity and $\bar{u}'$, $\bar{v}'$, $\bar{w}'$ are the three components of the fluctuation velocity. Therefore, TI is the value of the turbulence fluctuation relative to the mean flow, and is a good indication of the strength of local mixing relative to the convective flow. As the ultrasonic anemometer is capable of high speed scanning (20 Hz), $\bar{u}'$, $\bar{v}'$, $\bar{w}'$ can be measured and the results are shown in Fig. 3 for all the four experimental conditions. The radii of the circles in Fig. 3 represent the magnitudes of the turbulence intensity of each measuring point in the mini-environment.

As seen in Fig. 3, for condition I (door closed and exhaust on), higher turbulence intensity occurs on the flow path of the incoming airflow. It seems that the incoming airflow from the ULPA filter forms a shear layer with the enclosure wall and thus causes an increase in the turbulence magnitude. For condition II (door closed and exhaust off), higher turbulence intensity is observed in Fig. 3 for most of the measuring points. This is due to low mean velocity and lesser recirculation induced by the exhaust of the color filter coater. Results for condition III (door open) show about the same trend. Higher turbulence intensity near the door is detrimental to the keeping of a clean environment. For condition IV, turbulence intensity is generally high at most the measuring points. Moreover, Fig. 2 shows that higher mean flow rates were obtained for the measuring points close to the cassette. Therefore, highest turbulence level defined as TI × U were actually obtained in comparison to three other conditions.

6. Results of particle contamination measurement

The results of the particle concentration measurement are shown in Table 1. In Table 1, particle concentrations in the mini-environment are compared to that of the outside environment. For all the conditions measured, the particle concentrations in the mini-environment were much less than that of the ambient The results confirm that mini-environment is effective in maintaining a cleaner environment.

It is noted that when the exhaust was off, as for conditions II and III, particle concentration was measured to be much lower. Lowest particle concentration was obtained when the door was closed and the exhaust was off. This was probably due to smaller horizontal flow components that could bring about particles to the air from the internal surfaces and setup. Experiments with condition III resulted in slightly higher particle concentration and the results were probably due to infiltration from the opened door.

The exhaust was on for conditions I and IV. Fig. 2 indicates that higher magnitude of horizontal airflow was obtained for these conditions. It also shows that horizontal flow is stronger when the door is open as for condition IV. The higher particle concentration measured coincides with the observation of stronger horizontal flow components. This phenomenon agrees with the general opinion that lateral mixing is not favorable to maintain a clean environment. Another fact that may contribute to the cleaner air for conditions II and III is that the higher pressure built up due to the off duty of the exhaust of the mini-environment may eliminate contamination due to infiltration.

7. Results of the VOC measurement

Results of the VOC measurements are shown in Table 2. When the exhaust was turned on, a negative pressure was maintained inside the mini-environment. Thus for conditions I and IV, VOC was not detected outside the door. But when the exhaust was turned off, VOC was detected at position A (outside the door).

Table 2
VOC concentration in various positions under various conditions. the values are relative to the acetone source of 1900. as absolute concentrations were not determined

Position Condition	A	B	C
Exhaust OFF, door closed	161	344	700
Exhaust OFF, door open	780	435	1000
Exhaust ON, door closed	0	159	850
Exhaust ON, door open	0	110	254

even when the door was closed. It seems that the exhaust is effective in containing the VOC pollution.

In contrary to particle contamination, horizontal airflow is favorable to the removal of VOC inside the mini-environment. It seems that strongest horizontal airflow will occur when the door is open and when the exhaust is on. This is the condition that results in much lower VOC concentration in the mini-environment.

8. Conclusion

A study was undertaken to reduce the particle contamination and also the VOC pollution of a color filter spin coater. A mini-environment was constructed to fit the color filter spin coater and experiments were conducted to study the effects of different operating conditions. Measurements of flow field, also VOC and particle concentrations were taken. It was found that the use of a mini-environment effectively reduced the particle contamination to the coating process. The mini-environment used an exhaust fan to keep a negative pressure. The exhaust although found to enhance somewhat the horizontal flow transportation that is not favorable to the control of particle contamination, but is effective in containing the VOC pollution. Therefore it can be concluded that a mini-environment can be designed to equip with an exhaust fan to contain VOC pollution and at the same time control the particle contamination to the process inside.

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