Enhancement of the Thickness Uniformity of a Phosphor Layer in the Cold Cathode Fluorescent Lamp

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Abstract

We report the techniques to obtain the high uniformity of the phosphor film thickness in the cold cathode fluorescent lamps, which are widely used as a back-light for the liquid crystal display. The thickness variation of the phosphor layer was sensitive to blowing conditions. The optimum conditions were obtained at flow rate of 15 sccm for 30 min at 40 ℃. The optimum and uniform thickness of a phosphor layer gives good luminous output.

1. Introduction

Rapid growth of the display industries such as liquid crystal display (LCD) monitors has attracted great attention on the back-light unit (BLU) as light sources. Fluorescent lamps have obtained wide usage among light sources using phosphors. Recently, the slimmer tube type cold cathode fluorescent lamps (CCFL) have been widely commercialized as back-light lamps for the devices using LCD, such as LCD TVs, computer monitors, and display accessories for the car. Because of its low power consumption, high brightness, long life, good color rendering and low heat radiation, the usage of CCFL is rapidly increasing.

Lamps are fundamentally constructed with a glass tube and metal electrodes. The inside wall of the glass tube is coated by the phosphors. There is an optimum thickness of the coated phosphor film. When the thickness of a phosphor film is thinner than this optimum value, the phosphor does not absorb ultraviolet radiation sufficiently; thus, the luminous output of the lamp is low. On the other hand, if the phosphor film is too thick, some fluorescent light will be absorbed by the phosphor layer, and some will be reflected back into the lamp, thus also lowering the luminous output. If the thickness of the phosphor layer is not uniform throughout the length and circumference of the tube, the luminous output will be lower than expected. To obtain a uniform phosphor film, the viscosity and specific gravity of the phosphor suspension in the coating process, as well as the temperature and air velocity in the drying process, should be carefully controlled.

In this study, we report the techniques to obtain the high uniformity of the phosphor film thickness by control of the above variables during coating of the phosphor suspension on the glass tube.

2. Experimental

We have made lamps using three-band type, white emitting phosphors, such as $Y_2O_3:Eu^{3+}$, $LaPO_4:Ce^{3-}:Tb^{3+}$, $BaMg_2Al_{11}O_{19}:Eu^{2-}$ as red-, green- and blue-emitting phosphors, respectively. A glass tube with a dimension of 2.4 mm in diameter and 425 mm in length was coated by the phosphors as follows. First, we have blended phosphor suspension inks by the mixing of phosphors and adhesives. Adhesive materials were made by blending of binders, which are the mixture of resin and solvent 1. Second, the phosphor suspension (or slurry) was made to flow up along the inner surface of a glass tube by the suction. After the inner surface of a glass tube was coated by phosphor suspension, excess suspensions were removed during the blowing process. Third, the blowing process was employed to dry the coated phosphors by blowing the air. Figure 1 shows the schematic diagram of the apparatus used in this study. Coating apparatus consist of mass flow controller (MFC), ventilator, agitator and automatic valve control system.

In the blending process of phosphor suspension, the optimum mixing ratio of the starting materials and mixing time were very essential for the uniform phosphor coating. During the suction and blowing processes, suction speed, blowing pressure and time were important variables for the high uniformity of the coating. In the baking process, we have checked the effects of baking atmosphere, heating temperature, heating time and speed on the uniformity of the phosphor coating layer.

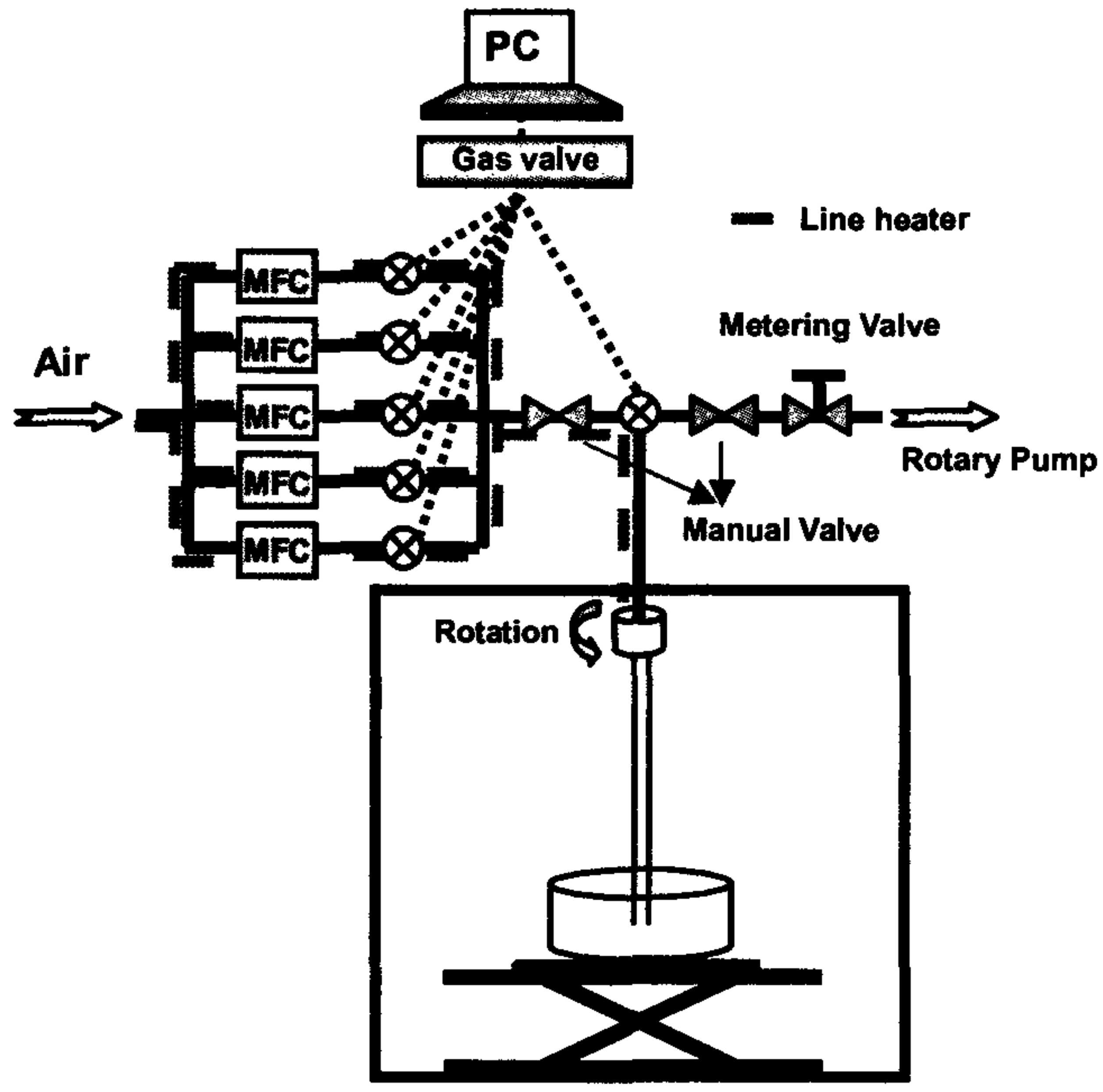

Figure 1 Schematic diagram of the apparatus for coating of the phosphor slurry

After cleaning the glass tube using acetone, ethanol and distilled water, pre-blowing process has been employed for warming up the glass tube. Then the glass tube was placed in the beaker containing phosphor slurry, which was agitated by magnetic stirrer. The suction of the slurry was conducted using vacuum pump along the inner wall of the glass tube. Flow speed of the slurry was 0.05 m/sec, and particle sizes of the phosphor powders were 3-5㎛. In order to get the uniform thickness along the length and circumference of the tube, a glass tube has been rotated during blowing process. The suction and blowing process was precisely controlled by computer. During blowing process, the lower end of the glass tube was cleaned using water or acetone to avoid agglomerations of the phosphor powders, which lead to non-uniform layer thickness or blocking of the lower end of the tube. During drying process of the coated slurry, we have also checked the effects of the temperature and blowing speed of the air on the thickness of phosphor layer.

In order to obtain the optimum thickness of the layer, we have measured the brightness of the lamps with different thickness of the phosphor layers. Then the effects of the temperature, specific gravity, viscosity and blowing conditions were studied on the formation of the optimum and uniform layer. The specific gravity of the suspension was controlled by the amounts of phosphors, while the viscosity by the nitrocellulose. Viscosity data were obtained using IWATA-Jahn Cup (model: NK-2) and thickness measurements of the layers were conducted using scanning electron microscope (SEM, model: Hitachi S-2400).

3. Results and discussion

In general, there is an optimum thickness of the coated phosphor film as described above. Figure 2 shows the variations of the brightness with the thickness of the phosphor layers. The highest brightness was obtained at thickness of 20-25㎛. When the thickness of a phosphor film is thinner than this optimum value, the phosphor does not absorb ultraviolet radiation sufficiently; thus, the luminous output of the lamp is low. On the other hand, if the phosphor film is too thick, some fluorescent light will be absorbed by the phosphor layer, and some will be reflected back into the lamp, thus also lowering the luminous output.

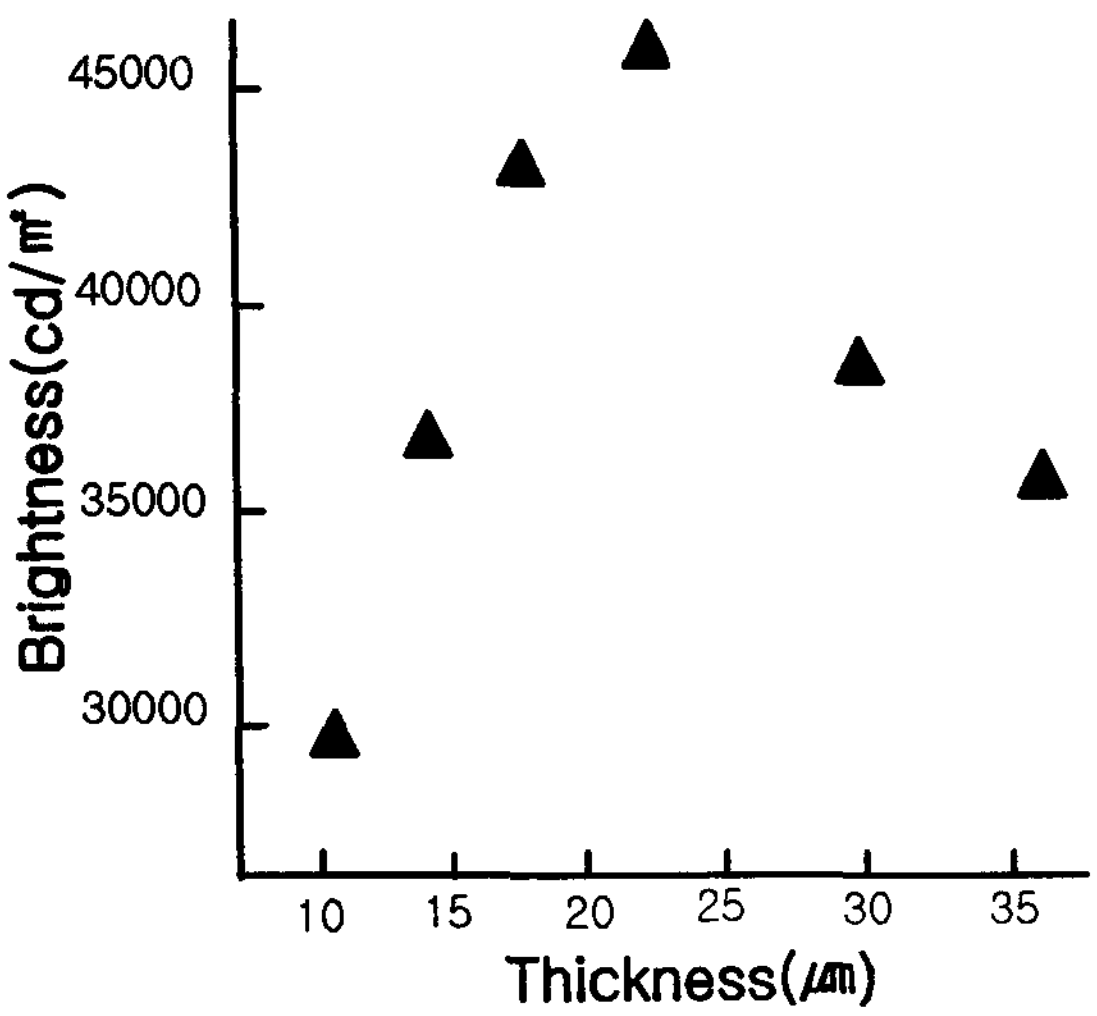

Figure 2 Variations of brightness with thickness of the phosphor layer

Figure 3 shows the variations of the coated phosphor thickness with drying time and temperature at the top and bottom of the glass tube, respectively. These relationships were obtained at constant specific gravity (1.58), viscosity (23 sec) and blowing rate (20 sccm). The layer thickness is increasing with temperature and the optimum value of the thickness, 20-25㎛, is obtained at layer dried at 40℃ for 30 min as shown in figure 3.

Figure 4 shows the effects of the various cleaning solutions on the thickness of phosphor layer. The thickness variations were measured along the tube length from top of the glass tube.

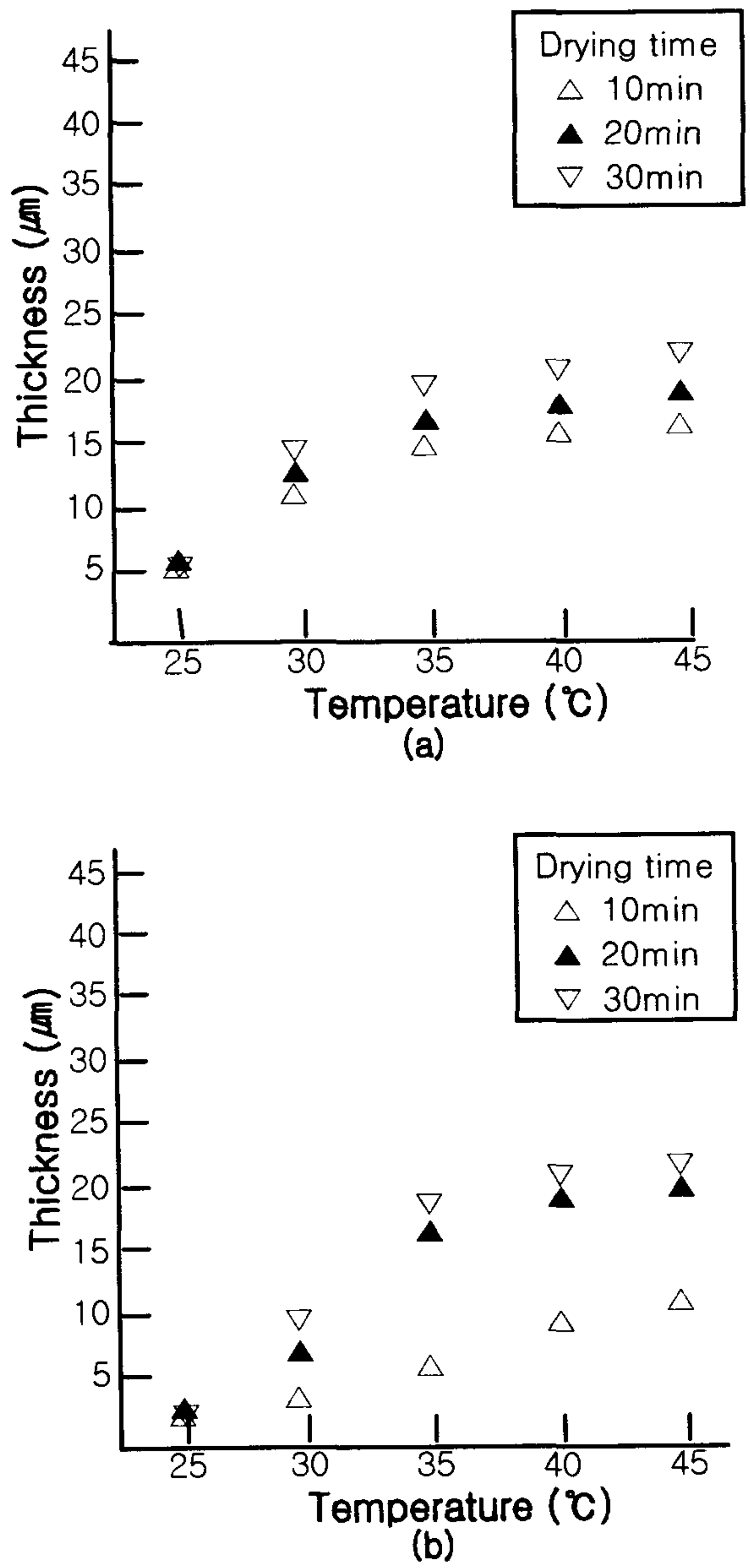

Figure 3 Variations of thickness of phosphor slurry with drying temperature and times at (a) the top of glass tube and (b) the bottom of glass tube, respectively.

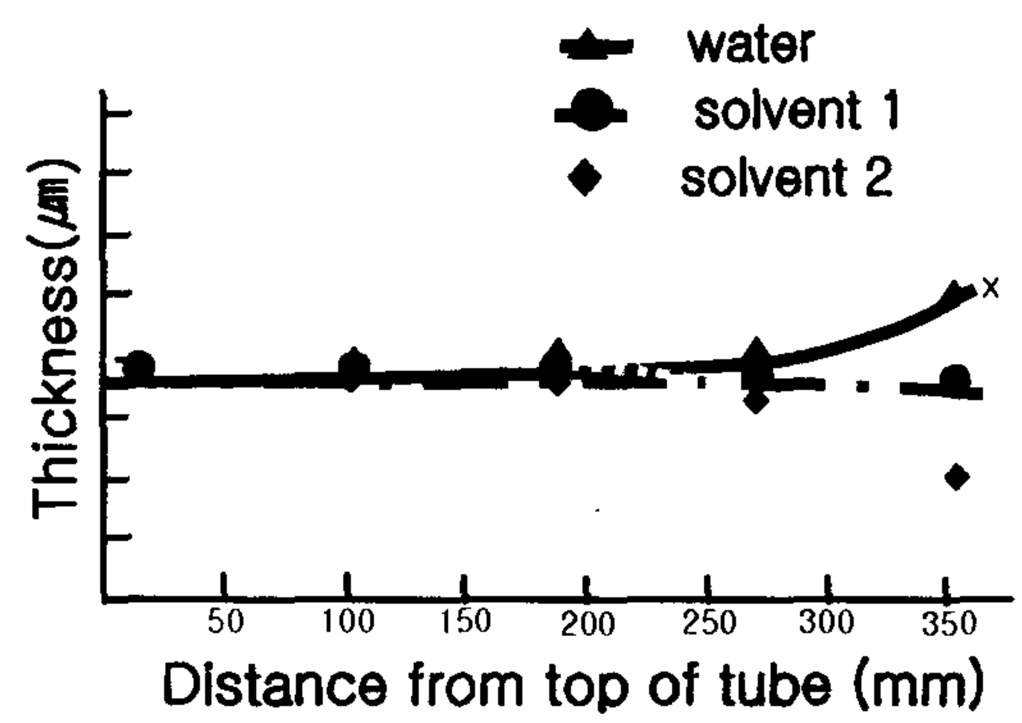

Figure 4 Variations of the thickness of phosphor slurry with glass tube length and various cleaning solutions

Cleaning is the essential process to avoid the agglomeration of the phosphor powders during drying process. During drying process, blowing causes the coated excess slurry to flow down along the inner surface of the tube. Therefore, without cleaning of the bottom of the tube, the excess slurries agglomerate and even block the lower end of the tube. As shown figure 4, the cleaning with water causes increase of the thickness, while the solvent 2 causes decrease of the thickness. However, the cleaning with solvent 1 produces the most uniform thickness.

Figure 5 shows the variations of the thickness with viscosity of the slurry. The optimum value of the viscosity was obtained at 17 sec as shown figure 5. Viscosity was controlled by mixing ratio of various resins to solvents.

Figure 6 shows the effects of the flow rate on the thickness along the tube length during blowing process. Higher flow rates than 15 sccm give rise to increase of the thickness at top of the tube, while lower flow rates below 15 sccm give a uniform thickness. Figure 7 shows the SEM images taken from phosphor layers coated at different flow rates; 15, 20 and 30 sccm. The uniform thickness of ~20㎛ was obtained at flow rate of 15 sccm as shown in figure 7(a).

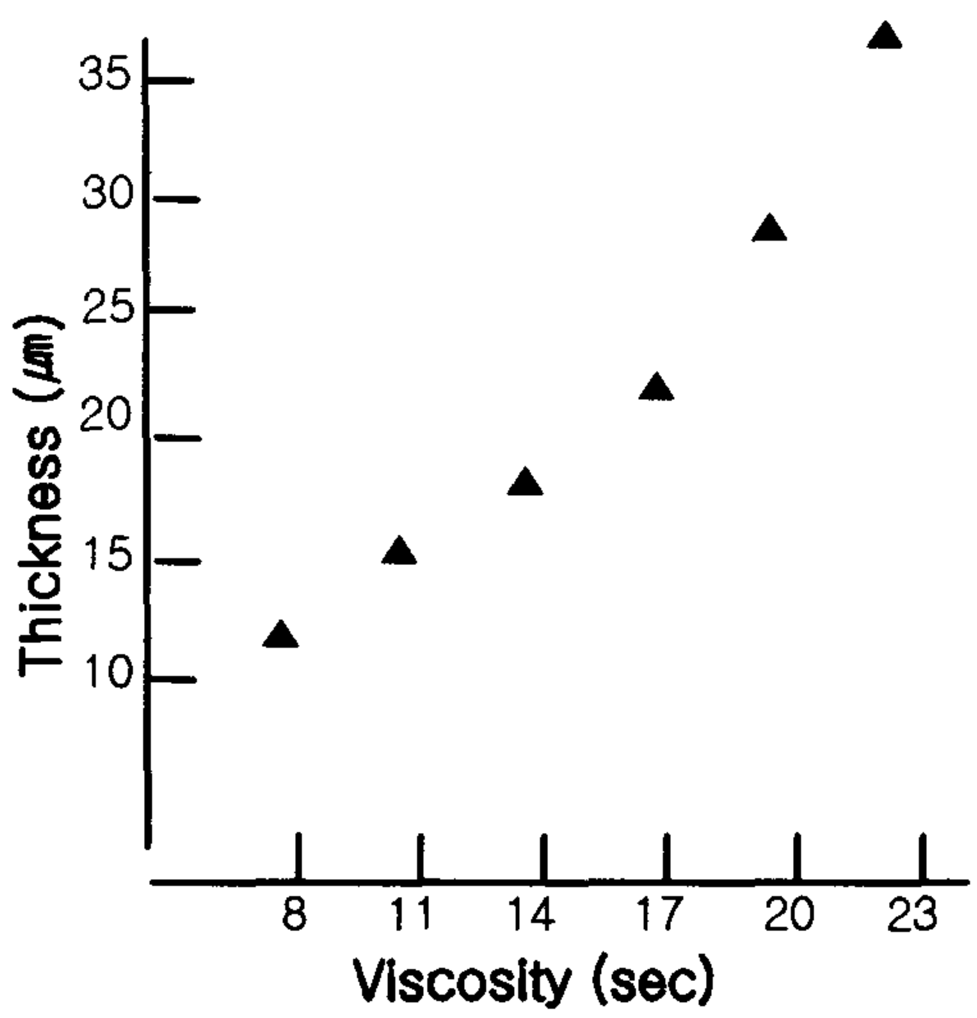

Figure 5 Variations of the thickness of phosphor layer with various viscosities

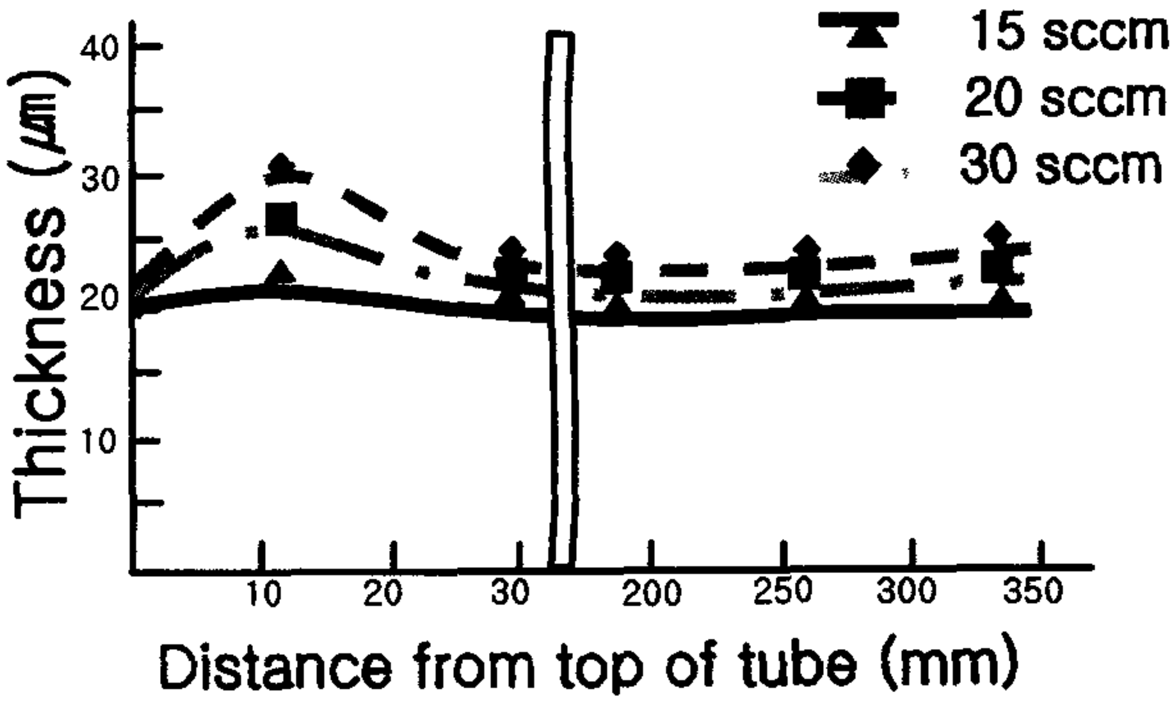

Figure 6 Thickness of phosphor slurry with lamp length and blowing flows.

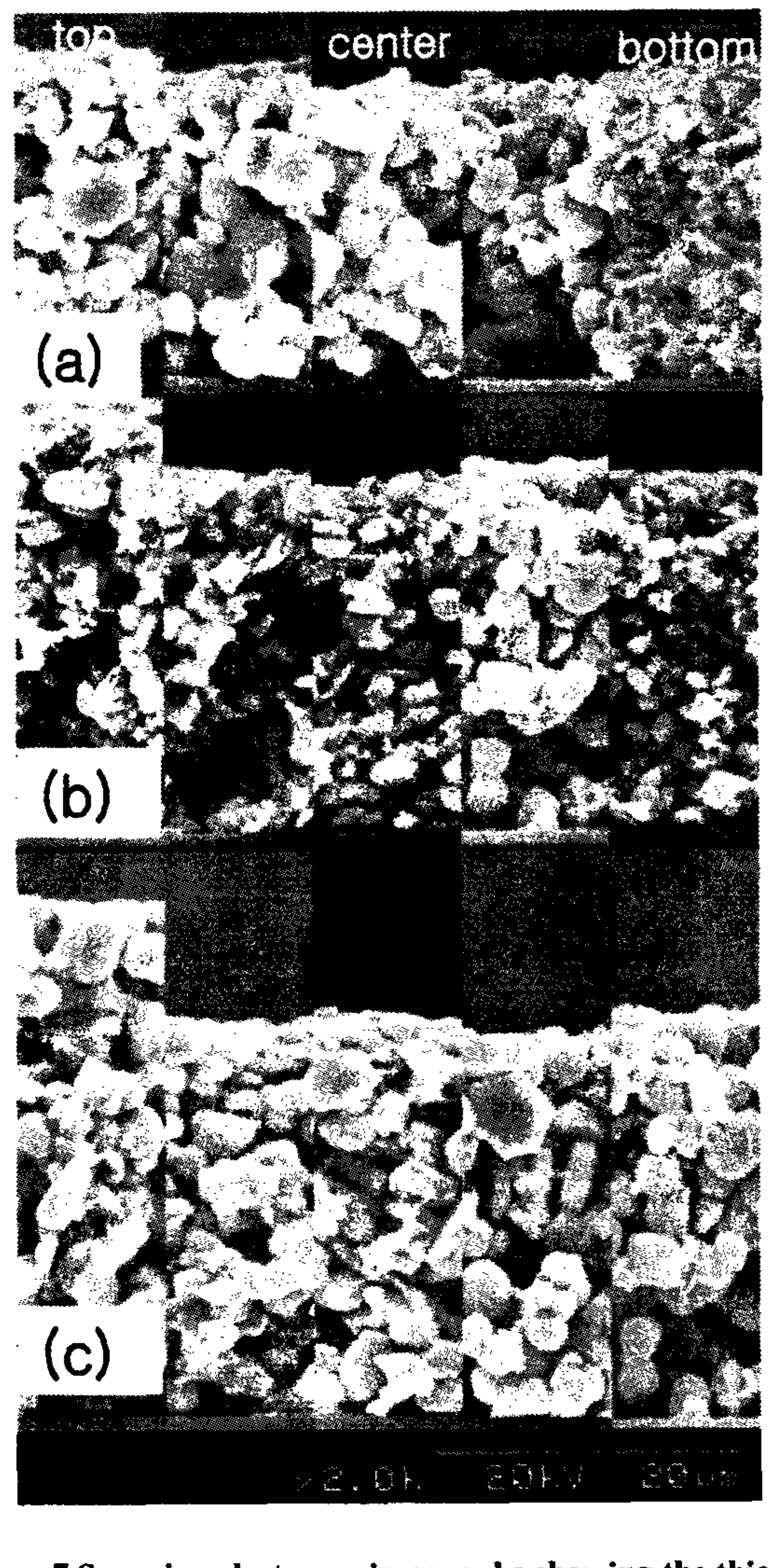

Figure 7 Scanning electron micrographs showing the thickness profile of the phosphor layers coated at different flow rates; (a) 15, (b) 20 and (c) 30 sccm, respectively. Each images consist of 5 sections; top: 10-30 mm, center: 160-180 mm, bottom: 320-340 mm from the top of the tube.

4. Conclusion

After careful studies, we have obtained the optimum process conditions producing the highly uniform coating thickness along the length and circumference of the tube. The thickness variation of the phosphor layer was sensitive to blowing conditions. The optimum conditions were obtained at flow rate of 15 sccm for 30 min at 40℃. We presented the techniques to improve the thickness uniformity of the phosphor layer in the cold cathode fluorescent lamps. Using these techniques may allow us to fabricate lamps with higher luminous output.

5. References

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