Observation of non-uniform air flow in an organic solvent coating dryer

T. Yahiro[a] and Y. Katagiri[a]

[a]Fuji Photo Film Co., Ltd.
Minami-Ashigara-shi, Kanagawa, 250-0193

Presented at the 13th International Coating Science and Technology Symposium, September 10-13, 2006, Denver, Colorado[1]

Solvent coating technology has been developed in various industrial fields such as photographic industry and paper industry. In this process, mottle is one of the most troublesome defects, which is encountered in a dryer. It reflects non-uniform air contact with the coated film in a dryer or before the entrance of a dryer.[1] The non-uniform air contact with the coated film creates localized non-uniform pressure and shear stress to the free surface. It also creates non-uniform temperature due to non-uniform heat and mass transfer. The non-uniform pressure, shear stress, or temperature may cause the surface flow and the non-uniformity of film thickness.[2] Therefore, increasing viscosity and decreasing surface tension of the coated film can reduce mottle. On the other hand, characteristic of the air motion in a dryer is not well-known. This study makes detailed investigation of the drying air motion.

There are various methods to observe or visualize air flow pattern as tracing method, taft method and optical method. The most important factor that causes mottle is the air flow pattern near the coated film. In this study, the air flow pattern on the wall is visualized by the non-uniformity of the solvent gas concentration evaporating from the wall. Methanol, acetone, methylethylketone are used as a tracer, and the gas concentration in the air is observed by the Schlieren method.

Since air flow direction is usually parallel to the coated surface, we assumed a counter-flow or a parallel flow dryer. Fig.1 shows the experimental apparatus composed of a channel, solvent sources, observation windows, a nozzle, and the Schlieren system. The channel is made of 4 sheets of aluminum plate. The solvent source is made of sintered stainless steel and is placed on the upper or lower plate of channel near observation windows. The inside surface of the channel is smooth not to disturb the air flow. The air is blown from the nozzle at the entrance of the channel and the air flow that passed over the solvent source is observed with the Schlieren System through the observation window.

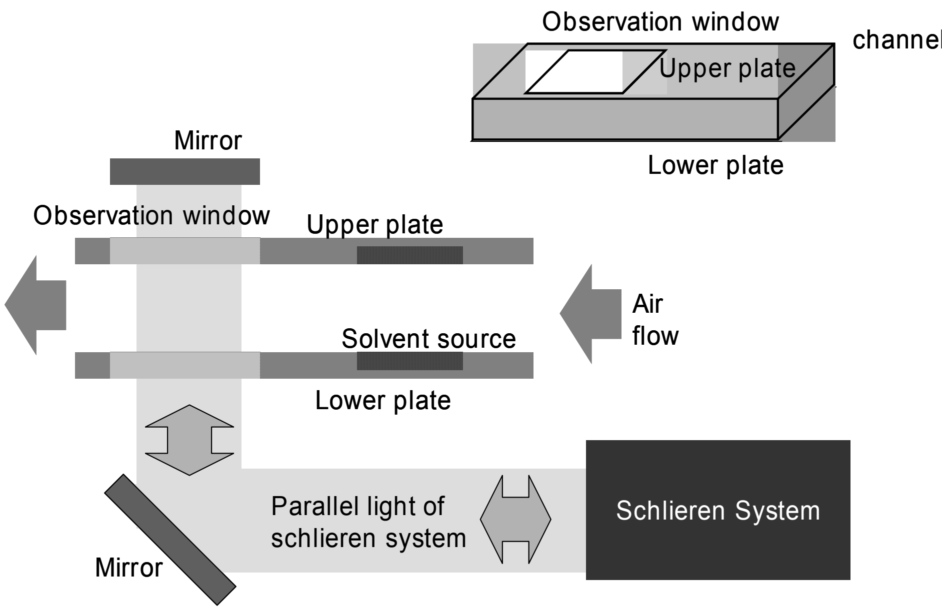

Fig.1 The experimental apparatus to observe the air flow containing solvent gas

The Schlieren system is an optical system shown in Fig.2. The parallel light is bent by the refractive index distribution in the observation space and then it is cut by knife edge. The refractive index distribution in the observation space is visualized as the contrast of the CCD image. Thus, the Schlieren system can visualize the solvent gas concentration variation in air flow as distribution of refractive indices.

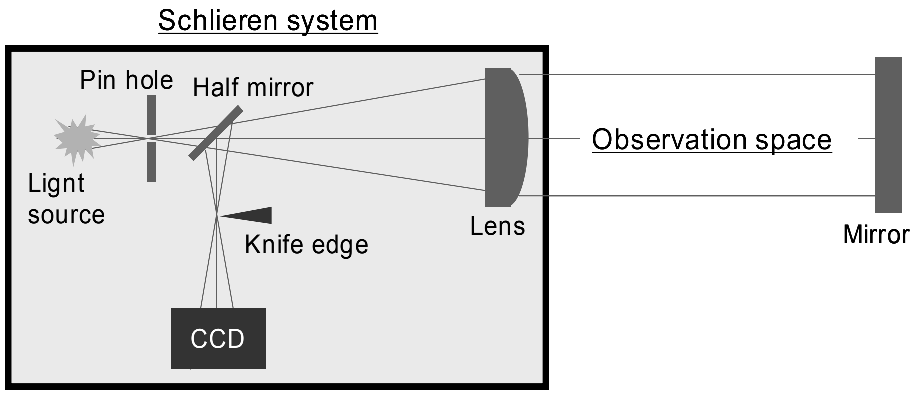

Fig.2 The Schlieren system

As air velocity was changed from 0.05m/s to 10m/s, mottle structure oriented to the flow direction was observed in Schlieren image at low air velocity and high air velocity. However, no mottle structure was observed at middle air velocity. Then the details of the observed structure were investigated at low or high velocities.

At low air velocity around 0.1m/s, the position of solvent gas source and the wall-to-wall distance of the channel were changed to confirm the effect of convection. The mottle structure at low air velocity was only observed when the solvent gas source was on the upper side of the channel and the wall-to-wall distance was above 10mm (Fig.3). It was found that the solvent gas boundary layer fell from upper side to the lower side of the channel at low air velocity by the observation through the lateral wall of the equipment.

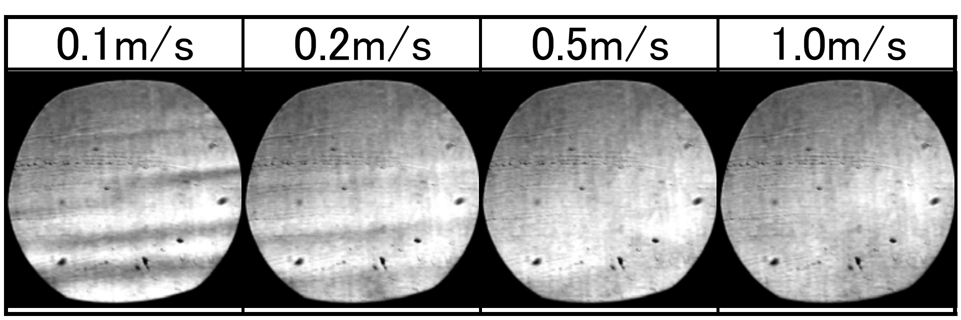

Fig.3 Schlieren photography at low flow velocity (The diameter of each circle is 100mm.)

At high air velocity above 0.5m/s, the mottle structure was also observed (Fig.4). This structure was discontinuous in contrast to the structure at low velocity which was always continuous. As the velocity was increased, the structure became finer and finer. By improving the nozzle, the critical velocity to generate the structure increased to around 2m/s.

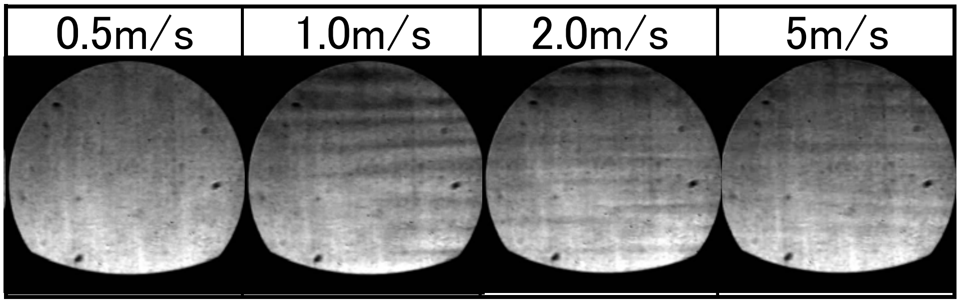

Fig.4 Schlieren photography at high flow velocity

The turbulent flow in the channel has low-speed streaks near the wall and the average spacing of the streaks gets finer as the velocity gets faster.[3] Therefore it can be inferred that the mottle structure shown in the Schlieren image is caused by the streak structure of the turbulent flow.

In this way, two factors of the mottle are suggested by the observation. One is the concentration driven convection and the other is the streak structure near the wall in the turbulent flow. Even though the air flow in the actual dryer is complex, understanding about the convection and turbulent flow structure would enable us to predict and improve the mottle in a dryer.

Reference

[1] E. Cohen, E. Gutoff, Modern Coating and Drying Technology, WILEY-VCH, 1992

[2] B. C. Bell, F. M. Joos, 10 th ISCST symposium, USA(2000)

[3] S. J. Kline, W.C. Reynolds, F.A. Schraub, and P.W. Runstadler, J. Fluid. Mech., 30, 741 (1967)