Gas Sealed UV Dryer for Optimizing UV Applications

Dr Géraldine Rames-Langlade, Air Liquide S. A., France

Abstract

Air Liquide has developed a novel inerted UV technology for the curing of coatings using UV irradiations under oxygen-free atmosphere. This technology consists in adapting a Gas Seal Kit to a standard UV-dryer allowing to cure under any desired stable residual oxygen concentration down to 30 ppm using a very moderate flow of nitrogen even at web speed up to 300 m/min. It can be easily implemented to existing printing or laminating lines and allows curing speed increase, UV specific power reduction, coating quality improvement and use of coatings in compliance with indirect food contact regulation.

Introduction

UV curing technologies are widely used in a vast range of converting applications in the plastics, wood, glass, electronics and other processing industries to induce ultra fast curing of varnishes, lacquers, paints or printing inks with high energy radiations.

UV curing processes are continuously operating, i.e. not entirely enclosed in specific UV dryers and the curing reactions take place in atmospheric air. Under these conditions, the curing of photocurable resins (mainly based on acrylate chemistry for which radicals initiate polymerisation and/or crosslinking) is inhibited by the presence of oxygen. The later shows a very high reactivity towards radical species leading to peroxy radicals which are inefficient for the polymerisation. Therefore, the presence of molecular oxygen during UV curing can slow down or even halt the curing reactions resulting in improperly cured surfaces. This is one of the crucial limitations of this technology. This drawback is particularly pronounced for the curing of thin coatings such as curable inks in printing industry.

The addition of a large excess of photoinitiators and/or synergists, in the coating formulation, is an effective means for reducing inhibition reaction induced by oxygen. Photoinitiators and synergists act as oxygen scavengers upon UV exposure, thereby consuming oxygen molecules dissolved in the coating whilst leaving enough components to initiate curing reaction. However, these components have undesirable effect on the cured products because they often give rise to a noticeable odour and show an increased tendency to yellowing. In food packaging applications, they also may migrate through the food contact layer and affect the foodstuffs making their use incompatible in regard to the European regulations.

The generation of a larger number of free radicals that scavenge oxygen is also a common way to overcome the oxygen inhibition. This phenomenon can be achieved by reducing the line speed or/and by increasing the UV specific power lamp. However, operating under these conditions causes lower productivity, higher energy consumption and induces high temperature inside the UV zone which may damage thermosensitive substrates.

According to the drawbacks of the inhibition by oxygen, it is obvious that to get rid of oxygen inside the UV reaction zone will present a great interest. Indeed, if the oxygen level inside the UV reaction zone decreases, the photoinitiators and the synergists concentrations required to initiate the polymerisation reaction and to get a tack-free coating will be reduced, the curing speed will be higher and the line speed could be increased or/and the light intensity reduced.

The technical solution proposed by Air Liquide is to remove efficiently the air boundary layer and to replace it by a pure inert gas such as nitrogen. Air Liquide has developed a high performance and low operating cost inerting device called Gas Seal Kit (GSK). The GSK technology meets the following technical requirements:

- Efficient peel off the bundary layer of air
- Low residual oxygen content at the surface of the moving substrate

- Low consumption of nitrogen
- Low oxygen content at high web speeds
- Operation under safe conditions
- Easy to install

For the converters, the main benefits of curing under an inert nitrogen atmosphere are:

- lower photoinitiators and synergists levels
- faster printing speeds at constant UV power lamp
- higher curing degrees
- lower electrical power consumption
- less migration of chemical constituents which makes printed package compatible with food.

This article first describes the performance of the Air Liquide GSK adapted to VTI-idealquarz UV dryer in terms of nitrogen consumption and residual oxygen concentration. Then, the beneficial effects of curing of UV printing inks under inert nitrogen atmospheres on operating conditions (curing speed, curing level, UV lamp power and photoinitiator consumption) are presented.

Air Liquide technical solution for UV curing processes under inert nitrogen atmosphere

The Air Liquide GSK (Gas Seals Kit) consists of a nitrogen injection slit specifically designed using numerical modeling and experimental data in order to achieve optimum air peel-off and inerting performances. The GSK, protected by a patent application [1], has already been implemented to an existing UV dryer of a laminating machine [2].

As an example, results of gas consumptions and level of oxygen using a VTI-idealquarz UV dryer are reported in this article.

The inerted UV dryer consists of a 450 mm-wide roller equipped with two GSKs ; one at the entrance and another one at the exit of the UV dryer. The first one is used to peel off the air boundary layer on the substrate surface and to fill up the UV zone with nitrogen and the later one is used to prevent both the release of nitrogen to the working area and the ingress of air into the UV dryer. A quartz window is slotted in order to shield the UV reaction zone from the air extraction system used to cool down the lamp. An oxygen probe allowing to measure the oxygen level is set up at about 2 mm from the surface of the substrate. The assessment of nitrogen consumptions has been performed using a plastic film moving at a speed ranged from 50 to 300 m/min. The control of the flow rates of nitrogen injected through GSK is achieved using a manually adjusted standard gas flow control unit. Nitrogen containing less than 5 ppm of oxygen has been used.

Oxygen concentrations as low as 30 ppm have been obtained inside the UV curing zone at any speed, from 50 to 300 m/min, with a nitrogen flow varying from 7 to 24 Nm^3/h, respectively. Considering the width of the UV dryer and the speed of the film, the nitrogen consumptions (in Nl/m^2) is comprised between 6 and 3 Nl/m^2 for a speed ranged from 50 to 300 m/min, respectively, as shown in Figure 1.

By reducing the flow of nitrogen, stable residual concentrations of oxygen ranging from 30 to 1000 ppm have been reached whatever the web speed while keeping low consumptions of nitrogen.

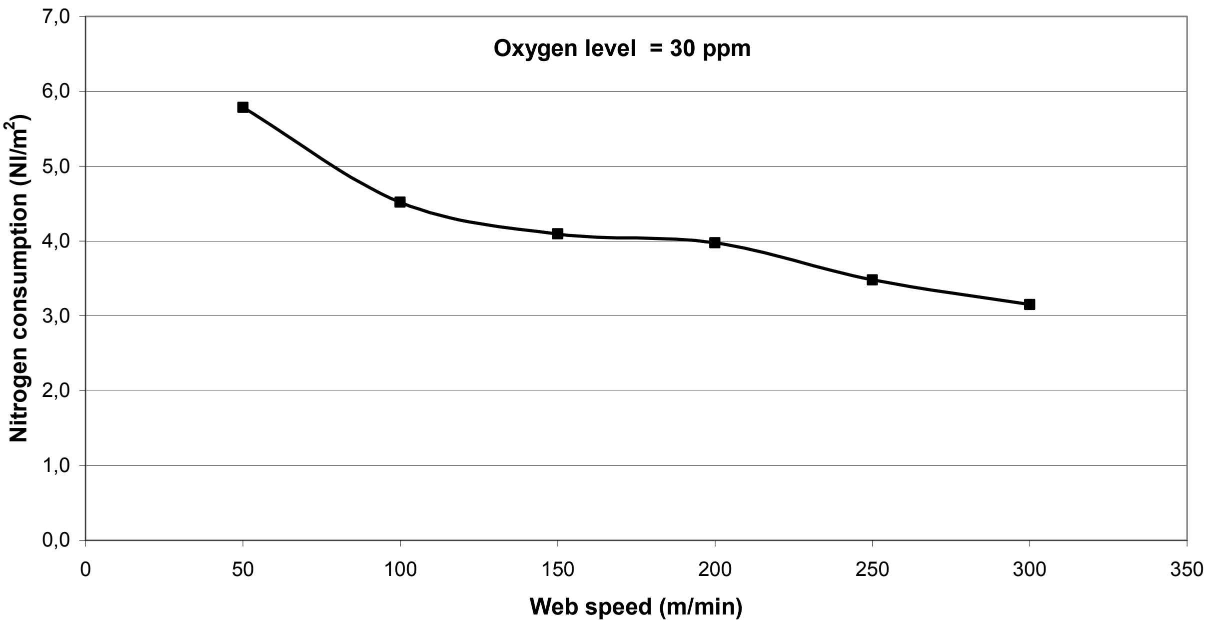

Figure 1 : Optimized nitrogen consumptions to reach 30 ppm versus speed

UV curing of printing inks under nitrogen atmosphere

The beneficial effects of nitrogen atmosphere have been quantified on the curing operating conditions of thin printing ink coatings. Curings under air and nitrogen atmospheres have been performed using different speeds and UV specific powers. The levels of curing have been calculated in order to evaluate the impact of low oxygen concentrations inside the UV reaction zone on the increase of speed and/or the reduction of UV specific power.

UV curing experiments were carried out using blue UV flexographic and offset printing inks. The UV flexographic ink is based on polyester acrylate resin and contains thioxantone as a photoinitiator (3 wt.%) and a benzoate amine as a synergist (5 wt.%). The UV offset ink is based on a polyol acrylate resin and contains a blend of photoinitiators (10 wt.%). The UV-curable ink formulations were applied on a polyethylene plastic film using an automatic printing machine (K printing proffer) to obtain a homogeneous 1,5 µm-thick coating.

The coated substrates were cured using a UV laboratory system from VTI-idealquarz (De Luxe UV system). This UV system has a medium pressure UV lamp mounted in a highly polished aluminium reflector. The UV lamp runs at three specific powers (40, 80 and 120 W/cm) and the conveyor belt moves at a speed ranged from 10 to 55 m/min. It also includes an inerting device able to lower the oxygen level to few ppm at the coated surface. A 3 mm-thick quartz window was used to shield the UV reaction zone. The dose of energy (mJ/cm^2) at the sample position was measured by radiometry (UV Power Puck®).

After irradation, the level of curing of the cured coated substrates are obtained by means of a FTIR spectrophotometer. The area of the IR absorption acrylate double bond band, located at 1410 cm^{-1}, is determined before (Ai) and after (Af) curing. The degree of conversion is directly calculated from the equation : (Ai – Af)/Ai x 100.

As an example, the degrees of conversion of the UV flexographic ink obtained under different operating conditions (type of atmosphere, speed, UV specific power) are shown in Figure 2.

It should be pointed out that under air, tacky-free surface can be achieved only when curing was performed at 20 m/min and at 120 W/cm (operating conditions recommended by the ink supplier). Under theses conditions, the curing conversion corresponds to 75%. Using other operating conditions, curing conversions are lower than 75% and tacky-free surfaces can not be obtained. On the contrary, curing under nitrogen atmospheres, whatever the operating conditions, leads to completely dried surfaces.

Under oxygen-free atmospheres, the curing conversions vary from 75 to 96% which are higher than those obtained under air. Under the standard operating conditions (20 m/min and 120 W/cm), using nitrogen rather than air induces the increase of the curing conversion from 75% to 96%.

According to the Figure 2, 75% curing conversion can also be achieved operating at 56 m/min (the limit speed of the conveyor) under nitrogen, while keeping constant the UV specific power (120 W/cm). Compared to air, the speed allowing to reach a tacky-free surface under nitrogen is nearly 3 times higher.

Concerning the specific power, Figure 2 shows that nitrogen allows to lower the UV specific power while keeping high the curing conversion. Under nitrogen, to operate at 80 W/cm instead of 120 W/cm (standard conditions) leads to curing conversions comprise between 79 to 93% for a speed ranged from 12 to 33 m/min. These curing levels are even higher than that obtained under standard operating conditions. For instance, the curing conversion obtained under nitrogen at 20 m/min (standard speed under air) and at 80 W/cm is equal to 90%.

These results fully confirm fully the interest of using nitrogen atmosphere instead of ambient air to operate with higher speed and/or lower UV specific power. Using flexographic printing ink, it has been shown that nitrogen allows to increase the speed by a factor of 3 and allows to reduce the UV specific power by at least 30%. Work is planned to demonstrate that curing under nitrogen enables to lower the level of photoinitiator and/or synergists.

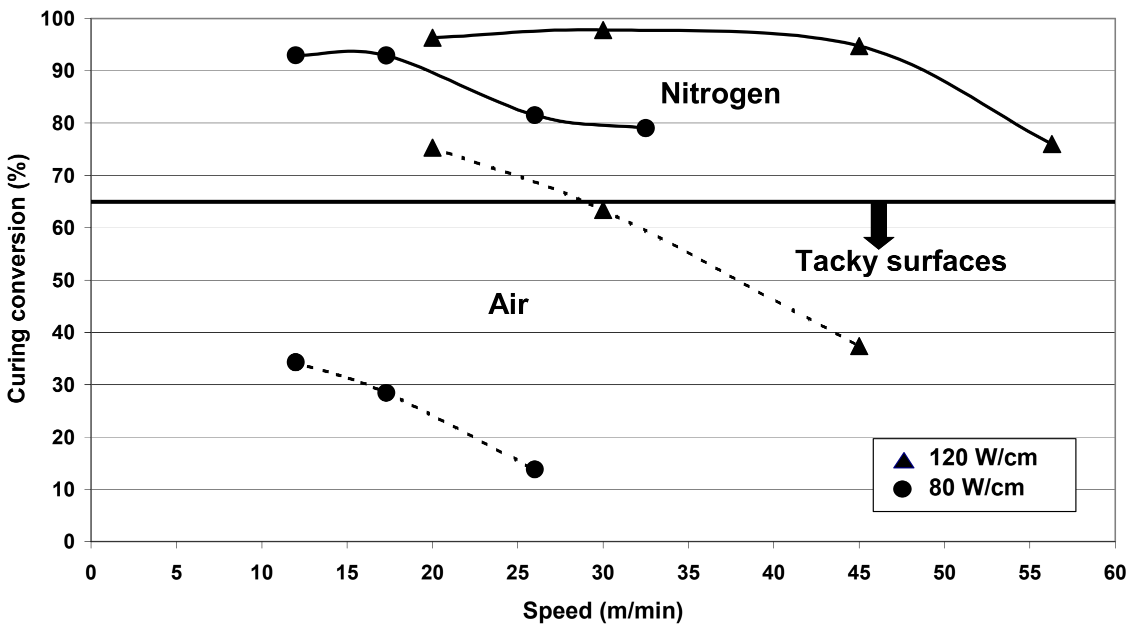

Figure 2: Curing conversions versus speed at different UV specific power – UV flexographic ink

References

[1] P. Cocolios, F. Coeuret, W. Doring, F. Forster, J.-L. Gelot, B. Martens, S. Melen, E. Prinz, J.-Y. Thonnelier, A. Villermet, L'Air Liquide, WO 02/40738, US patent 6 458 330
G. Rames-Langlade; F. Coeuret, A. Spizzica, L'Air Liquide, FR 0450155 (2004)
[2] A. Guilleux, Henkel KGaA, Düsseldorf, "Radiation Cure: A New Laminating Adhesive Technology for Flexible Packaging?", MKVS 2004: Chemical and Radiation Curing Systems, October 25th to 27th, 2004