

Drying of water- and solvent-based thin polymer (adhesive) coatings... ...a practically-based description

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All adhesive coatings, with the exception of hot melt adhesives, are applied to a carrier in the form of aqueous dispersions or as a solution of solids in an organic solvent. The liquid components of the coating material subsequently have no functional purpose in the end product but serve only as aids to enable the creation of a uniform and smooth coating of the desired thickness.

In the coating process, the carrier is unwound and transported through the coating head and the dryer. Usually, dryers are constructed as convection units and have the purpose of evaporating the liquid components (“coating aids”), i.e. the solvent (aqueous or organic). After drying, in the simplest of cases, the finished product is rewound.

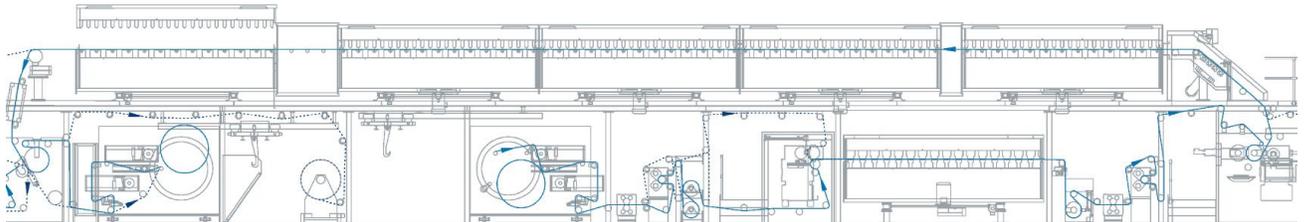


Fig. 1 Schematic illustration of a coating line.

The significance of the dryer as an important part of the production line is immediately recognisable in the schematic. The evaporation of the liquid components is a time-consuming and complex step in the processing of coating materials. Often the dryer is the limiting factor in the productivity of the total production line and this means that a very good understanding of the drying process is essential to the effective employment of the coating line.

This presentation is concerned with the typical construction and performance of convection dryers, which have found wide application in the drying of coated films. After dealing with the design of such dryers, the effects of adjustments to the different possible parameters for this type of dryer are described in practical terms.

A straight-through dryer consists of a number of identical sections placed one after the other (Fig 1), which can each be adjusted with different appropriate parameters. In Fig 2, one possible airflow pattern of a convection dryer is shown schematically.

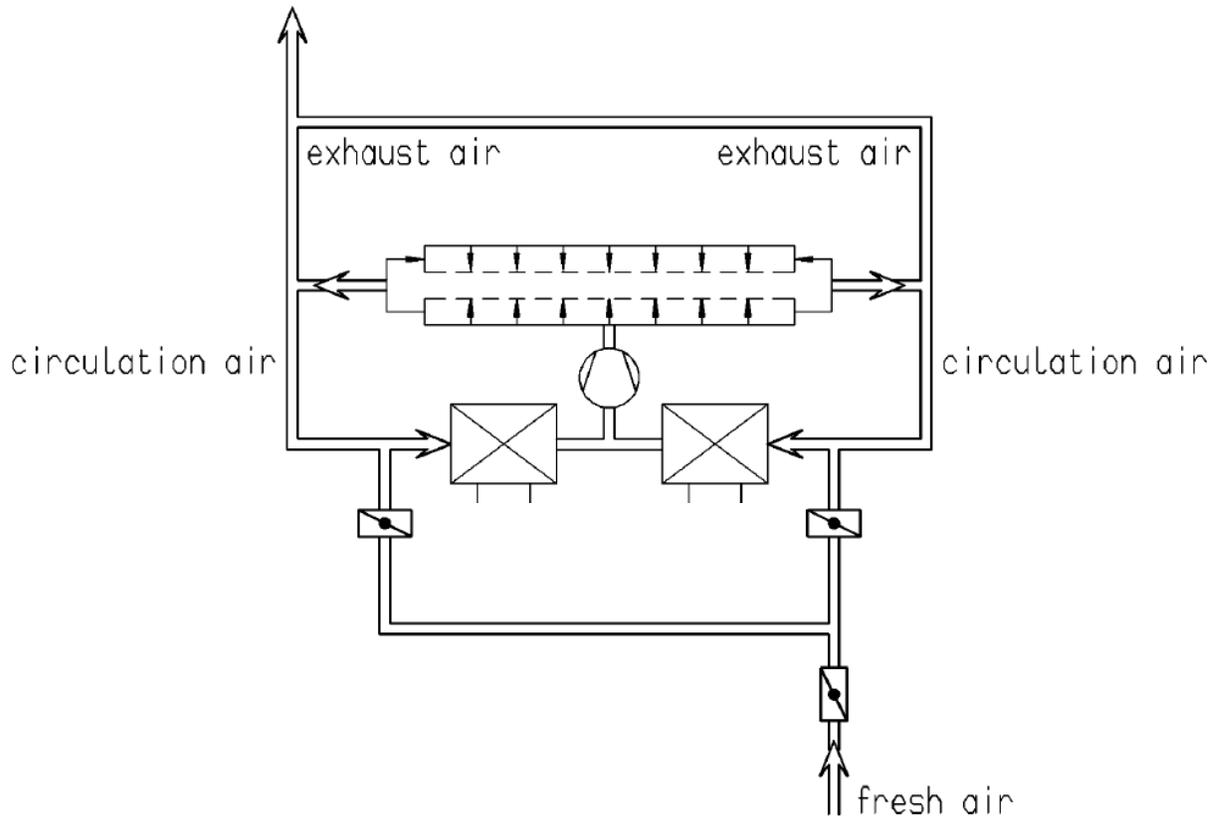


Fig 2: Schematic of the airflow in a convection dryer (Flowchart)

A circulating fan drives the air, which has been heated in a heat exchanger, via an air guidance system onto the product to be dried. The air warms the product on its upper side and, where applicable, also on the lower side. A certain proportion of the liquid evaporates and is carried away by the exhausting air. This exiting air is partly exhausted to atmosphere and partly mixed with fresh air and re-directed via the heat exchanger onto the product

So which direct influencing factors can be adjusted for the drying process and what are the resultant changes?

Fig. 3 shows a typical drying process during the evaporation of a liquid, which is applied to a substrate.

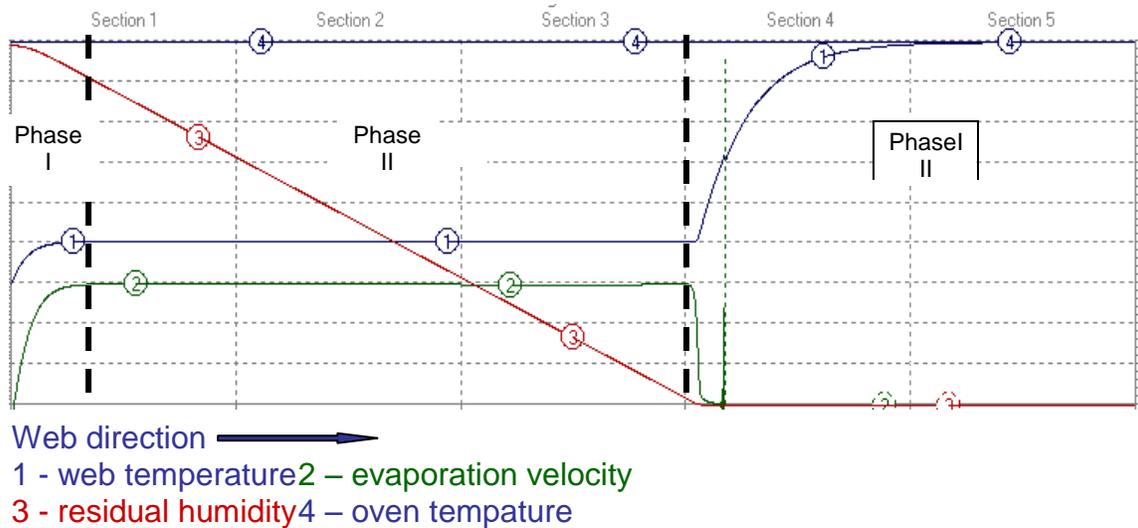


Fig 3: Drying sequence of a pure solvent material applied to a substrate in a straight-through dryer

The substrate and the coating enter the dryer as web at ambient temperature. In the dryer, warm air is directed via air nozzles onto one or both sides of the web. At first, the temperature climbs rapidly and then more slowly (Curve 1). The temperature difference between the air and the web causes the web to be warmed. As the material temperature increases, the vapour pressure in the coating liquid rises, causing the evaporation to start. On the one hand, the amount of heat which is transferred into the product decreases as the temperature difference between the air and the product falls (-> levelling of the curve), whilst on the other hand, heat is taken out of the coating by the evaporation of the liquid. These influences continue until an equilibrium is achieved and a balancing temperature is reached, known as the temperature of constant evaporation. If none of the boundary conditions such as air temperature, air velocity, air humidity is changed, this temperature will remain constant with further dwell time in the dryer until the liquid has been linearly dried out (see curve 3 in Fig. 3) .

This point is reached at the changeover from Phase II to Phase III.

In Phase III, the introduced heat serves only to raise the temperature of the substrate further, until the temperature of the air is nearly reached in the substrate.

Let us take the influences named above – air velocity, air temperature and air humidity and observe the qualitative changes in the drying process.

An increase in the air velocity results, after the equalization of the convective heat transfer (see Fig 4), in an increase in the heat transfer coefficient α .

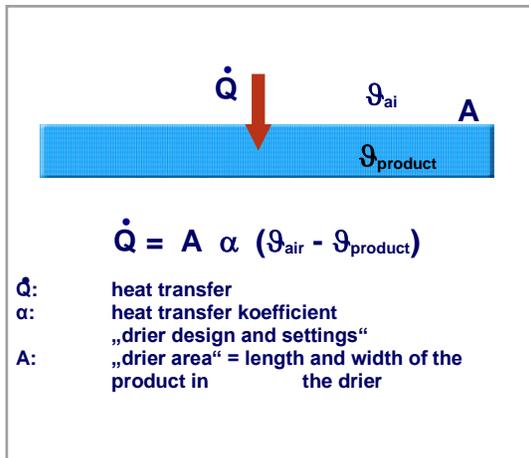


Fig. 4. Functional relationship of convective heat transfer

If, to supplement the qualitative representation of the three phases in drying of a pure liquid as in Fig 3, a variation of the heat transfer coefficient is effected, this leads to a resultant behaviour as shown in. Fig. 5.

Put simply, for an unchanged dryer design, this is the same as a variation in the air velocity. As a substitute for the product temperature, evaporation rate and residual moisture curves, only the product temperature is considered in the following group of curves.

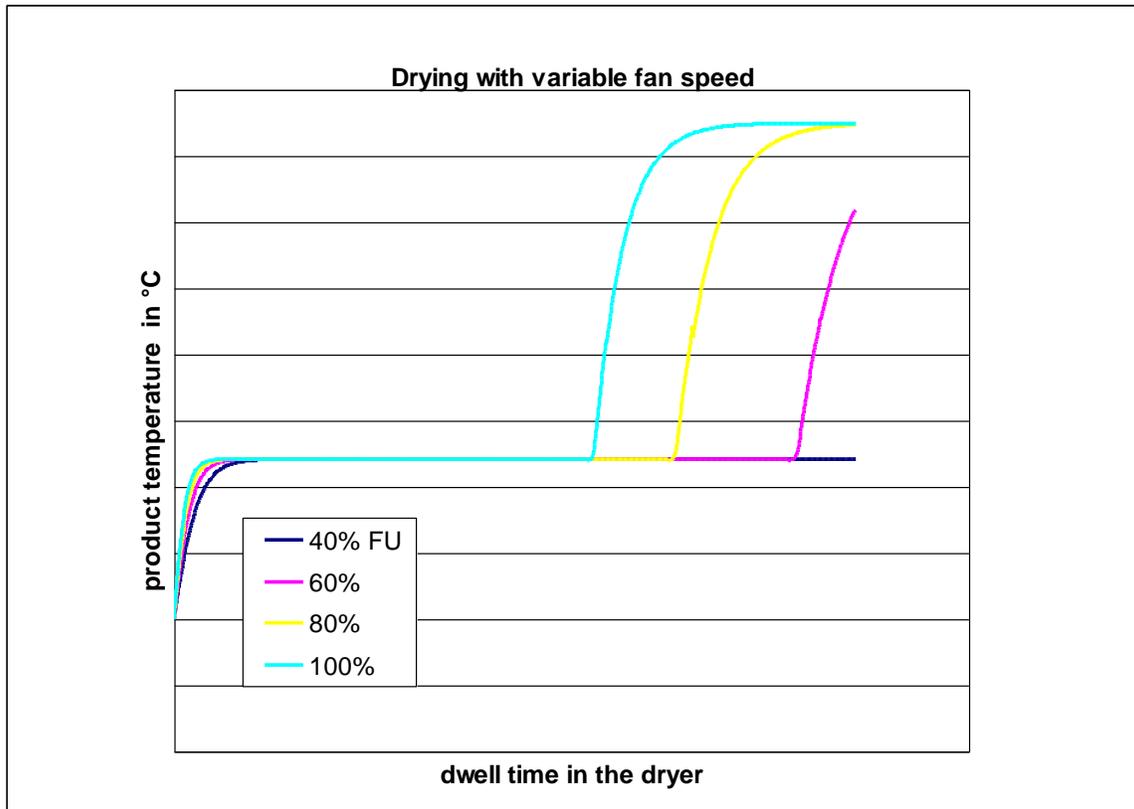


Fig. 5 Temperature curves for different heat transfer coefficients α

If α is increased, the material is warmed more quickly. Phase II, the area of constant evaporation rate at constant material temperature, is thus reached earlier. A higher evaporation rate is also achieved, which results in the drying process being completed more rapidly. In the example shown in Fig. 5, at the lowest value of 40% fan speed (FU), the heat transfer coefficient α is so low that the end of Phase II, ie the complete drying, is never reached.

This variation is always an option when the material cannot withstand a long a time at too high a temperature. This might be, for example, because of the strength of the carrier. An increase in the air velocity, however, increases the mechanical stress on the surface of the product, so here too, product-specific limits apply.

A change in the drying can also be achieved at constant air velocity by changing the air temperature, as shown in Fig .6.

In Fig. 6 drying curves at different air temperatures are shown.

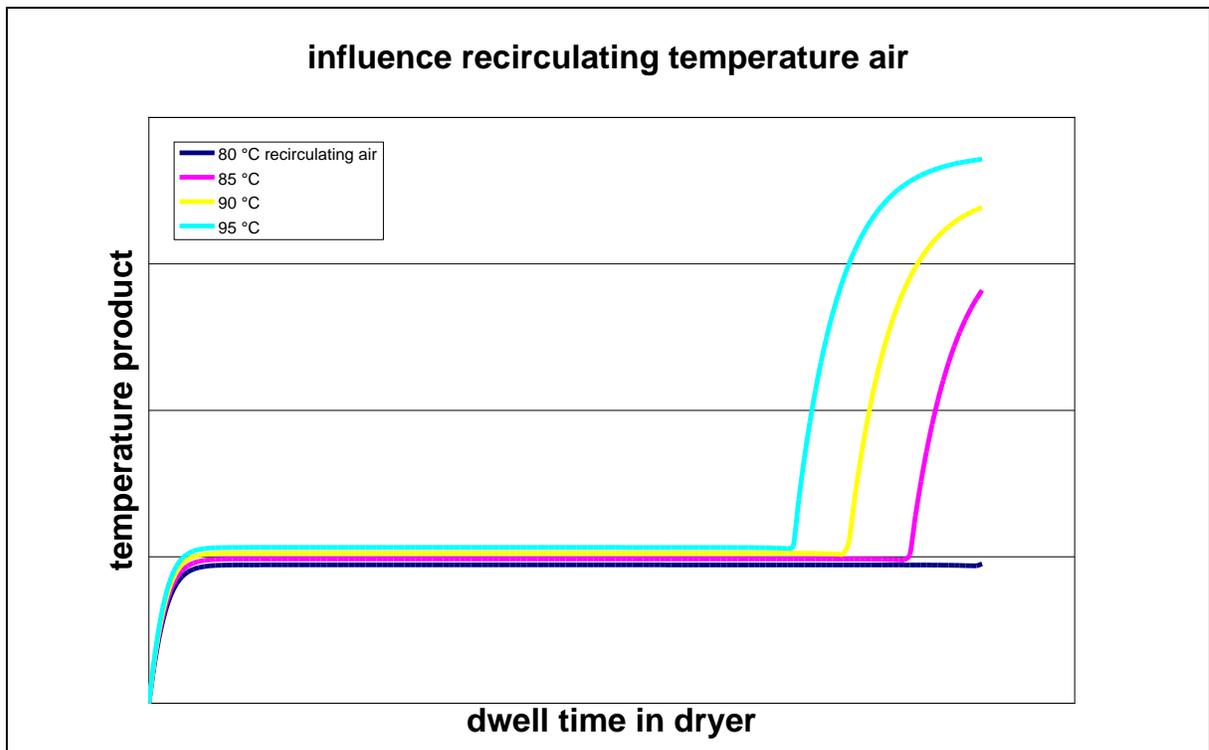


Fig. 6: Temperature curves for different air temperatures in the dryer.

Here, the temperature of the product similarly increases more quickly with increasing air temperature at the start of the process. The Phase II with constant temperature is reached at approximately the same time as in the previous example, although the temperature is higher at increasing air temperature. As would be expected, the total evaporative capacity is higher with increasing air temperature. If the material can withstand the higher constant evaporation temperature and if the coating is comparably mechanically capable, then an increase in the air temperature, rather than a higher air speed, is the preferred method to achieve a more rapid drying.

In this connection, the humidity of the air - in other words, the amount of solvent contained in the air flowing onto the material - has also to be considered. The phenomenon of the differing drying behaviour of water-containing products in summer and winter is generally well known. A cold winter night is better for drying than a “close” or sultry summer’s day. The reason for this is the relative humidity of the air.

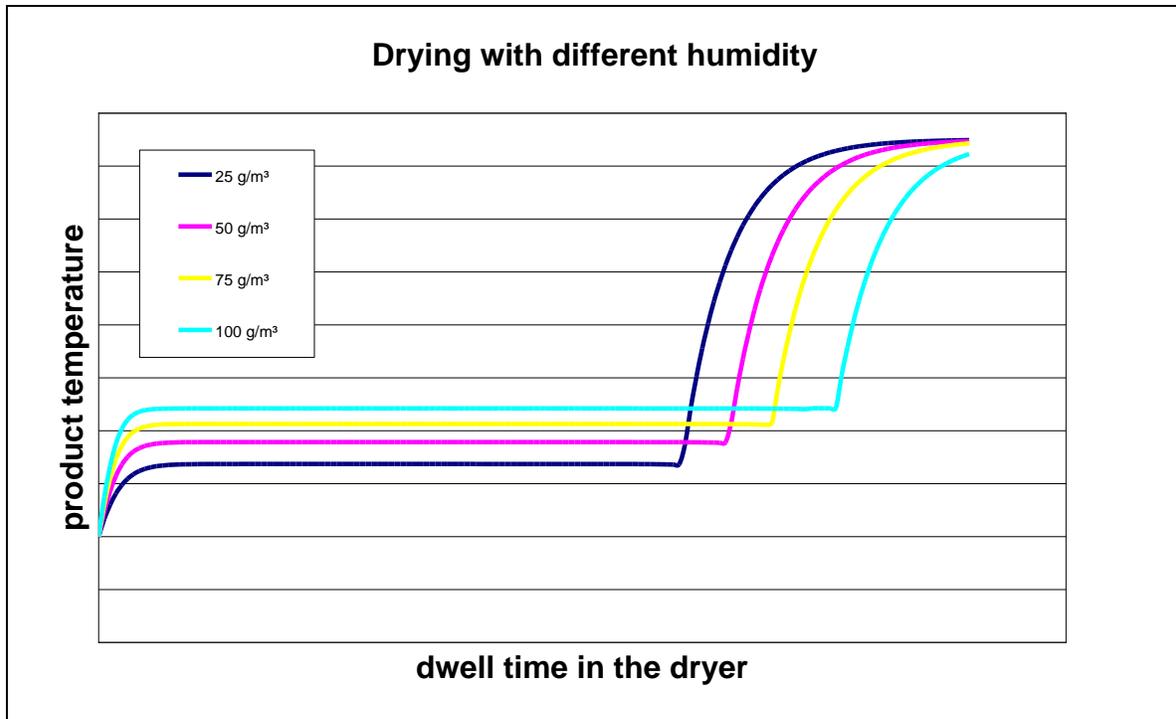


Fig.7: Temperature curves for different air humidity values

Related to our example, this means that for increasing air humidity the Phase I is shortened. In other words, the slope of the curve at 100 (g.solvent/m³ air) is greater than at 25 (g.solvent/m³ air). It should be noted, however, that at the increased air humidity, the evaporation rate is lower, as through less evaporation, less heat is taken out of the system. But because the same amount of heat is introduced to the material, the surface temperature of the product increases.

The reduced evaporation rate leads to a lengthening of the Phase II as the air humidity increases and thus the time necessary to achieve total drying of the coating is increased.

Under certain conditions, therefore, it can make sense to adapt the air humidity specifically to the drying application, whether by air conditioning or by altering the supply and exhaust air flow quantities.

So much, then, for the practically-based description of the drying of a pure liquid. For the majority of applications in coating technology, however, this analysis is not sufficient. In the adhesives industry, the actual product is a solid.

The technical counteractions in the drying of solvents and solids are more complex than the consideration of purely driving out solvents by drying.

In the advanced drying process of a nearly pure liquid, the characteristics of the solids in the coating play an ever increasingly important role.

To understand the drying it is necessary to take two phenomena into account. First, the effect of the solid on the surface and second an effect in the coated film itself.

The effect on the surface can be explained by the dilution of the solvent. During the drying process, the proportion of the solvent is reduced, the surface becomes drier and theoretically achievable partial pressure of the solvent at the particular temperature is no longer reached.

For this surface effect, we have already seen the influence of the change in the partial pressure reduction for a pure solvent. It is evident that, when the circulating air humidity rises, the evaporating velocity is reduced, when other conditions remain unchanged.

Here, the circulating air humidity is clearly not increasing, but the surface humidity is becoming less, which leads to reduced partial vapour pressure at the coating surface. A lower drying speed, dependent on the residual moisture is the result.

The second influence results from the necessity to transfer the solvent from the interior of the coating to the surface. This diffusion and also the diffusion speed is dependent on the quantity of residual solvent in the coating as well as the distribution of the solvent in the coating and the temperature of the coating itself.

Both these influencing factors result in a shortening of the Phase II - the area of the constant evaporation temperature - in the drying curves shown above.. Due to the continuing reduction in solvent on the surface and the differences in concentration of the solvent in the applied coating mass, an asymptotic residual humidity curve results. In Fig. 8, the developments of temperature and residual moisture of a typical water-dispersed adhesive compared to the curve without solids but with identical solvent quantity are shown. Whilst the drying of the pure solvent occurs constantly and without surface effects and in this case is also actually complete at the end of the dryer, it can be seen by examining the solid and the corresponding effect on the drying, that the Phase II is very much shorter (compare also Figs.5 -7). Furthermore, the residual moisture no longer reduces linearly, but finalises asymptotically down to a residual moisture level, which is not zero and which is known as the equilibrium moisture value.

drying ideal liquid vs. real dispersion

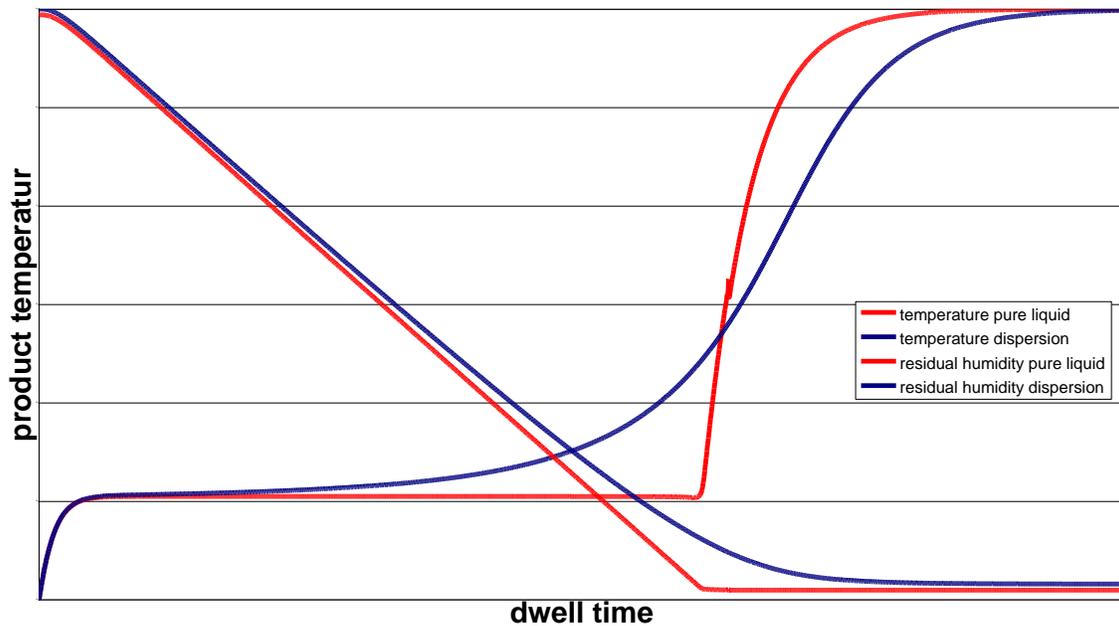


Fig.8: Comparison between drying of a pure liquid and an aqueous dispersion.

The equilibrium moisture value is dependent on the binding energy of the liquid in the solid and on the ambient humidity.

Today, thanks to a knowledge of a range of values for the solids in the particular adhesive, it is possible to make very good predictions about the optimal settings of the individual dryer sections and thereby to minimise both the drying time and the number of drying defects that occur.

In the foregoing presentation, it was explicitly intended to reduce the mathematics of the drying process to a minimum and to give those who are involved daily a practical summary of the possibilities for configuring a convection dryer for their individual products.