Drying of Barrier Coatings

Blistering Free and Fast Drying of Barrier Coatings

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Coat drying is a critical part of paper making. Particular difficulties arise when drying barrier coatings, as the drying process also creates the barrier effect. If there is still water below the formed film on the surface of the functional coating, it will later - but usually earlier - damage the surface as soon as it evaporates. Therefore, the correct drying curve is an essential part of drying barrier coatings. In most cases, the production speed has to be reduced considerably in comparison to normal coatings, as barrier coatings often have a very high wet coat weight. In special cases, the production speed is only a third or even a quarter of the normal speed.

If, on the other hand, the barrier coating is dried optimally starting from the initial sediment layer, there is no premature film formation on the surface and all the water can be evaporated without subsequently damaging the barrier.

We show the physical principles of drying and their influence on the drying of barriers, but also on coatings in general; and we show how the operating window can be considerably widened, especially in terms of production speed.

1. Introduction

Very long hot-air hoods are often used to dry barrier coatings in order to slowly heat the coating and prevent premature film formation. The disadvantage is the size of the machines and the low production speed. Most manufacturers of barrier papers have already found that gas-powered infrared emitters are counterproductive. Electrically operated infrared emitters are the tool of choice, but here too there are different concepts with distinct energy efficiency.

Compact Engineering has developed special infrared lamps which allow coatings to be dried starting with the initial sedimentation layer and which are particularly energy efficient. With barrier coatings, high production speeds can be achieved without compromising on paper quality. The cost efficiency is similar to the efficiency of gas-powered infrared emitters.

This article examines the physical principles of drying coatings, but in particular those of functional coatings, which are typical for barrier papers. At the same time, it is shown how dryers specifically developed on the basis of these physical laws extend the narrow operating window for papermakers in the production of barrier papers.

In addition, an application case for drying a special coating based on a polyvinyl alcohol is presented.

2. Difficulties in Barrier Drying

Barrier coatings are particularly difficult to dry, and papermakers often complain about the small operating windows of their coaters. In addition to the difficulties of normal coat drying, there is the problem that the drying of the coating activates the barrier. If the surface dries too quickly, it films prematurely and further water cannot be evaporated through the barrier. However, the water under the film will later - or usually earlier - make its way to the surface and escape through the barrier. The result is micro blistering.

For this reason, drying with hot air hoods has become the established method nowadays, in which the surface temperature is increased very slowly by means of low production speeds and long dryers. Thus the temperature in the coating can slowly equalise itself. This prevents premature filming at the expense of low production capacity.

It has already been discussed among manufacturers of barrier papers that gas-powered infrared dryers installed in front of the hot-air hoods should not be used in coating machines in order not to endanger the quality of the barrier. However, most users are unaware of the physical principles involved.

3. Physical Principles of Drying

Drying is a two-step process. In the first step energy is transferred to the material to be dried, in the second step the evaporated solvent is removed. In paper making and coating, water is used as the solvent. Ideally, when the water evaporates, most of the energy is removed from the material to be dried - paper or coating.

The energy transfer can take place in different ways:

- Heat Conduction: in papermaking, this is done by steam-heated drying cylinders whose hot surface heats the material to be dried in direct contact. This is the most effective way of transferring energy, but can only be used for coatings once they have reached their immobilisation dry solids.
- Radiation: this is done either by infrared or microwave, the latter being difficult to use on an industrial scale. Radiation is normally the most expensive form of energy transmission, but in special applications it is the most energy-efficient.
- Convection: by means of a transmitter such as air, water, or oil. The latter two are not suitable for drying. In paper industry, typically hot air is used. Hot air drying is the most cost-effective way of transferring energy, but less efficient than heat conduction.

3.1. Coat Drying by Means of Hot Air

Hot-air hoods are used after the coating head, which blow dry, warm air onto the surface of the material to be dried and simultaneously exhaust the moist air again. The main disadvantage of hot air drying is that it only heats the surface of the material to be dried. Therefore, during coat drying, care must be taken to ensure that the temperature rises slowly enough in the passage under the drying hoods to control migration into the substrate and avoid mottling. If the surface is heated too quickly, the liquid phase of the coating flows too quickly into the substrate. This is especially a problem as the basis weight increases.

With barrier drying, the temperature increase must be slower than with normal coat drying. Heating of the surface must be slower than heat conduction within the coating. Otherwise, the coating surface heats up too quickly, which leads to a depletion of water on the surface. On the other hand, the film formation temperature of the barrier chemicals is reached. Both together lead to a film formation of the barrier at the surface and thus to a dramatic reduction of the water permeability - which in many cases is the purpose of the barrier. The water trapped under the barrier will later make its way to the surface in the course of further drying and thus lead to micro blistering.

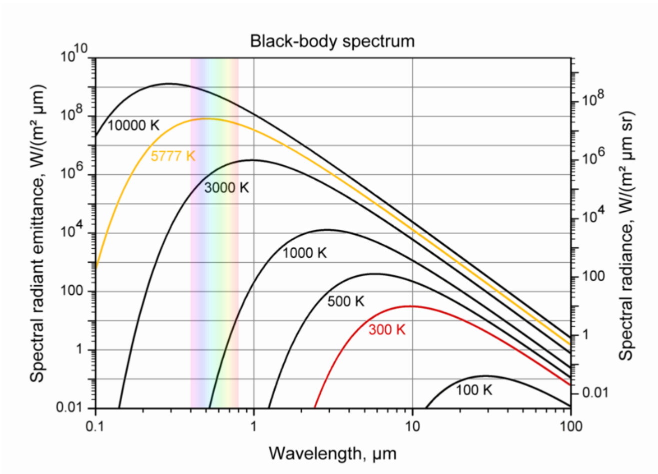
3.2. Coat Drying by Radiation

In coat drying, infrared radiators are therefore frequently used in front of the hot-air hoods in order to immobilize the coating more quickly and to introduce energy below the surface into the dry material. Both, gas-operated as well as electrically operated infrared emitters are in use.

3.2.1. Radiation spectrum of different infrared emitters

The radiation of the different infrared dryers differs both by their wavelength and their black body temperature. The radiation generated by the lamps belongs to the electromagnetic radiation. In the wavelength range it is adjacent to the visible light. Infrared radiation is usually divided into three [1] to five [2] bands:

- Near infrared NIR or IR-A: contiguous to visible light at 780 nm to 1.4 µm wavelength, corresponding to a black body temperature according to Wien between 3,700 K and 2,070 K;
- Shortwave infrared SWIR or IR-B: between 1.4 µm and 3 µm wavelength, temperature between 2,070 K and 966 K respectively;
- Medium wave infrared MWIR or IR-C: between 3 µm and 8 µm wavelength, with a temperature according to Wien between 966 K and 362 K;
- Longwave infrared LWIR or IR-C: between 8 µm and 15 µm, with temperatures from 362 to 193 K; as well as
- Far infrared FIR or IR-C: between 15 µm and 1,000 µm with a temperature between 193 and 3 K.



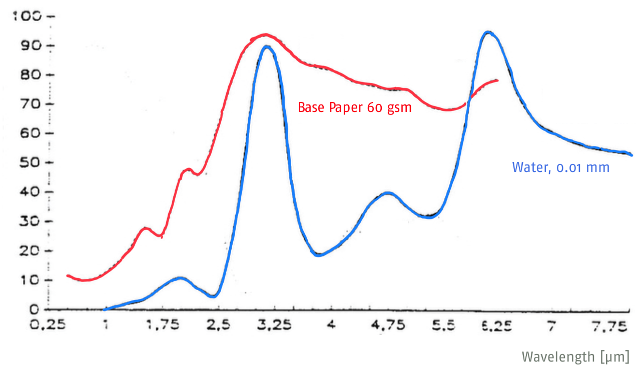
Ill. 1: Planck's radiation spectrum for different blackbody radiators, with spectral specific radiation and spectral radiance.
Yellow: radiation of the sun, red: radiation of the earth on a sunny day.

With one exception, electrically operated infrared emitters have their maximum radiation at a wavelength of 1.18 µm in the near infrared, at a blackbody temperature of about 2,450 K. Gas-powered radiators operate, depending on the version, at peak wavelengths between 2.5 µm to 3.5 µm, i.e. in the transition between shortwave and medium wave infrared, at absolute temperatures between 1,160 and 830 K. Optimized electric emitters have their maximum power in the short-wave infrared at 1.45 µm wavelength, corresponding to a temperature of around 2,000 K.

The shorter the wavelength, the higher the radiation intensity, which according to Stefan-Boltzmann's law increases with the fourth power of the absolute temperature. A doubling of the temperature means a sixteenfold radiation density. A higher temperature would therefore result in better drying if radiation were the only relevant factor.

3.2.2. Absorption of Radiation

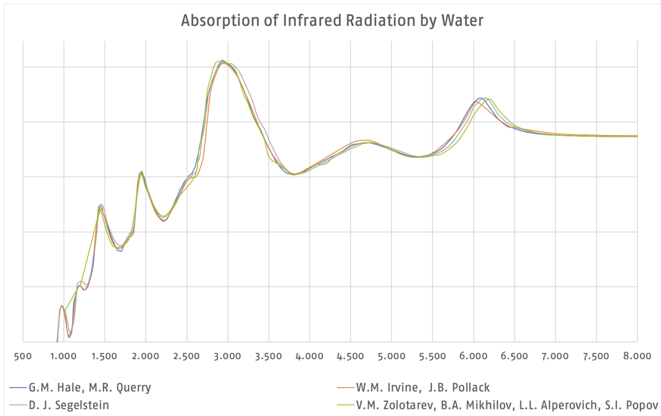
The radiation is only the first of four steps of the drying process. The absorption of this radiation by the substrate and the coating has a considerable influence. Essentially, the hydrogen bond between water molecules, water and coating components or water and cellulose fibres is stimulated by infrared radiation.



Ill. 2: Absorption of infrared radiation by a thin water layer and coating base paper [3]

In 1991 Helmut Graab published the absorption of infrared radiation by a thin layer of water with a thickness of 10 µm and a coating base paper, comparing different emitter systems in coat drying. As can be seen in illustration 2, water has a very strong absorption at a wavelength of about 3.25 µm and 6.10 µm. In the near infrared range, the peak at 1.45 µm is missing in his graph, but it is listed for the substrate.

This peak in the near IR range is well documented in other publications (see ill. 3).

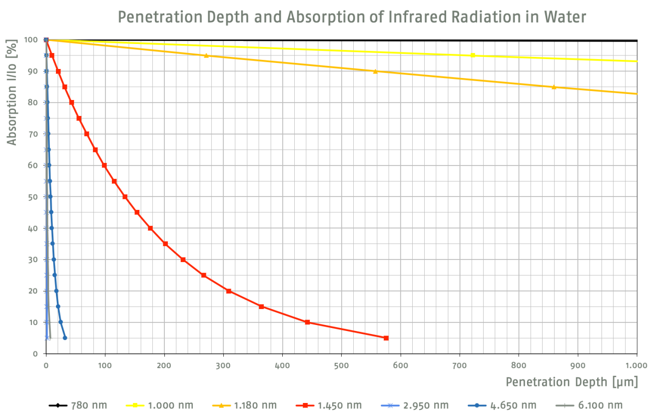


Ill. 3: Absorption of infrared radiation by water as a function of wavelength [4 5 6 7]

For the drying of barrier coatings, those wavelengths that excite hydrogen bonds are the main contributors to drying. The absorption of infrared radiation by water is therefore exemplary for coat drying. The various published values show that radiation with wavelengths smaller than 1.3 µm only converts negligible radiation into heat. Any light emitted below this wavelength does not contribute to drying.

3.2.3. Penetration of Radiation into Coating and Substrate

The radiation and its absorption are only the first steps in the drying process, the most important factor, especially in the drying of barrier coatings, is the penetration depth of the radiation. It depends strongly on the wavelength of the radiation. In principle, the penetration depth is very low at those wavelengths where radiation is very strongly absorbed. Already in the uppermost layers, the radiation is absorbed by the hydrogen bonds between water molecules. This relationship is described in Lambert-Beer's law and shown in illustrations 4 and 5 for selected wavelengths.



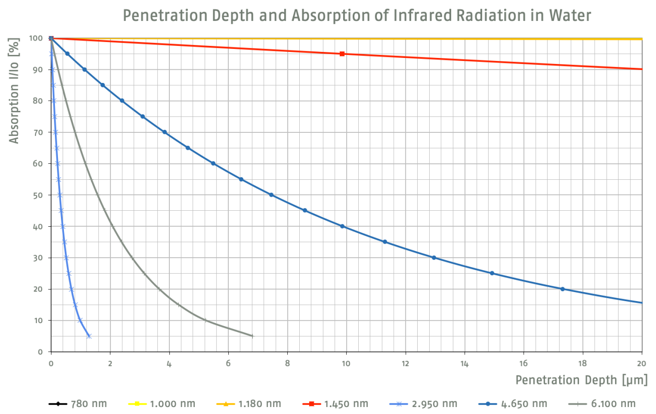
Ill. 4: Penetration depth and absorption of infrared radiation by water for selected wavelengths of conventional and optimized electric emitters, penetration depth 1,000 µm

The average penetration depth for dome shaped emitters is shown, i.e. not only the rays which hit the water exactly perpendicularly but the integral of the rays are taken into account.

Illustration 4 shows very clearly that red light (780 nm) at the border to infrared penetrates very deeply into the water and is hardly absorbed. Infrared light with a wavelength of 1,180 nm - on which commercial electric emitters radiate their maximum - also penetrates very deeply. At a depth of 860 µm, only 15% of the radiation is absorbed by the hydrogen bonds and converted into heat. 80% of the radiation of optimized electric radiators, which have a maximum power at a wavelength of 1,450 nm, is absorbed at 310 µm depth.

Illustration 5 exhibits the penetration of selected wavelengths of infrared radiation within the first 20 µm depth. It can be clearly seen that 80% of the medium wave infrared radiation with wavelength of 2,950 nm - at which water has the highest absorption of infrared radiation - is already absorbed at 0.7 µm depth. At the second relevant peak of MIR, at 6,100 nm, 80% of the radiation is absorbed within a depth of 3.6 µm. At the third peak of the MIR spectrum, at wavelengths of 4,650 nm, 80% of the radiation is absorbed within 17.3 µm.

On average, 80% of the energy of gas-powered infrared radiators is absorbed within the first 3 µm. In practice, this leads to a strong heating of the surface of the coating. The radiation hardly manages to penetrate into deeper layers, the substrate is virtually not heated. With a PVA-based barrier coating of 15 to 20 g/m^2 wet coating weight, only the top 15% to 20% of the coating is heated. This leads to a depletion by water and thus to premature film formation on its surface. At a later stage, when the water under this film is evaporated by the following hot air hoods, it will reach the surface through the formed film and destroy the barrier.



Ill. 5: Penetration depth and absorption of infrared radiation by water for selected wavelengths of gas-powered emitters at penetration depth 20 µm

3.2.4. Efficient Evaporation

The fourth step of the drying process is the most important, the evaporation of the heated water - only then the drying process will be complete. A very thin laminar layer lies on the sheet, which moves with the web at production speed. If this layer is saturated with water vapour, no more water can be evaporated from the coating and substrate. It is therefore essential to disturb this laminar layer in a turbulent manner during the energy supply in order to dissipate as much water vapour as possible.

4. Blister Free Drying of Barriers

For fast immobilization of the initial sediment layer of the coating, a radiation with the shortest possible wavelength that can be absorbed must be selected in order to release the largest part of the energy to the substrate and only the smallest part into the coating to prevent premature filming.

At the same time, care must be taken to ensure that as little as possible of the energy with a wavelength of less than 1.3 µm is transferred, as this part of the energy does not contribute to heating and evaporation. Optimally, a large part of the energy is released at wavelengths between 1.4 µm and 1.8 µm.

If the substrate is heated efficiently, drying of the barrier (like any other coating) starts from the initial sediment layer. The film formation of the barrier is only completed when all the water has evaporated. This happens last on the surface of the coating. The dryers must be able to dissipate more water vapour than is generated by heating the water in order to prevent a rise in temperature to film formation temperature, regardless of humidity.

Compact Engineering has developed its XenTec dryers in such a way that at full load the maximum energy is released at a wavelength of 1.45 µm. Losses at wavelengths less than 1.3 µm are kept to a minimum, while at the same time very deep penetration into the substrate is guaranteed. Typically, three quarters or more of the energy heats the substrate. Compared to conventional electric lamps, in which only around 35% of the electrical energy used is absorbed by the coating and converted into heat, XenTec lamps convert well over 60% of the electrical energy used to heat the water in the substrate and coating.

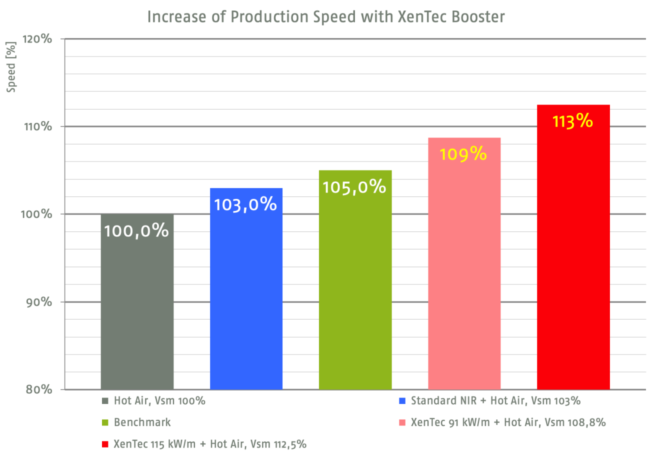
At the same time, the laminar boundary layer is replaced by hot, dry air before the radiant energy is applied in order to increase evaporation. Under the emitter, the laminar layer is turbulently disturbed with impingement air and the laminar layer is replaced again directly after the emitter. Saturation of the laminar boundary layer is thus successfully avoided. This means that the XenTec dryers can theoretically evaporate more water than is heated by the radiation. This contributes to the cooling of the coating so that even difficult coatings, such as thermo coatings - despite the extremely high energy density of the radiators - are not heated above a critical temperature but cooled by the evaporation enthalpy.

To optimise cost efficiency, this XenTec dryer is ideally placed as a booster in front of the hot air hoods to make their work easier and to leave the main evaporation to the more economical hot air.

5. Application Case

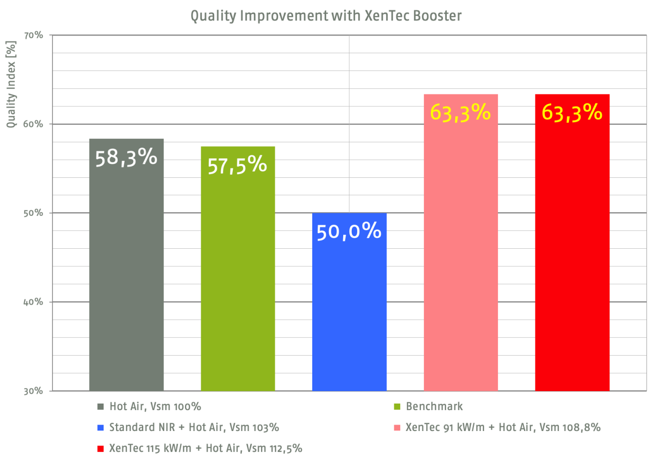
PVA-based Barrier Coating

A typical barrier coating based on a modified high-viscosity PVA with a coating weight of 1.2 g/m^2 and a solids content of 8% - thus a wet coating weight of 15 g/m^2 and a layer thickness of about 15 µm - must be dried. The coating machine has several coating heads on both sides of the paper. So far, only hot-air hoods that are quite long have been used. Nevertheless, the drying of the barrier coating is the bottleneck of the production. In some cases the production speed is 60% to 70% lower than with normal coatings.



Ill. 6: Speed gain with XenTec Apollo as booster in front of the hot air hoods.

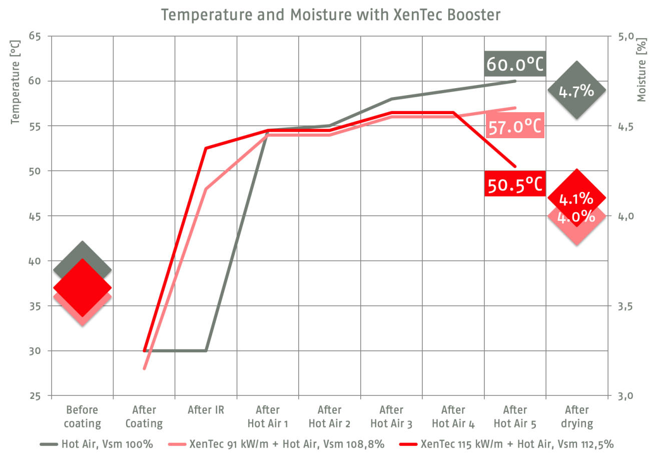
A XenTec Apollo was used as a booster between the coating head and the hot air hoods, as well as a ventilated reflector on the reverse side to minimise radiation losses. A little more than 50 cm of installation space is required in the machine direction.



Ill. 7: Quality improvement by drying starting from the initial sediment layer and preventing premature filming of the surface.

The XenTec Apollo has an output of 160 kW/m, and evaporates as much as conventional infrared lamps with 320 to 350 kW output. This was preceded by various experiments with infrared emitters to increase performance. It was known that gas-powered burners were disadvantageous. With a conventional electric emitter the speed could be increased by 3%. At higher output, the quality of the paper was impaired because this emitter did not allow the immediate evaporation of the water. For a reasonable payback period the speed would have had to be increased by at least 5%. With the XenTec Apollo, an increase in production speed of 8.8% and 12.5% was achieved at 91 kW/m and 115 kW/m respectively (Fig. 6). The overall quality did not drop, but even improved (see Fig. 7).

This is due to the temperature curve during drying: the maximum temperature remained 3°C or even 9°C below the temperature achieved with the exclusive use of drying hoods. Humidity has also been reduced by 0.5%. Sign that the production speed can be further increased - but boosters must now be used on the other coating heads for this purpose.



Ill. 8: The heating of the substrate facilitates the work of the hot air hoods. These can evaporate much better if drying is started from the initial sediment layer. Efficient evaporation cools the coating.

The essential critical point is the cooling of the coating by the very timely evaporation during the warm-up phase. The thermography of an experimental installation (Fig. 9) clearly shows that a high energy input - and thus evaporation performance - is possible if heat is extracted from the coating and substrate as quickly as possible. With an appropriate drying concept, it is even possible to achieve a considerably lower temperature at the reel (see Fig. 8) and prevent blocking, which is particularly common with heat-sealable barrier papers.

This prevents premature film formation and thus damage to the barrier.

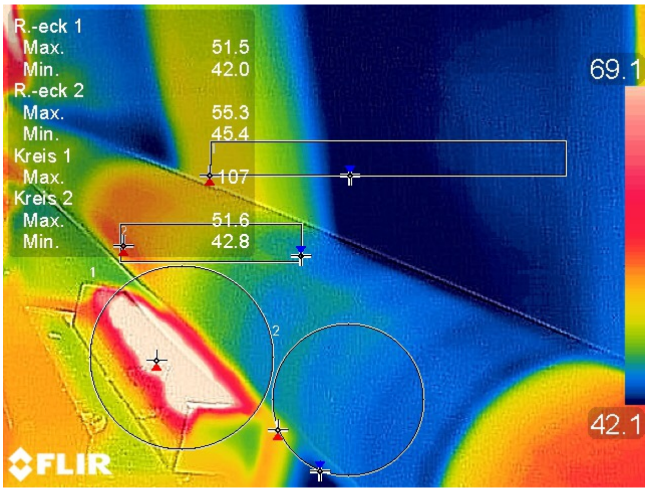


Abb. 9: Thermography of a test installation with XenTec Apollo as booster after a barrier coater (R.-eck 1 = square 1; R.-eck 2 = square 2; Kreis 1 = circle 1; Kreis 2 = circle 2).

On the thermal scan it becomes clear that the XenTec Apollo heats the coating by only around 9°C, despite the high energy input. In the example shown, this means an increase in production speed of a whopping 20%. This is ensured by drying from the initial sediment layer, which allows the heated water to evaporate optimally towards the surface.

6. Summary

The challenges for the papermaker in the production of barrier papers lie in the restrictions in drying and the associated small operating window of the production facilities. The drying of the barriers leads to their filming and thus to reduced permeability for water and vapour.

If the mentioned physical conditions are correctly implemented, they considerably extend the operating window. Selecting the right wavelength and thus the optimum penetration depth and absorption of the radiation, as well as the simultaneous removal of the evaporated water, the barriers are dried from their initial sediment layer, thus preventing premature filming of the surface.

Ideally, the suitable infrared dryer is used as a booster in front of the hot-air hoods. This permits achieving higher production speeds, better cost efficiency and optimal product properties of the paper.

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