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Scheuter, Karl R.; Dosdoğru, Günay

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INVESTIGATION OF IMPINGING AIR JET DRYERS WITH RESPECT TO POSSIBLE AUTOMATION

Karl R. Scheuter* and Günay A. Dosdogru*

Summary: A survey is given on investigations concerned with drying problems of gravure and flexo printing, pertaining also to offset printing in cases where mainly physically drying inks are used.

On the one hand the investigation includes the aerodynamic optimization of impinging air jet dryers, on the other hand the drying behaviour of solvent based inks on an imprinted material.

For an optimization of the dryer the knowledge of the local heat -or mass- transfer coefficient under various conditions is necessary. The local heat-transfer coefficient was measured by means of an automatical, very fast working measuring method, which will be reported upon below. On the basis of some measuring results it will be shown in which way an optimization is possible.

The drying behaviour of the printing inks is characterized by the decrease of solvent as a function of dryer length for a given air temperature and air velocity. The content of residual solvent in the material to be dried is a criterion for the actual state of drying. The measurement of the residual solvent content is carried out by means of an infra-red spectrophotometer. Thereby the imprinted web is scanned continuously directly behind the dryer. For this purpose suitable isolated infra-red absorption peaks had to be found by means of the infra-red spectrograms of the com-

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*Institut für Druckmaschinen und Druckverfahren der Technischen Hochschule Darmstadt (Institute for Printing Machines and Printing Processes of the Technical University Darmstadt/Germany)

bination of printing ink and printing substrate. Examples of infra-red spectrograms of some actual production gravure inks as well as of paper and plastic film as printing substrates are indicating that the determination of the solvent contents by infra-red techniques is possible nearly always for any material combination.

Finally proposals are being presented for a possible future development of an automated drying control system by application of an infra-red scanning device. By means of this scanning method, additional temperature measurements on the web and a simple computer the dryer air velocity, the dryer air temperature and the amount of exhaust air could be controlled to obtain always optimum drying conditions.

Significance of Drying Process on Press Performance

Modern rotogravure and web offset presses are mechanically able to run at very high speeds. In actual printing operations, however, quite often the press speed has to be reduced considerably either to match the limited drying capacity of the dryers or to avoid unwanted side effects on the printing substrate respectively the printed product. thus in many cases the press is running at drying speed rather than press speed. In order to increase the efficiency of the press it is therefore absolutely necessary to speed up the drying operation without impairing the quality of the final printed product.

Basically the drying rate can be increased by raising either the air temperature or the air velocity. Increased air temperatures automatically are leading to increased paper temperatures - and, by loosing part of its moisture the paper experiences dimensional as well as stability changes, impairing the runnability of the paper web. Therefore a temperature increase is not advisable.

Another approach to speed up drying without raising the air temperature would be to extend the dryer length at otherwise constant drying conditions. Since this solution would involve a very long web lead its application is only limited.

Modern gravure and flexo presses as well as many offset presses are equipped almost exclusively with dryers based on the principle of high velocity air impingement. The following presentation will deal exclusively with such impinging air jet dryers. Experience made with these dryers indicates an extremely careful drying of the material. In order to obtain optimum results, these dryers still have to be improved.

Since next to the temperature the velocity of the jet component parallel to the web is of great influence on the drying rate, the question arises for an aerodynamic optimization of the impinging air jet dryer.

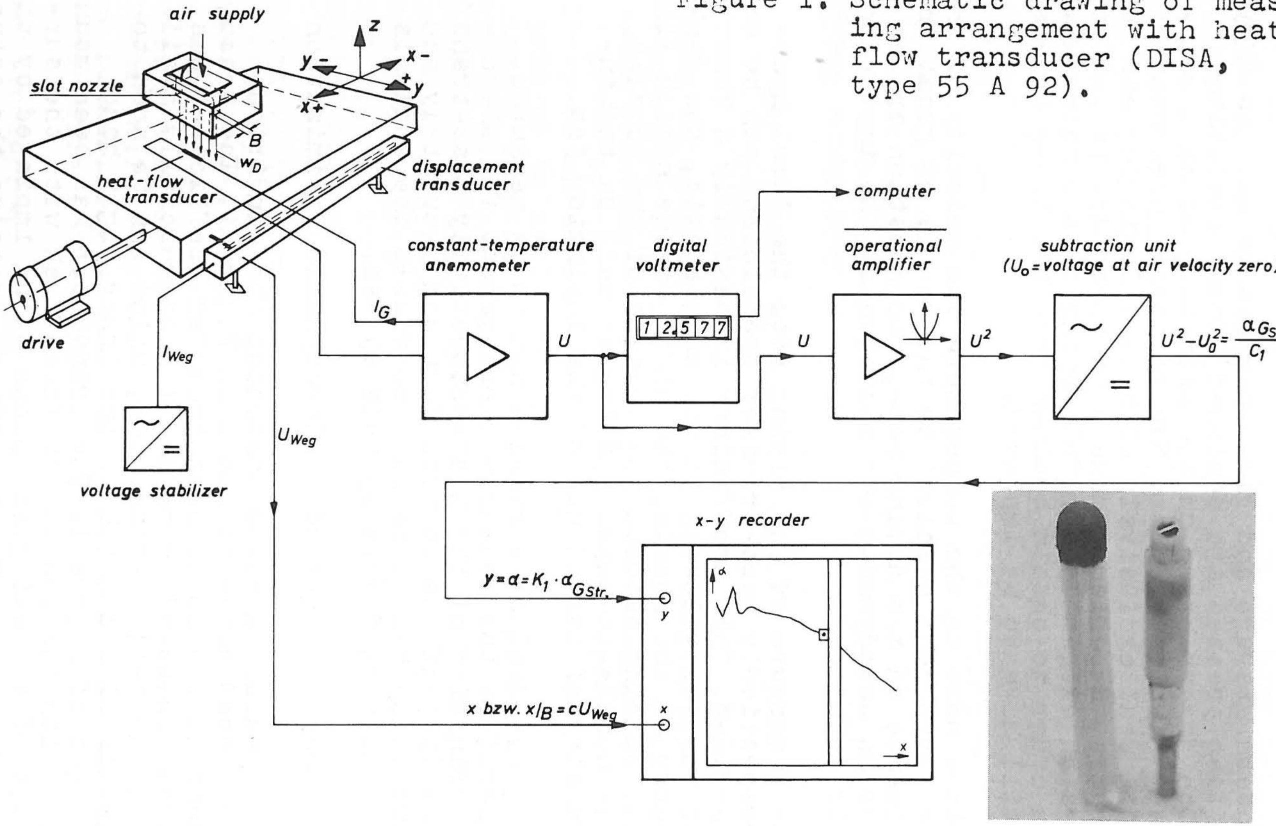
As a measure of the drying rate the local heat-respectively mass-transfer coefficient can be determined. This coefficient is basically a function of the jet velocity at the nozzle exit, the geometry of the nozzle, the width of the nozzle slot, the spacing between the centers of the nozzles, the nozzle-to-paper spacing as well as the intensity of turbulence of the impinging jet.

A great deal of variables has to be measured. Therefore the measuring arrangement for the determination of the heat-respectively mass-transfer coefficient has to work fast and accurately and provision has to be made to enable the analysis of existing dryers by this system.

Measuring Method of Aerodynamic Optimization

The measuring method matching the conditions mentioned above is shown in Figure 1. The measurement of the local heat-transfer coefficient has been conducted by means of a commercially available heat-flow transducer, which can be seen together with a match in the lower right hand corner of Figure 1. The transducer has been mounted with its sensing surface flush with the surface of a plexi glass plate being impinged by the air jet dryer. The transducer contains the actual measuring element, an electrically heated hot-film with an active width of o.25 mm, whereas

Figure 1. Schematic drawing of measuring arrangement with heat-flow transducer (DISA, type 55 A 92).



the plate itself is not being heated. Its heat-transfer coefficient is a measure for the effective heat-transfer coefficient of the plate.

The heat-flow transducer has been connected to a commercially available constant-temperature-anemometer (DISA). The square of the output voltage of the anemometer is proportional to the specific heat-transfer coefficient of the transducer. This value is multiplied by a constant gage factor (in this case e.g. K=1/13), and finally we obtain the effective local heat transfer coefficient of the plate at forced convection. In the measuring set up this calculation is being carried out automatically by means of an operational amplifier. In order to determine the lateral variation of the heat-transfer coefficient the plate with the transducer was equipped with a variable speed drive to traverse the flow field of the nozzles. The position of the heat-flow transducer was determined by a displacement transducer, generating a voltage proportional to the displacement. Finally the heat-transfer coefficient $\alpha = f(x)$ was recorded by an X-Y-recorder as a function of the lateral distance (x) from the stagnation point. By means of this measuring arrangement it was made possible to measure and record the lateral variation of the local heat-transfer coefficient fully automatically over a length of e.g. 500 mm within 10 to 15 minutes. The influence of the turbulence on the local rate of heat-transfer can be determined qualitatively by the amplitude of the 'oscillation' being observed at the recorded curve. The anemometer can be further used in connection with a hot-wire transducer for measuring the intensity of turbulence in the air jet. Thus it is possible to determine the heat-transfer coefficient, the turbulence as well as the jet velocity with one basic test set up. Further details on the test procedure, calibration and test arrangement can be found in the reference Scheuter and Dosdoğru (1970b).

Selected Results of Aspects of Aerodynamic Optimization

The local heat-transfer coefficient respectively mass-transfer coefficient of two-dimensional impinging jets so far has been investigated by Korger and Křižek (1966), Gardon and Akfirat (1965, 1966), Krassnikow and Danilow (1965), Schlünder, Krötzsch and Hennecke (197o) and Martin and Schlünder (197o).

In these references part of the influencing parameters has been taken into account and certain criteria of optimization can be deducted. Other parameters, however, such as nozzle geometry and turbulence, have been mentioned only seldom.

Gardon and Akfirat (1965, 1966) probably were so far the only ones to report on the influence of turbulence on the rate of local heat-transfer of two-dimensional air jets. According to our own investigations the nozzle geometry and the jet turbulence are of the utmost importance for the aerodynamic optimization of the drying process. Therefore in this paper these influence parameters shall be dealt with exclusively.

In order to specifically study the influence of turbulence on the rate of heat-transfer at otherwise equal boundary conditions, first of all air jets of particularly low turbulence had to be generated. The intensity of turbulence of the air flow is being determined mainly by the geometrical configuration of the nozzle. For this purpose slot nozzles were built with profiles calculated for an adiabatic expansion, assuming a constant pressure gradient along the centerline of the nozzle. Two types of nozzles were studied: nozzle type 1, milled into the bottom plate of the plenum chamber, and nozzle type 2 having a long out-flow. (Dosdoğru 1969, Scheuter and Dosdoğru 197oa) With both nozzle types unexpectedly low intensities of turbulence could be observed - at the nozzle exit as well as at the centerline of the jet. At the exit of the nozzle the average intensity of turbulence was found to be o.5 percent and e.g. at a spacing nozzle-to-plate z' of quadruple width of the slot nozzle - i.e. at z'/B=4 - to be usually 2.5 percent. Thus the intensities of turbulence of these nozzles were considerably lower than those of usual nozzles.

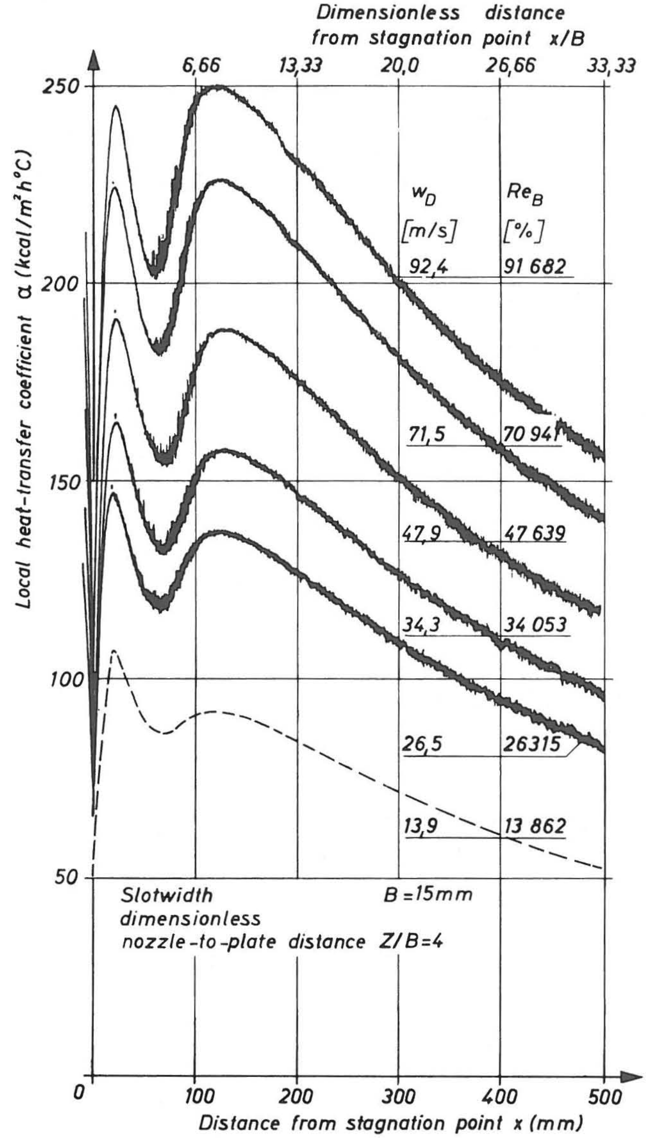


Figure 2. Lateral variation of local heat-transfer coefficients α at various nozzle exit velocities w_D respectively Reynolds numbers $Re_B = w_D B/\nu$. (nozzle type 1/15)
The dotted curved has been taken from another series of measurements.

The variation of the local heat-transfer coefficient as a function of the lateral distance from the stagnation point and the nozzle exit velocity is being exhibited in Figure 2. The curves have been recorded at a constant nozzle-to-plate spacing Z of quadruple slot width (i.e. $Z/B=4$) and a slot width of B=15 mm. It has to be pointed out especially that a low intensity of the jet turbulence is effecting a low heat-transfer coefficient at the stagnation point, connected with a relatively low minimum of the curve, being more or less distinct, depending on the ratio Z/B.

This effect seems to be independant of the nozzle exit velocity within a wide range of velocities. Plotting the local heat-transfer coefficient versus the dimension-less distance from the stagnation point x/B the curves show a first peak for $x/B\approx1.3$, a minimum for $x/B\approx4$ and finally a secondary peak at $x/B\approx7$. At short nozzle-to-plate distances Z/B this curve is characteristic for all nozzle profiles investigated.

Nozzles with a high intensity of turbulence may show a maximum heat-transfer coefficient at the stagnation point, as reported e.g. by Gardon and Akfirat (1965, 1966). The secondary peak at $x/B\approx7$ may disappear completely.

The existence of the secondary peak and its absolute value, however, is of greatest significance for the aerodynamic optimization of any dryer system. For single jet dryers as well as multiple jet dryers the average heat-transfer coefficient in relation to the total drying length is of great importance, because the secondary peak definitely contributes to a considerable increase of the average heat-transfer coefficient, when referred to a greater drying length. The value of the heat-transfer coefficient at the stagnation point is comparatively subordinate, as it is only effective in the immediate vicinity of the stagnation point.

At higher turbulence intensities but otherwise equal conditions, the secondary peak may disappear completely as shown in Figure 3 for two different nozzle exit velocities

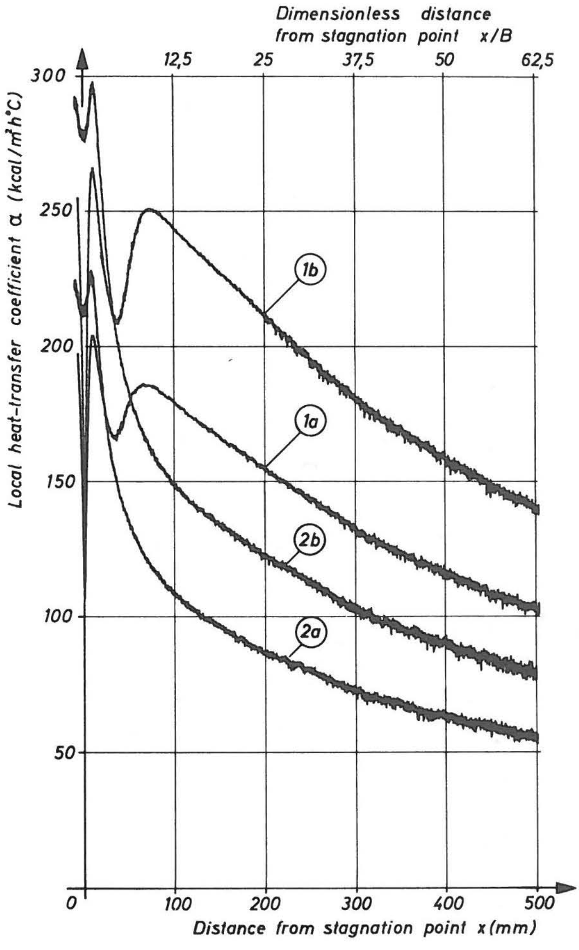


Figure 3. Effect of jet turbulence on the lateral variation of the local heat-transfer coefficient.
(nozzle type 1/8, for all curves: $B=\underline{8}$ mm, $Z/B=4$).
Recorded at natural turbulence:
curve 1a: $w_D=48$ m/s , $Tu^{*}=2.85\%$ at $z'/B=4$
curve 1b: $w_D=9o$ m/s , $Tu^{*}=1.3$ % at $z'/B=4$
Recorded at artificially increased turbulence (grid turbulence):
curve 2a: $w_D=48$ m/s , $Tu^{*}=9.3\%$ at $z'/B=4$
curve 2b: $w_D=9o$ m/s , $Tu^{*}=7.3\%$ at $z'/B=4$
$Tu^{*}=\sqrt{\overline{u'^2}}/w_D$ intensity of turbulence related to the nozzle exit velocity.

The graphical integration of the curves shown in Figure 3 corresponding to the distance from x=0 to x=5oo mm (respectively x/B=0 to 62.5) resulted approximately in the following average heat-transfer coefficient α_m(kcal/m^{2}hgrd) :

$\alpha_{m1a}=143$; $\alpha_{m1b}=195$; $\alpha_{m2a}=90$; $\alpha_{m2b}=124$;

A comparison between the average heat-transfer coefficient of the curves 1a and 2b leads to the conclusion that a lower nozzle exit velocity at a low turbulence intensity may result in a considerably higher average heat-transfer coefficient than a higher velocity at a high intensity of turbulence.

With increasing nozzle-to-plate spacing exceeding a value Z/B=4 the secondary peak is flattening out and finally disappears effecting a slight decrease of the average heat-transfer coefficient. Nevertheless the low turbulence nozzle remains superior.

The facts discussed above are leading to the following conclusions:

1. The nozzles and plenum chamber should be designed to generate jets of lowest turbulence.
2. The nozzles should be placed as close to the paper as possible being just far enough to avoid contact.

Naturally the nozzle exit velocity w_D - or, to be more precise, its component parallel to the web - is finally deciding the values of the heat-transfer coefficients. For low turbulence nozzles - i.e. optimized nozzles - the heat-transfer coefficient increases by the square root of the nozzle exit velocity. This correlation is confirmed by the findings illustrated in Figure 2. This leads to the third point:

3. The nozzle exit velocity should be adjusted to a value as high as possible.

The investigations so far have dealt with a single jet. The actual dryer, the multiple air jet dryer, however, usually consists of an array of nozzles. It was found by Gardon and Akfirat (1966) that neighboring nozzles are influencing each other's heat-transfer coefficients only slightly. The maximum average heat-transfer coefficient can be obtained when the spacing between the centers of the nozzles is chosen in such a way that the two secondary peaks at $x/B \approx 7$ of two adjoining nozzles coincide, Gardon and Akfirat (1966), Korger and Krizek (1966). Thus we get to the following conclusion:

4. The optimum spacing between nozzle centers results to:
   $t/B \approx 7$ plus $7 \approx 14$ to 15.

For extremely narrow dryers small spacings like that may be realized easily, because only a small amount of dryer air has to be removed. For wider dryers the question of air exhaust becomes critical because of the small space between the nozzles.

Figure 4 shows an example for the fact that even for relatively simple sheet metal slot nozzles combined in an array the secondary peaks for the heat-transfer coefficient are existing for small nozzle-to-plate spacings, which is shown for two different nozzle exit velocities. The measurement of the intensity of turbulence Tu^{x} along the jet axis resulted in a very low value despite the simple construction of the nozzle ($Tu^{x} \approx 3.3$ percent at $z'/B=4$ and $Tu^{x} \approx 6$ percent at $z'/B=10$), since a great air reservoir was used for a constant air supply. Since this multiple-nozzle array with a nozzle-to-nozzle spacing of $t=63$ mm respectively $t/B=31.5$ is deviating from the optimum nozzle-to-nozzle spacing ratio of $t/B=14$ to 15, an overlapping of the secondary peaks cannot be observed. The existence of the secondary peaks, however, contributes to the fact that the average heat-transfer coefficient assumes quasi-optimum values. Furthermore can be seen that the secondary peak is disappearing with increasing nozzle-to-plate spacing. In actual dryers these spacings still can be adjusted to values small enough not to exceed a ratio of $Z/B \approx 10$, thus keeping the decrease of the average heat-transfer coefficient within tolerable limits.

The measuring results and conclusions presented in this chapter certainly do not answer all questions pertaining to an aerodynamic dryer optimization. They are supplementing, however,

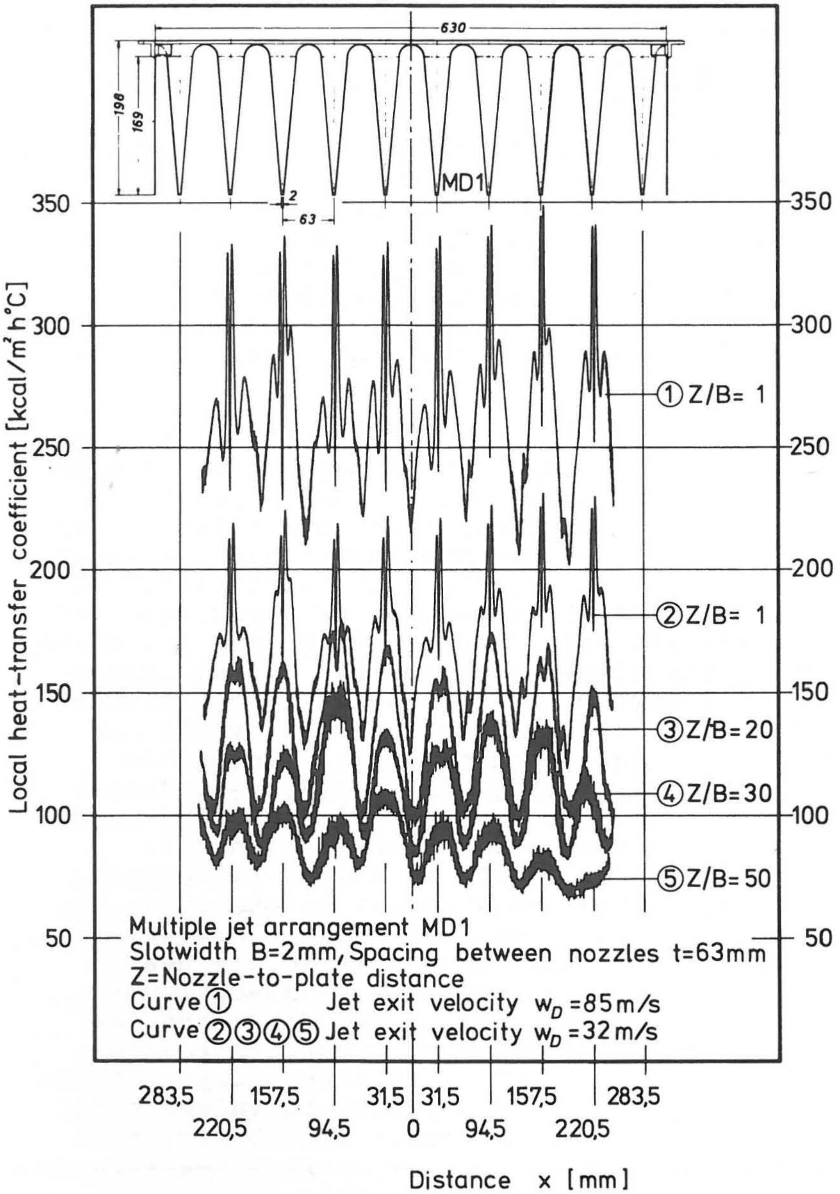


Figure 4. Lateral variation of the local heat-transfer coefficient α of a multiple jet arrangement (MD1) for various nozzle-to-plate spacings Z/B and nozzle exit velocities w_D.

these investigations by aspects rarely dealt with so far, but nevertheless very important.

Experimental Method to Investigate the Drying Behaviour of Solvent Based Printing Inks.

In the following a method is being described to investigate the drying behaviour of solvent based printing inks. This method may lead to a future automated dryer control system, by which the drying conditions can be accomodated to a great extent to varying ink-substrate combinations.

In order to study the drying behaviour of solvent based printing inks under realistic conditions, an infra-red spectrophotometer had been installed in a laboratory web gravure press, continuously scanning the printed web. An impinging air jet dryer had been mounted immediately before the scanning point of the spectrophotometer, as can be seen in Figure 5. To enable the variation of the drying conditions, provision was made to alter the jet exit velocity as well as the jet temperature within wide limits. Further the number of nozzles, the distance between the nozzle-centers and the length of the dryer could be varied. For greater changes of the dryer length the lab press as well as the drying device could be shifted relative to each other by means of a rail system.

The experimental method of determining the rates of solvent evaporation per unit time at varying drying conditions is based primarily upon quantitative analytical measurements, as being usually applied in infra-red spectrophotometry. In order to continuously measure the residual solvent content on the web immediately after the dryer, use was made of the instrument's ability to register the variation of absorption as a function of time at a selected constant wave length.

In the investigation of solvent evaporation a wave length has to be found exhibiting a strong absorption peak of the solvent. Just at this wave length all other components of the material to be dried (pigment particles, resins, plasticizers, printing substrates etc.) should posses a relatively low absorption.

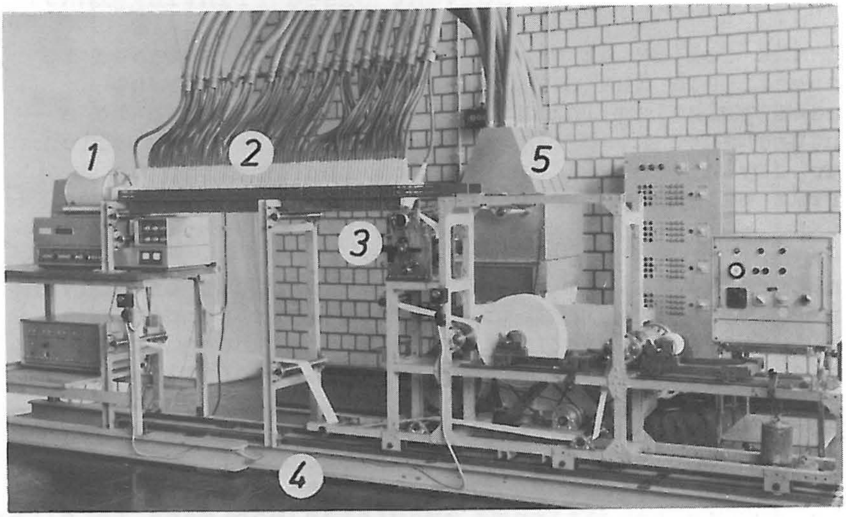


Figure 5. Experimental arrangement on a lab gravure web press to determine the drying behaviour of solvent based printing inks,
Legend: 1) spectrophotometer, 2) impinging air jet dryers, 3) printing unit, 4) rail,system for dryer length adjustment, 5) plenum chamber

In the following a review is given of some investigations which were aimed at determining isolated absorption peaks of the solvent -e.g.toluene- being only one of several substances in the ink-substrate system of the printed web. The spectrophotometer recorded in an linear scale at the wave number which is defined by the equation

$$\text{wave number (frequency)} \quad \nu(\mathrm{cm}^{-1}) = \frac{1}{\text{wave length}\,\lambda(\mathrm{cm})} = \frac{10000}{\lambda\,(\mu\,\mathrm{m})}$$

Therefore in the spectrograms reproduced in Figure 6 to 15 the wave numbers of the important absorption peaks are given additionally due to the higher accuracy of the counter of the instrument compared with the registration paper.

The spectrogram of the solvent toluene (Figure 6) shows stronger absorption peaks at the wave numbers 3031, 1494, 730 and 694 cm^{-1}. Further we can observe somewhat lower absorption peaks at the wave numbers 2921, 1605, 1460, 1081 and 1030 cm^{-1}, being also of interest. The strongest absorption peak can be found at the wave number of 730 cm^{-1}.

Figure 7 shows the spectrograms of two different gravure papers recorded under equal conditions. Both papers have a weight per unit area of 60 g/m^2. These spectrograms can be considered representative for all the other papers investigated - the difference in the transmittance not being included in this consideration.

Compared with Figure 6 the paper spectrograms have been recorded with a 13-fold ordinate expansion and a greater slit width of the photometer (greater energy) in order to obtain a useful spectrum.

Comparing Figure 6 and Figure 7 we find that among the wave numbers of the strong toluene absorption peaks both papers have their highest transmittance at 730 cm^{-1}. Furthermore we observe, that paper sample 1 has a higher transmittance than paper sample 2. A second, but somewhat inferior combination could be established at wave number 1494 cm^{-1} with the third strongest toluene absorption peak. All the other toluene absorption peaks- eventually the peaks at the wave numbers 1605 and 694 cm^{-1} could be considered - fall into the region of strong paper absorption and cannot be utilized for evaporation tests.

Among the variety of printing paper stocks not being used in gravure printing some paper stocks have been found being well suited for these tests. To demonstrate this Figure 8 shows a spectrogram of a bible print paper with a paper weight of 23 g/m^2. The curves 1 and 2 are spectra of the bible print paper - curve 1 showing the normal spectrum (0 percent and 100 percent lines

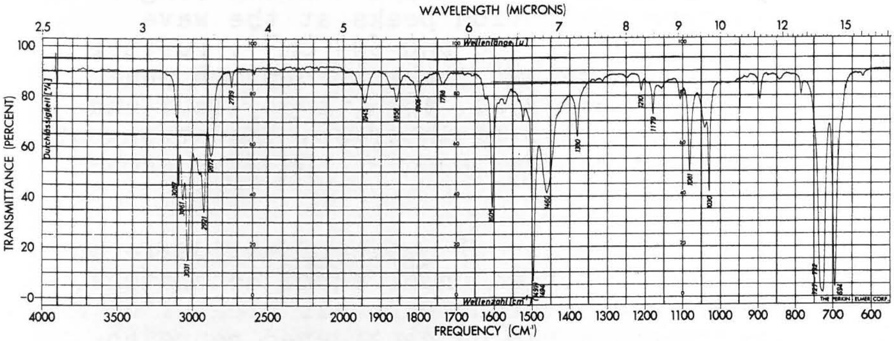


Figure 6. Spectrogram of liquid toluene, recorded in a liquid-cell with KBr-window, layer thickness o.o17 mm.

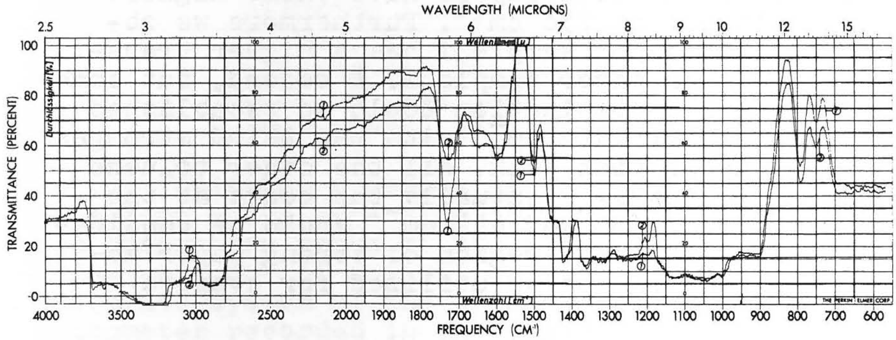


Figure 7. Spectrogram of two paper stocks, weight per unit area of both stocks=6o g/m^2, solid (fixed path length). Both spectra are recorded at 13-fold ordinate expansion.

in real scale) and curve 2 showing the spectrum recorded under the same conditions but reproduced with an ordinate expansion of a factor 3.3 and a shifted zero-line exhibit the details of the spectrum. The normal spectrum of this paper (curve 1) shows that at 15oo cm^{-1} a transmittance of 25 percent is existing, matching excellently the toluene absorption peak of 1494 cm^{-1} (cf. curve 3). Two further toluene absorption peaks at the wave numbers 73o and 694 cm^{-1} could be utilized too.

Contrary to the paper stocks, causing some difficulties due to their strong absorption, many films used as printing substrates are not problematical at all. Due to their very high transmittance in certain infra-red ranges they can be combined easily with the toluene absorption curves. Figure 9 illustrates this fact by showing the spectrogram of the low density polyethylene film 'Suprathene' (curve 1). For comparison's reason a toluene spectrum was reproduced on the same chart (curve2). As can be deducted very easily from these spectra, at the wave numbers of the important toluene absorption peaks high transmittances of the film material are present.

To demonstrate the effectiveness of the measuring system even in difficult cases a machine coated gravure paper stock of 6o g/m^2 was wetted with toluene. At the constant wave number 726 cm^{-1}, having the strongest toluene absorption peak, the evaporation process was recorded as a function of time. The result can be studied in Figure 1ob. Recordings of absorption curves of various paper samples under equal conditions (curves 1-8) are shown in Figure 1oa. It can be seen that the thickness of the paper web is varying slightly, but this measuring error is being averaged out by the constantly moving web. The reproducibility of this measuring method is quite sufficient as can be deducted from the recordings of the samples 1a to 1c.

The specific toluene absorption peaks at 1494 cm^{-1} and at $\approx$73o cm^{-1} should be taken into account when formulating gravure inks suitable for

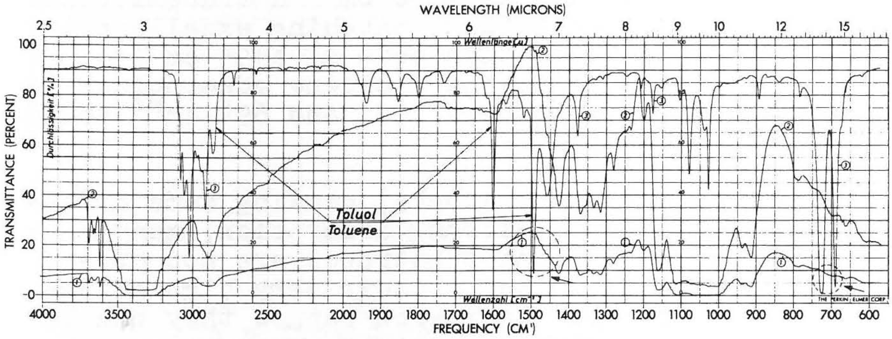


Figure 8. Curve 1 and 2:Bible print paper, solid, 23 g/m^2. (curve 2 recorded at 3.3-fold ordinate expansion).
curve 3:liquid toluene, layer thickness o.o17 mm.

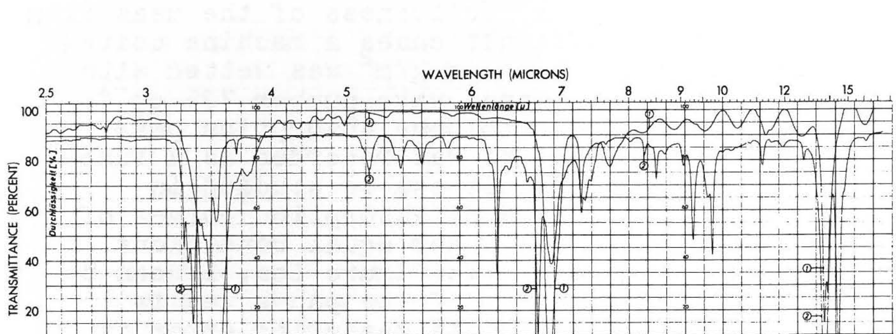


Figure 9. Curve 1:Low density polyethylene film 'Suprathen' solid, film thickness o.o4 mm
curve 2:liquid toluene, layer thickness o.o17 mm, recorded in a liquid-cell with KBr-window.

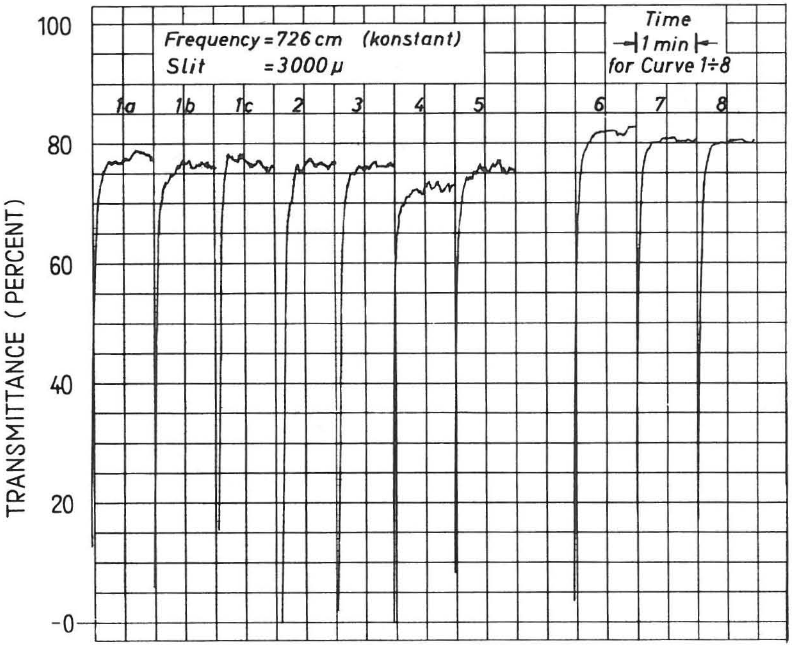


Figure 1o a. Transmittances of various paper samples,
curves 1-5: gravure paper, 65 g/m^2
curves 1b, 1c: paper sample of curve 1 check on reproducibility,
curves 6-8: machine coated gravure paper, 6o g/m^2

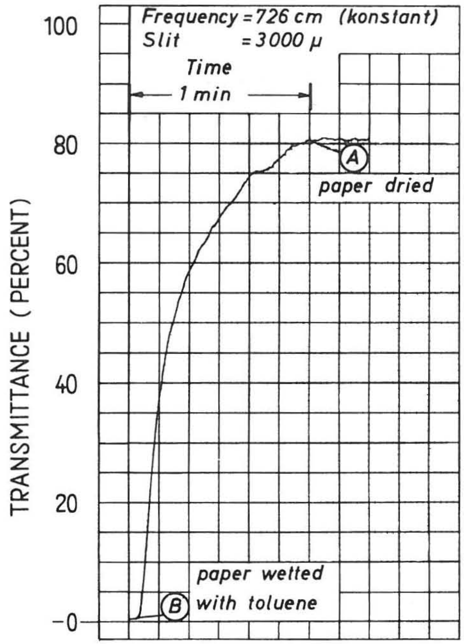


Figure 1ob. Evaporation test, sample 8 of Figure 1oa wetted with toluene.

evaporation tests. All ink components other than toluene should possess high transmittances just at the wave numbers mentioned above.

Figure 11 shows the spectrogram of a blue pigment ('Heliogenblau LBG'), exhibiting a strong absorption peak exactly at 731 cm^{-1}. The analysis of the spectrogram of an unknown printing ink incorporating this pigment would be a difficult task due to the fact that the pigment absorption peak would exactly coincide with the toluene absorption peak at $\approx$ 73o cm^{-1}. At the wave number 1494 cm^{-1}, the other specific toluene absorption peak, however, this pigment would be ideally suited for a test, since it possesses a very high transmittance at this wave number.

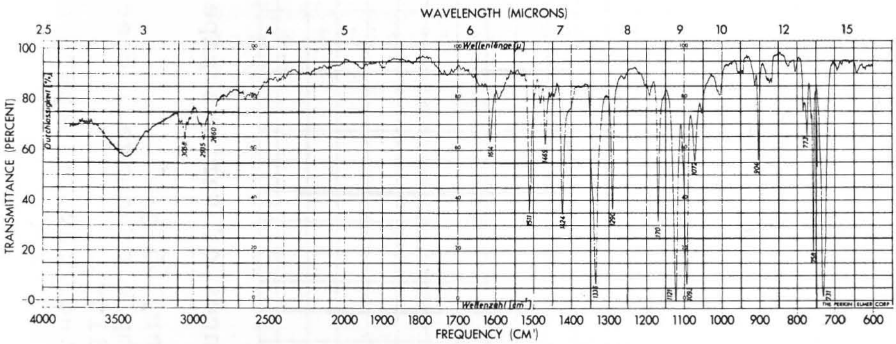


Figure 11. Spectrogram of blue pigment "Heliogenblau LBG", solid, 1 mg pigment, 2oo mg KBr in pellet of 13 mm diameter.

The best transmittance at the specific absorption peaks, as well as at other absorption peaks, has been found for the blue pigment 'Miloriblau', the spectrum of which is recorded in Figure 12. In the investigated range of wave numbers this pigment shows a very strong and wide peak at 21oo cm^{-1} and a somewhat smaller peak at 6o5 cm^{-1}. Both do not overlap with toluene absorption peaks. In Figure 13 the spectrum of a commercially available gravure ink is seen, the con-

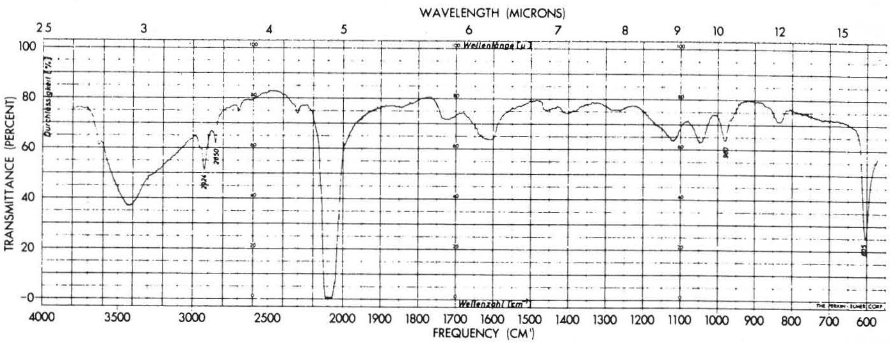


Figure 12. Blue pigment "Miloriblau", solid,
1 mg pigment in 2oo mg KBr, in pellet
of 13 mm diameter.

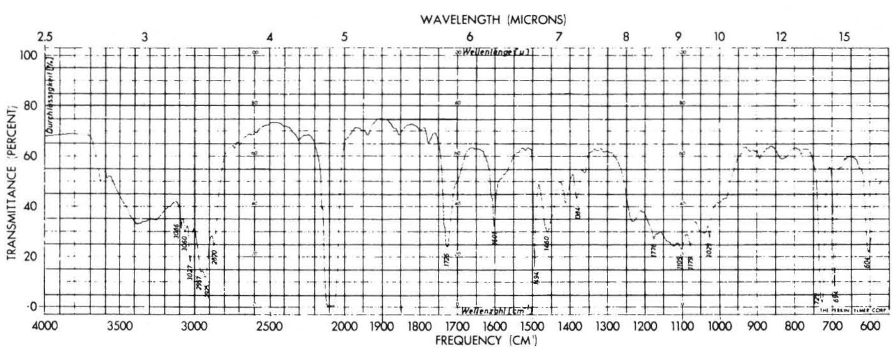


Figure 13. Blue gravure ink, liquid, in a liquid-
cell with KBr-window, layer thickness
o.o15 mm.

tent of which was unknown. A comparison of the peaks with Figure 12 shows immediately that this ink is containing the blue pigment 'Miloriblau'. Since this ink exhibits distinctly isolated toluene absorption bands, it is extremely well suited for the evaporation tests.

In Figure 14 and Figure 15 the spectrograms are given of two resins used in normal gravure ink production. From the examination of the two spectra it can be easily deducted that these resins could be incorporated in the ink due to their good transmittances at the specific toluene absorption peaks.

Without giving further examples it can be said that also among red, yellow and black gravure inks ink formulations suitable for the tests could be found.

By means of these relatively detailed examples it has been demonstrated that with the ink-substrate combinations dealt with in actual printing operations in most cases the determination of the residual solvent content of the web is possible. Whether this is valid for all actual combinations of materials, can only be decided by compilations of spectrograms of various materials and comparison of their absorption peaks. As long as the solvent in use is showing specific absorption peaks stronger than those of the other components at the corresponding wave numbers, this measuring method is always applicable.

Possible Future Development of an Automated Drying Control System

The residual solvent content of the printed web is a measure of the effectiveness of the drying process. A direct statement concerning the drying rate therefore can only be made by a determination of the residual solvent content on the printed substrate. Highly sensitive analytical methods have been applied earlier for a direct determination of the residual solvent content in stationary tests - i.e.by taking single samples from the printed substrate - since the amounts of the solvent to be traced were very small. A

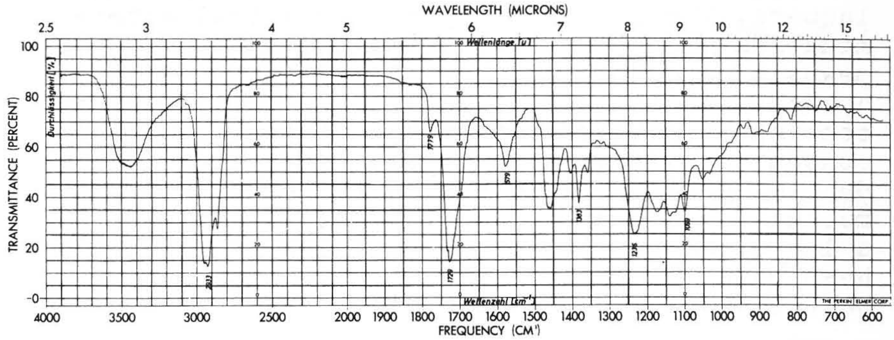


Figure 14. 'Calcium-zink'-resin, solid, 1 mg resin in 2oo mg KBr in pellets of 13 mm diameter.

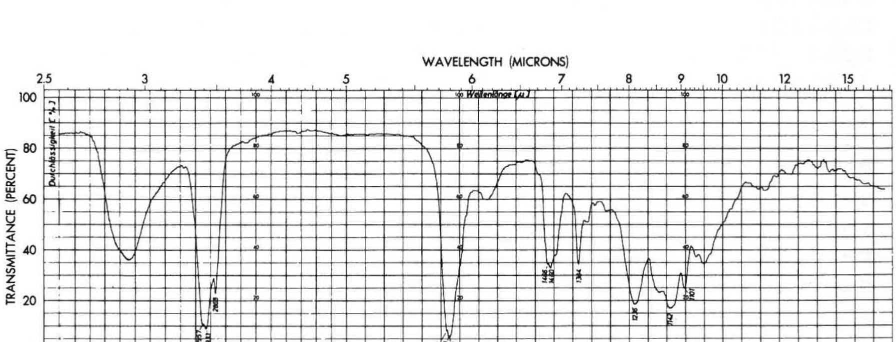


Figure 15. 'Collophony' resin modified with acrylic acid, solid, 1 mg resin in 2oo mg KBr, pellet of 13 mm diameter.

determination of residual solvent contents by means of gas chromatography has been carried out by Eschenbach, Wagenbauer and Fink (1964). Further gas chromatographical measurements were conducted by Dätwyler (1960) to determine the residual solvent content in the drying process of laquers. The infra-red spectrographical determination of the residual solvent content by means of a heatable gas cell has been described by Scheuter and Dosdogru (1969). So far a direct continuous measurement of the residual solvent content of the printed product in running production presses is unknown. With the infra-red method described above -presently restricted to a lab press- a first step in this direction has been made. The method is characterized by a destruction -free measurement.

A first condition for an introduction of this measuring method is the existence of a compilation of spectrograms of the current printing inks and substrates, comprising also specific spectra of solvent, pigments and resins. Generally speaking, a kind of 'spectra atlas' is being wanted, adapted particularly to printing inks and substrates. Using this atlas it would be possible to obtain the necessary informations on the wave numbers of specific absorption peaks for any ink-substrate combination. An infra-red scanning device, adapted to the practical applications in a press, should be able - like a spectrophotometer - to emit infra-red beams adjustable continuously in a wave length range of at least 3 to 18 μm. By means of interference filters this is already principally possible. The device would then allow only to adjust a few selected wave numbers, since it is impossible to install as many interference filters as were required for a continuous variation of the wave number. Possibly further developped lasers could step in here.

As to the system controlling the residual solvent content the following considerations could be made:

On the one hand the drying rate is essentially dependant on the heat-transfer coefficient between impinged air and paper surface and on the other hand on the temperature difference $\Delta t = t_L - t_W$ between dryer air and paper surface. The surface temperature t_W itself is dependant indirectly on the heat-transfer coefficient and directly on the dryer air temperature t_L. The heat-transfer coefficient can be manipulated by the nozzle exit velocity and thus by the fan speed (RPM). The air temperature depends on the adjustable heating power. Both variables would represent the manipulated variables of the control system with the residual solvent content being the variable to be controlled (output quantity). Since the surface temperature of the paper cannot be allowed to exceed a maximum value, it would represent an additional output quantity. It would have to be measured also continuously.

For the effectiveness of a dryer the concentration of solvent in the dryer air plays a role not to be neglected. It is determined by the amount of exhaust air which cannot be allowed to drop below a minimum value, varying for any given press speed and ink coverage. The solvent concentration of the dryer air would represent a third output quantity, being connected with the amount of exhaust air as manipulated variable. It can also be determined by the infra-red method. The output quantities of the control system then would have to be fed into a simple computer, which would have to decide - according to some preset criteria - whether and how the fan speed, the heating power or the amount of exhaust air should be varied or if in a boundary case the machine speed of the press would have to be reduced.

As these considerations indicate, a big step has to be made as yet towards a complete and satisfactorily working drying control system.

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