Preferred citation: D. Wahren and G. Bryntse. An improved model of the reflectance properties of uneven solid prints. In **The Fundamental Properties of Paper Related to its Uses**, *Trans. of the Vth Fund. Res. Symp. Cambridge, 1973*, (F. Bolam, ed.), pp 616–621, FRC, Manchester, 2018. DOI: 10.15376/frc.1973.2.616.

AN IMPROVED MODEL OF THE REFLECTANCE PROPERTIES OF UNEVEN SOLID PRINTS

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Synopsis A theoretical model relating the print density and mottle of solid prints to the optical properties of the paper, the ink, the amount of ink and the unevenness of the ink distribution in the print has been developed.

The model differs from previous models in that the effects of speckle are included and in that the effects of the variables mentioned above can be clearly distinguished. The model is compatible with the assumption that stochastic processes govern the ink distribution and that the intensity of these processes may be related to the structure of the paper. Only a brief review of some results is given.

General comment

In making a solid print, a certain quantity of a given printing ink will yield different print densities and different mottle effects on different papers. The relations between sheet structure and the reflectance properties of solid prints are being investigated in a current project. In the course of this work, an improved and in some respects entirely new model, describing the relations between the mass distribution of ink in the print and the reflectance properties and mottle of the print, has been developed.

The model

The model is based on two fundamental concepts, namely, the local validity of the Kubelka-Munk set of formulae and the concept of an uneven layer of ink, the amplitude distribution of which is described by a continuous distribution function having the same moment generating function as the Poisson distribution. It is the latter assumption that is new and that yields results compatible with experimental observations. In this note, only a brief presentation of the model will be given: a more complete version and experimental verification will be published in due course.

The total intensity of the print unevenness U_i is defined as the coefficient of variation of the local basis weight of the ink layer—

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$$U_i = \sigma(w_i)/\overline{w_i}$$

It should be noted that *all* non-uniformities of any size down to the wavelength of light are included in this definition. What is experimentally observed in the measurement of mottle is often an entirely different matter. In order to facilitate the presentation of data, the amount of ink on the print is expressed in terms of the dimensionless parameter x—

$$x = s_i w_i / R_{i\infty}$$

where s_i is the scattering coefficient of the ink (m^2/kg) and $R_{i\infty}$ is the reflectivity of a thick and perfectly even layer of ink.

The amplitude distribution, $f(z)$, of the local basis weight of the ink film is defined by its moment generating function—

$$\int_0^\infty f(z)e^{tz}dz = \exp\{\bar{z}(e^t - 1)\}$$

where $z = w_i/\overline{w_i}$ is the ratio of the local basis weight of the ink w_i to the average amount of ink on the print. The amplitude distribution function can be numerically evaluated. It is shown in Fig. 1, where it is compared with the gamma distribution used by Tollenaar & Ernst[1] for the same purpose.

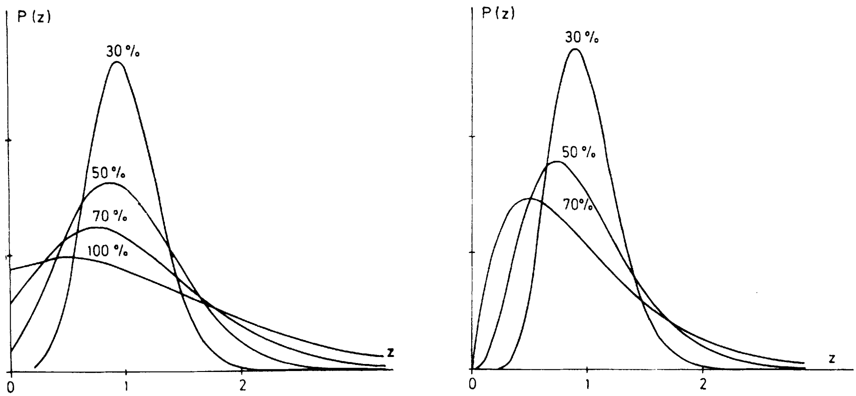

Fig. 1—Normalised amplitude distribution of the ink film thickness (basis weight) as assumed in the present work (*left*) and by Tollenaar & Ernst (*right*): parameter is the coefficient of variation of the ink film basis weight U_i

The new distribution function is considered to describe the mass distribution of ink layers, built up from a great number of randomly distributed ink pigment particles and particle agglomerates and/or ink film fragments of varying thickness.

Speckle

It can be observed in the diagram that, when the intensity of the mass distribution is above a certain level, a fraction of the area will not be covered by ink—that is, speckle is present. The fraction of the area not covered by ink is shown under the heading *speckle* in Table 1.

TABLE 1

U_i *per cent*	*Speckle, per cent*
30	0·017
50	7·5
70	27·0
100	43·7

Print density

Another feature of the model is that the print density as a function of the amount of ink on the print follows well-known empirical relationships, notably those proposed by Tollenaar & Ernst. The relationship is, however, a function of the unevenness of the ink film—as illustrated in Fig. 2.

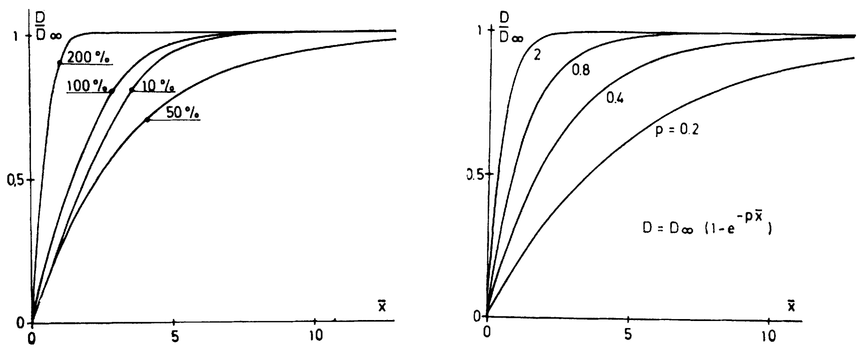

Fig. 2—Print density as a function of the average amount of ink on the print, normalised plots valid for $R_p = 65$ per cent: the present model in which $R_{i\infty}$ is a proper constant characteristic of the ink is shown to the left and the empirical formula developed by Tollenaar & Ernst to the right

Experimental values can be fitted very well to the theoretical relations. It can be observed that, as the unevenness of the print increases, the curves shift in a slightly irregular fashion. This is because the model predicts that the maximum print density D_∞ should shift with the unevenness of the print. In the idealised case, D_∞ is a function only of the reflectance of the paper and of and ink characteristic $R_{i\infty}$. The model predicts, however, that the observable values of the ink characteristic change with the paper grade and quality—or rather with the degree of evenness that can be obtained on any particular type of paper.

Ink requirement

An increase of the ink requirement with increasing unevenness of the print is also predicted. This is shown in Fig. 3. The parameter x_o is the ink requirement for a perfectly even print.

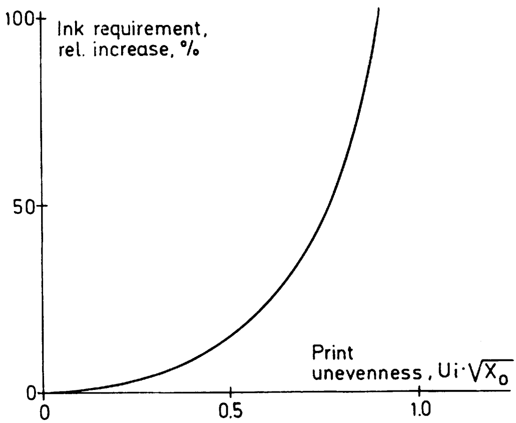

Fig. 3—The relative increase of the ink requirement above the theoretical ink requirement x_o of a perfectly even print is shown as a function of the print unevenness U_i times the normalising factor $\sqrt{x_o}$

Mottle

The model also predicts mottle as a function of the amount of ink on the print or as a function of the print density. Mottle in this case is defined as the coefficient of variation of the reflectance of the print $V(R)$. Using an approximate model, it has been shown earlier[2] that mottle can be expected to increase to a maximum, then decrease as the amount of ink on the print is increased at constant unevenness of the ink layer—that is, at a constant value of U_i. The new model describes these relations much more accurately. In particular, the model predicts that the mottle will not disappear under certain circumstances even at high inking levels. This is in agreement with our own measurements as well as with those performed, for instance, by Perilä.[3] Examples of results calculated with the aid of the new model are shown in Fig. 4 & 5.

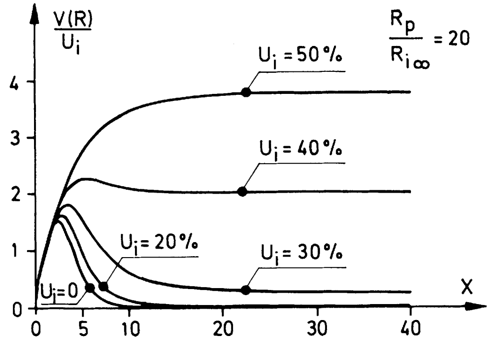

Fig. 4—Mottle as a function of the average amount of ink on the print: the ratio of the coefficient of variation of reflectance to the total intensity of the mass distribution of the ink layer is shown as a function of the average amount of ink on the print for two different values of ideal maximum contrast, $R_p/R_{i\infty}$

It can be observed that, as the value of the ideal maximum contrast $R_p/R_{i\infty}$ is increased, the reflectance variations at any given unevenness of the ink film also increase. (R_p is the reflectance of the printing substrate.)

It can also be observed that the maximum disappears at high values of the unevenness U_i, whereas the functions tend at low values towards the function given by the earlier approximate model.[2]

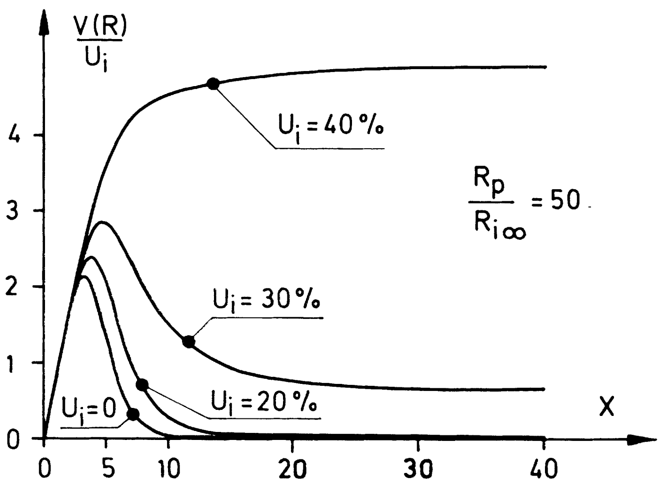

Fig. 5

Conclusions

The mathematical model of the reflectance properties of solid prints presented above appears to provide a much improved tool for relating observable properties of solid prints to the more fundamental concept of the mass distribution of the ink layer. It remains to be shown, however, which parameters of the paper structure govern the mass distribution of the ink layer. This is the objective of a current project.

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Transcription of Discussion

Discussion

Mr G. F. Underhay I believe that, in our printability discussions, we have rather forgotten some of the good work that was done 10 or more years ago. I would like to refer especially to a paper by G. L. Larocque (*Pulp & Paper Mag. Can.*, 1967, **68** (1), T16) of the *New York Daily News* and formerly of PPRIC. Gerry was very down to earth and, as I remember his conclusions, he hardly mentioned things like tear, tensile and burst. Instead, based on 20 years of detailed records, he showed that satisfactory runnability was linked with good stretch characteristics, better winding, higher moisture content, minimum roll damage and low shive content (consequent upon improved shive removed facilities in the papermills). Thus, he moved substantially away from tests on ridiculously small bits of paper, which may well be completely unrepresentative; he studied whole rolls rather than square centimetres. How otherwise can you spot a single shive or other potential fracture points as being likely to cause a break in several miles of paper? (For further comments and references, particularly to George Sears, see my paper 'Mechanical Pulp —the Neglected Gold Mine', *Tappi*, 1968, **51** (9), 39A.)

Dr L. S. Nordman Prof. Renata Marton did not mention the time lag between printing and splitting of the sheet of paper. It must have a profound influence on the appearance and situation of the maximum value, because we have found that there is a marked redistribution of the vehicle in the sheet when the time after printing increases.

Prof. Renata Marton We did not split right away after printing, because it is impossible to split 14 or 15 layers very fast, though we consider the time to be very important. We have not yet determined how long the vehicle continues to migrate, but we intend to do so. The time between printing and testing was about 15 min.

Dr J. Marton As Mr Underhay has already mentioned, the runnability of newsprint is more affected by mechanical condition of the roll and by the

Under the chairmanship of Dr J. A. Van den Akker moisture content than by some other fundamental paper properties like tear or smoothness. Nonetheless, printability problems are quite important for other categories of paper like fine papers coated or uncoated used for more quality printing. We should not therefore consider everything from the point of view of newsprint.

Dr J. Grant I am not quite clear how Prof. Marton's method, which intrigues me very much, differentiates between the progress of the pigment and the progress of the ink vehicle through the thickness of the paper. One illustration showed both as separate curves; but, if she activates the ink as a whole, how is one distinguished from the other?

I would like to add a few remarks of a general nature, which suggest themselves to me as a result of listening to the papers this week.

I am all with George Underhay in that we should try to keep our feet on the ground in the practical applications of the knowledge that we are hearing about, although this symposium is of course concerned with the fundamental properties of paper as distinct from their immediate practical use.

I have always regarded paper as having properties in equilibrium. Thus, when you attempt to improve one property, you invariably lose on another. The simplest example I suppose is the one I mentioned the other day—when one beats pulp to improve strength, one loses opacity, dimensional stability and one can give many other examples. So the problem really arises how can we take this welter of complicated factors that go to make up good printability or runnability and find optimum compromise among them all to give the best results on the papermachine.

My suggestion is of course not original—I know that it has been applied, especially in North America. I refer to furnish optimisation, which I believe is the real answer to the practical application of these recondite properties. I have carried out large-scale experiments on this and was very impressed by the results obtained by feeding into a computer the desirable characteristics from a number of different pulps—hardwood pulps, long-fibred pulps and others—and programming the computer to give the proportions that we should use and how we should treat the pulps in order to obtain the best combination of printing characteristics. I believe that this is really going to be the best way of achieving something practical out of the theory that we have heard during the course of this meeting.

Prof. Renata Marton I was rather expecting this question. We were unable to provide specific information about the distribution of the radioactive tracer between the carbon black and the ink. We are working on this now, but we assumed equal specific activities of the carbon black and the ink vehicle. We know, however, that errors are introduced by this assumption, but they should not affect the qualitative conclusion I have presented.

Dr J. Grant The difficulty is that the vehicle and the carbon black travel through the paper at different rates and to different extents. Unless you separate their effects, the results are really meaningless.

Prof. Renata Marton Observation under the microscope of each layer helped to establish where the carbon stopped and how the vehicle continued to migrate. I presented a few examples of what we are doing, but the work is not finished and we hope greatly to improve on this promising method.

Mr R. Rahkonen I would like to add one point that might be of interest. I think it might be possible separately to label the pigment and rhe vehicle with two labelling substances having different spectra of radioactive radiation. Then it should be possible using Prof. Marton's technique to measure separately the amounts of pigment and vehicle in the different layers of the paper simply by measuring the intensity of radiation at two different wavelengths. At Rauma, we have used the same technique to measure separately the flow of wood chips and of coating liquor in a continuous digestion system.

Mr J. R. Parker May I ask Prof. Marton how her work compares with that by Larsson, who has used similar techniques?

Prof. Renata Marton Yes, we know of Dr Larsson's work very well and we co-operate closely. He uses a Geiger-Müller counter, which is much less sensitive than a liquid scintillator counter, for this counts a hundred times less radioactivity than a Geiger-Müller counter. Our curves are similar to some extent, therefore, but we regard the scintillation method to permit much greater precision, since we can detect parts of milligrams of ink in each layer.

Dr A. B. Truman It is intriguing to think that one might be able to feed into a computer the basic physical data on paper properties to obtain from it the desirable printing characteristics of the sheet (which I would suspect are very difficult to define).

In my opinion, the problem is more educational than technological. The papermakers must be educated to make a consistent product with controlled properties and the printer must learn to use the paper in an intelligent way. I can cite an example of a troubleshooting job that I went on recently; a printer of newsprint had had considerable web breaks on his machine. On questioning him closely, I discovered that the firm had recently installed air conditioning equipment that considerably reduced the ambient moisture content. I explained to him the relationship between that and paper properties, the tensile strength and stretch—and really that in itself was the solution to the problem.

However erudite our study of the factors contributing to good printability and runnability, the effort will be to no avail if we do not communicate effectively with the papermaker and the printer.