STUDY OF INK MISTING PHENOMENA

Anne Blayo*, Sandrine Waig Fang*, Alessandro Gandini* and Jean-François Le Nest*

Keywords : Offset Ink, Misting, Rheology, Tack, Viscoelasticity.

Abstract : The aim of this study is to give a better understanding of ink misting phenomena. The occurrence of this particular behavior leads to various problems, especially in the field of high-speed printing. Several parameters influence this complex behavior of an ink running on the rotating rollers of the press. Among these, rheological properties are of prime importance. In our study, special emphasis was placed on the visco-elastic features of the ink, together with other aspects related to ink flow in the nip. The rheological measuments were conducted on a cone-plate rheometer and on a visco-analyser.
Different attempts were made to quantify and analyze the phenomenon, including image analysis of patterns obtained from misting of ink or varnish samples running on a Tack-o-Scope compared to weighing methods.
The correlations obtained between these results and the rheological properties of the inks suggest solutions concerning ink formulation.

Introduction

Misting - or flying - typically occurs at the exit of a printing nip, ie the nip of two rotating rollers of the ink distribution system. Rupture of ink filaments is confirmed as a source of ink mist. The ink is first compressed, then subjected to shear stresses, followed by extensional forces (see Fig. 1).

*Polymeric Materials, Paper and Printing Laboratory,
URA 1100 CNRS, French Engineering School of Paper and Printing,
I.N.P.G., BP 65, 38402 Saint-Martin-d'Hères, France.
E-mail: Anne.Blayo@efpg.inpg.fr; Sandrine.Waig-Fang@efpg.inpg.fr
Alessandro.Gandini@efpg.inpg.fr;Jean-Francois.Lenest@efpg.inpg.fr

The ink film is elongated, and eventually split into filaments.The way these filaments break is determining: if they break in more than one place, the free fragments coalesce into microscopic droplets,which may form a relatively stable mist of ink around the rolls and the machine [Van der Meulen, 1987; Leach et al, 1993]. Obviously, misting has direct negative consequences on ink transfer and may moreover produce dirty working conditions, which generates printing troubles and environmental hazards. The phenomenon, quite rare in sheetfed offset, occurs predominantly on high speed web offset presses and was particularly well-known in newspaper pressrooms, a few years ago [Reif, 1964]. The increasing speed of web offset may involve ink misting. Ink misting has also been reported in other situations, namely (i) in printing areas concerned with letterpress, metal decorating, UV-cured inks and varnishes [Volz, 1996], and (ii) in fields other than printing, e.g. paper coating [Benjamin et al., 1994], painting and any other situation where a liquid flows between rotating rollers.

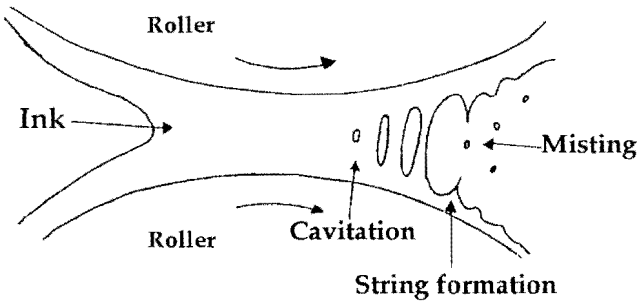

Figure 1: Ink film splitting

Despite all this, few systematic studies are available in the literature concerning ink misting and only rather empirical techniques are described for reducing this problem.
In this study, we investigated some of the parameters which affect this complex phenomenon. Among these, rheological properties and, more precisely, viscoelastic characteristics of the ink are of prime importance.

I. State of the art

I.1. Description of the ink splitting and the mist generation

In a recent review, MacPhee has presented ink misting as a particular behavior of ink splitting [MacPhee, 1997a and 1997b]. Misting is a problem associated with oil-based past inks. It has been first studied

in the context of letterpress, when the limiting speed was 1500 feet/min [Voet, 1951; 1956]. In the earlier studies of ink misting [Howard et al., 1957], high speed photography proved useful to gain a better insight into the formation of cavities and the ink film splitting phenomena related to letterpress printing. In those years, the problem of ink misting was particularly relevant to newspaper printing, where little could be done to improve the rheological properties of the low-cost inks involved. Therefore, efforts concentrated on electrostatic solutions (see par. I.2).
Later, the increasing press speeds led the printers and the inkmakers to consider the analogous problem in offset printing [Fallani, 1983; Pugliesi et al., 1983; Van der Meulen, 1987; Leach et al., 1993; McKay, 1994].
The droplet size distribution of ink mist can cover a wide range viz. from below 1 μm to above 5 μm. The particles may form streams from the exit of the printing nip to the rear of the rolls, where the two air streams collide. The amount and the size of the droplets of mist generated and the actual mechanism of droplet generation depend on such factors as:

- the rheological properties of the ink,
- the dynamic adhesion (ie: the tack) of the ink,
- the ink film thickness,
- the atmospheric conditions,
- the peripheral velocity of the rollers, thus their diameter,
- the number of rollers.

Concerning this last parameter, it is worth noting that the keyless inking system, used in letterpress, reduced ink mist to negligible levels, due to the reduced number of inking rollers. It was also observered that an increasing temperature gave rise to an increasing tendency to mist [Traber et al, 1993], while a rise of humidity led to lower electrostatic fields, which reduced ink misting. It has long been known that increasing ink film thickness increases misting [Voet, 1956; Leach et al, 1993]. The volume of ink mist increases with roller speed, thus creates a significant problems at very high speeds. Tasker found a correlation between roller speed and the amount of misting, under laboratory conditions : Misting = k $(\text{speed})^n$, where n varies from 2.2 to 2.8 [Christiansen, 1995].

Several studies report the development of ink formulations with a lower tendency to mist [Southard, 1958]. In early approaches, the ink shortness (i.e. the ratio of its yield stress to its plastic viscosity) was considered as a governing factor so that the shorter the ink with respect to its filaments, the less the misting [Kelly et al., 1974]. However, experiments were performed which proved that ink shortness is not the only controlling property [MacPhee et al, 1989].
Finally, the elasticity of the liquid is put forward to be a key characteristic [MacPhee, 1997b; Leach et al, 1993; Gutoff et al., 1995].

Few is reported concerning cohesive properties of the ink. No clear-cut conclusion is found about the electrostatic factors.

I.2. Some techniques to reduce ink misting

Two major techniques may be used: modifications of the printing conditions or ink formulation changes.

The basic principle of electrostatic methods consists in electrically charging the mist particles and then using electrical fields to drive them back onto the ink rollers. An unespected difficulty arose in controlling misting of colored inks. The direct potential electrical field caused the constituents of certain colored inks to separate, which resulted in improper transfer and poor color reproduction [Reif, 1964; Rauenbuehler, 1966].

On the other hand, the problem can largely be overcome by formulation changes. Ink misting is often a function of the nature of the vehicle, but will obviously depend on a multitude of other parameters, e.g. pigments, extender type and level [Leach et al, 1993]. In controlling misting, the choice of the resin system is determining. One usual cause of misting is the use of resins containing long linear molecules.

Misting is decreased with the addition of certain additives, including pigments. For example, increasing both pigment loading and the size distribution of the pigment particles reduce misting [Voet, 1956; McKay, 1994]. Different interpretations are proposed to explain this. First, the extenders used in this context have a high oil absorption value, which reduces the capacity of ink to flow into long strings [Leach et al, 1993]. For example, silica or micronized talc have a high oil absorption value. The amount added (up to 2 %) is optimized to minimize flying while retaining good flow properties. The other explanation is that the additives in the form of particles cause the filaments to break sooner [McKay, 1994]. Increasing the concentration of extenders also increase the elastic nature of the ink. This property ensures that the ink snaps on elongation of the ink filament, thus preventing the formation of ink droplets.

In a recent study [Volz, 1996], several UV-cured printing ink formulations are compared according to their rheological properties. Different vehicles are examined : a non-gelled vehicle, an ink with a thickener and a chemical gel-based vehicle. The non-gelled ink showed the worst misting, lower yield value and most flow. The ink containing thickener appeared similar in physical properties to the chemically gelled ink. They have similar rheological properties, viscosities, yield values and flow. Misting characteristics were also similar, producing less misting than the ungelled ink.

I.3. Measurement of the amount of ink mist

There is no standard measurement of this parameter. The tendency to mist can be evaluated by running an ink through a series of increasing film weights and speeds on a tack measurement device and assessing the amount of mist drops which fall onto a piece of paper placed near the rollers [Leach et al, 1993].
It is important to compare the perfomances of the ink under test with those of a reference ink whose misting tendency on a printing machine is already known, because small changes in atmospheric conditions may modify the results. It is also preferable to have one roller oscillating to reduce the tendency of the ink to form ridges.
Comparisons among different inks can be obtained by :
- measuring the weight increase per unit area of the collecting sheet;
- visually assessing the droplet distribution per unit area.
The parameters for consideration should be the following:
- ink film thickness
- the temperature of the roller surfaces: certain inks can dramatically change their rheological properties as the temperature varies, e.g. a decrease in viscosity as the temperature rises.
- the roller speed
- the location of the target: the paper must be placed at a point which reflects ink misting level.
Another measurement technique by air sampling is described in the literature [Anon, 1984].

In summary, the investigations reported so far were essentially empirical in nature and lacked therefore any clear-cut conclusion.

II. Experimental

II.1. Systems examined

In order to simplify the interpretation of the results, we chose to work with model systems, namely alkyd resins and test-varnishes with known formulations.

II.1.1. Alkyd resins

Three different alkyd resins were examined, namely:
- A1 which was based on a blend of different vegetable oils (linseed and soyabean oils). Its oil length was 71 %.
- A2 which was a linseed alkyd resin with an oil length of 76 %.
- A3 which was a linseed alkyd resin with an oil length of 68 %.

Figure 2 presents a model structure of an alkyd resin modified by vegetable oil. The oil length of this oligomer corresponds to the

amount of fatty acids derived from vegetable oil, which was used to modify the polyester radical of the alkyd. These fatty acid moities play the role of internal plastifiant of the polymer. Thus, the rheological properties of the alkyd resins will depend strongly on their oil length.

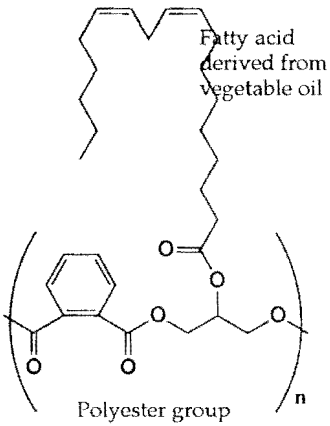

Figure 2: Model structure of an alkyd resin modified by vegetable oil

II.1.2. Test-varnishes

Test-varnishes were formulated using two polymers P1 and P2. P1 had a linear structure, while P2 gave a gel when dispersed in a suitable solvent. Two series of samples were prepared, one based on mixture of polymers and a petroleum distillate with a 260-290 °C boiling range, the other containing linseed oil as third component. Table 1 summarizes the compositions of these model varnishes:

Sample name	P1	P2	Petroleum distillate	Linseed oil
VT1	40 %	0	40 %	20 %
VT2	35 %	5 %	40 %	20 %
VT3	30 %	10 %	40 %	20 %
S1	40 %	0	60 %	0
S2	35 %	5 %	60 %	0
S3	30 %	10 %	60 %	0

Table 1 : Compositions of the samples examined

II.1.3. Additives

To both alkyd resins and test-varnishes we added two different modifiers, viz. a classical bentone compound or a polyamide-type rheological modifier. These two components, called respectively « b » and « a », were added up to 2 % in the samples.

II.1.4. Black coloration of the samples

In order to observe the patterns made by the droplets during ink mist measurements, it was necessary to color those samples. The best contrast was obtained by stirring of a small amount of carbon black, predispersed in an offset varnish. The resulting pigment content was estimated to be lower than 1 % in weight and particular attention was paid to check that the rheological properties of our samples were not altered by this additional component.

All the preparations were made in a laboratory disperser.

II.2. Misting evaluation

II.2.1. Gravimetry

The first evaluation of ink misting was carried out by weighing the amount of product collected on an aluminium foil set up around the rolls of the Tack-o-Scope (see Figure 3). The ink mist is expressed as a % in weight of the total quantity of sample spread on the distribution roll. Experiments were carried on with a known volume of sample at 30°C, using rotating speeds from 50 to 350 m/min. The sample was carefully spread on the distribution roller, then the motor and the distribution rollers were allowed to rotate in contact during 1 min at 50 m/min, in order to correctly distribute the liquid. Then, the tack-measuring roller was set up and the mist was collected on an aluminium foil after a ten-minute rotation period.

II.2.2. By observation and image analysis

A piece of white non-absorbent paper was placed next to the Tack-o-Scope rollers. The patterns obtained with the black samples were observed, compared, and then analysed in order to characterize the various propensies of the samples to mist.

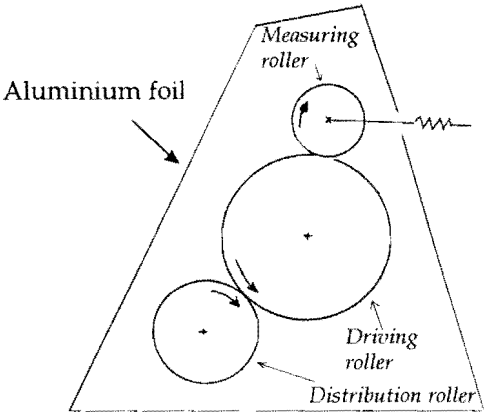

Figure 3: Collecting the ink mist around the Tack-o-Scope rollers

II.3. Rheological measurements

Rheological tests were conducted on a CSL²500 controlled-stress rheometer, with a cone-plate geometry (diameter=2 cm, top angle=4°). Steady shear and oscillatory flow experiments were conducted within appropriate stress and frequency ranges.
In addition to the dynamic measurements on the Carrimed rheometer, the viscoelastic properties of the varnishes were measured on a Metravib viscoanalyser, as described in a previous study [Blayo et al, 1996]. All the experiments were performed in the annular shearing mode. The temperature was allowed to vary from -15 to 20 °C, and 20 frequencies were scanned, from 5 to 500 Hz, at each temperature. With these measurements and the use of the time-temperature superposition principle, master curves were obtained, which enlarged the range of frequencies towards higher values.
The tack of the varnishes was evaluated with a Tack-o-Scope. Experiments were carried on with 0.6 cm^3 samples at 30°C, and at 150 m/min rotating speed.

III. Results and discussion

III.1. Preliminary results

The aim of these experiments was to quantify the influence on misting of parameters such as the sample film thickness or its chemical structure. These experiments were carried out with the alkyd resin

samples. The results presented in Table 2 clearly show that misting dramatically increases with the sample film thickness, which is consistent with the previous studies.

Initial volume spread on the distribution roller (cm^3)	Corresponding thickness (μm)	Amount of misting (%)
0.4	6	2
0.6	10	15
0.8	12	42
1.0	16	60

Table 2: Influence of the sample film thickness on misting. Alkyd resin A1, 30 °C, 150 m/min.

The results presented in Table 3 clearly indicate the dependence of the chemical structure of the sample and its tendency to mist. For example, an alkyd resin with a high oil length (A2: 76 %) is more likely to produce filaments, thus misting, than an alkyd resin with a moderate oil length (A3: 68%). This comparison is valid between A2 and A3 because they are of a similar series. Moreover, this experiment permit to verify that the viscosity cannot explain completely misting phenomena; other rheological characteristics, like elasticity, must be involved.

Sample name	Oil length (%)	Viscosity at 30°C (Pa.s)	Amount of misting (%)
A1	71	50	15
A2	76	9	62
A3	68	71	10

Table 3 : Misting of alkyd resins (30°C; 0.6 cm3; 150 m/min)

III.2. Rheological properties of the samples

III.2.1. Flow characteristics

The test-varnishes studied presented a shear-thinning behavior in the range of shear rates considered. The power-law model (Shear stress = Consistency . (Shear rate)^n) gave a good description of this behavior. The results are summarized in Table 4. The introduction of the polymer P2 led to the increase of the viscosity of the systems, together with a more pronounced shear-thinning behavior. Moreover, the replacement of the petroleum distillate by linseed oil gave a pronounced thickenning of the systems.

Sample name	Consistency ($Pa.s^n$)	n : power-law index	Viscosity at 1500 Pa (Pa.s)
VT1	21.3	0.93	15.7
VT2	31.4	0.90	20.5
VT3	62.0	0.81	28.8
S1	15.1	0.92	10.0
S2	25.2	0.89	15.0
S3	36.8	0.84	18.7

Table 4: Parameters of the power-law model, obtained for the test-varnishes from flow experiments at 20 °C.

The effect of the additives a and b is illustrated similarly by Table 5. The polyamide-type rheological additive had a stronger effect on viscosity than the bentone additive b. The presence of a vegetable compound (linseed oil or alkyd resin) enhanced this effect.

Sample name	Consistency ($Pa.s^n$)	n : power-law index	Viscosity at 2000 Pa (Pa.s)
A3 + a	841	0,97	832
A3 + b	235	0.97	223
S2 + a	56	0.91	31
S2 + b	49	0.88	31
S3 + a	78	0.86	48
S3 + b	75	0.83	41
VT2 + a	72	0.91	53
VT2 + b	68	0.89	47
VT3 + a	122	0.87	86
VT3 + b	105	0.84	65

Table 5: Parameters of the power-law model, obtained for the test-varnishes added with a or b from flow experiments at 20 °C.

III.2.2. Viscoelastic characteristics

The evolution of the elastic character of the samples as a function of the frequency was estimated by the variations of the tangent of the loss angle (tg δ). The figures 4 and 5 present the results obtained for the test-varnishes and the alkyd A3. The increasing content of resin P2 gives a pronounced rise of the elasticity of the samples.

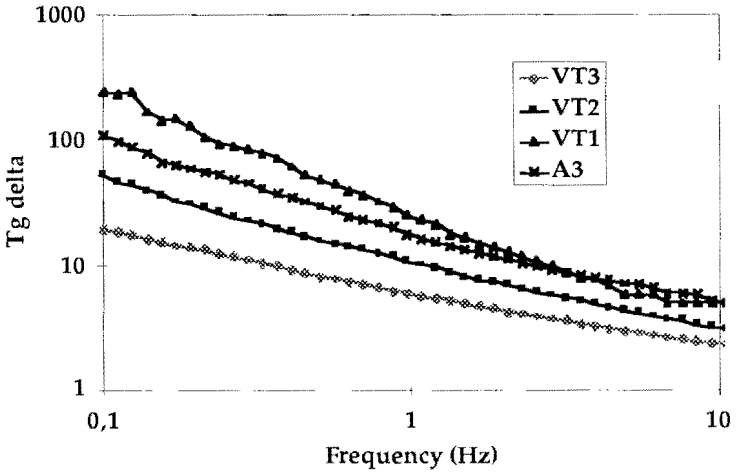

Figure 4: Variations of tgδ of A3, VT1, VT2 and VT3, as a function of the frequency, measured on the rheometer, at 20°C

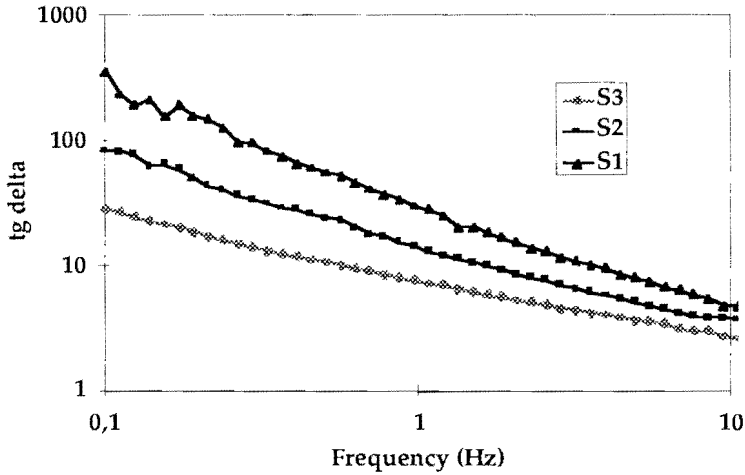

Figure 5: Variations of tgδ of S1, S2 and S3, as a function of the frequency, measured on the rheometer, at 20°C.

The effect of the additives a and b on the viscoelastic characteristic of these samples is presented similarly on the figures 6, 7 and 8. The effect of the additive a on the rheological properties of the samples was more pronounced for A3 than for the test-varnishes containing petroleum distillates. This can be attribute to the stronger interactions between the polyamide and the alkyd resin than between the bentone particles and the alkyd resin. On the contrary, the elasticity of the

samples containting more petroleum distillate (Fig. 8) is more affected by the additive b than the a.

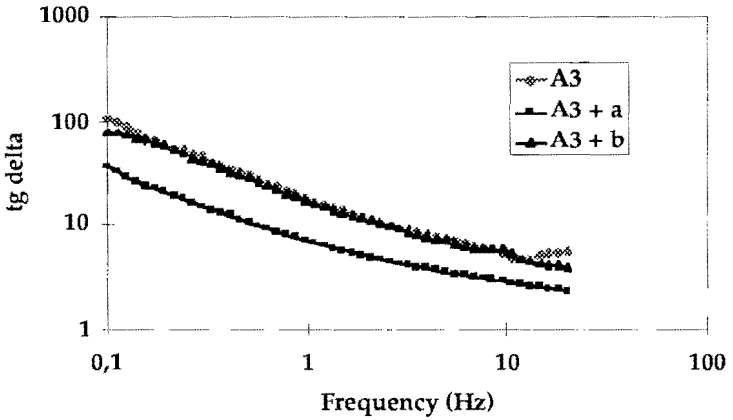

Figure 6: Variations of tgδ of A3, A3 + a and A3 + b, as a function of the frequency, measured on the rheometer, at 20°C.

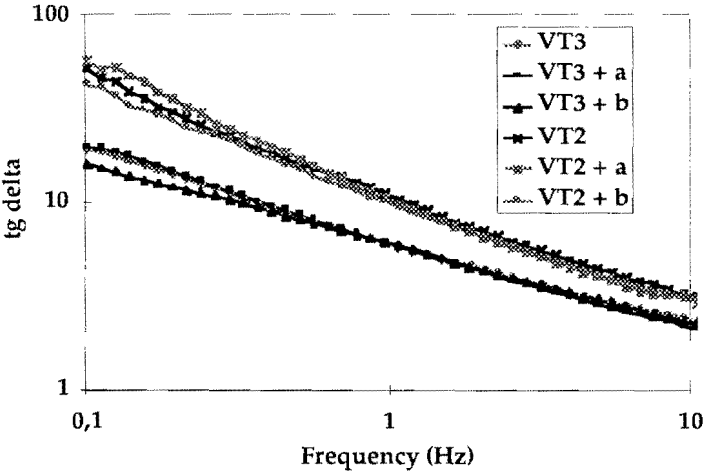

Figure 7: Variations of tgδ of VT2 + a, VT2 + b, VT3 + a and VT3 + b, as a function of the frequency, measured on the rheometer, at 20°C.

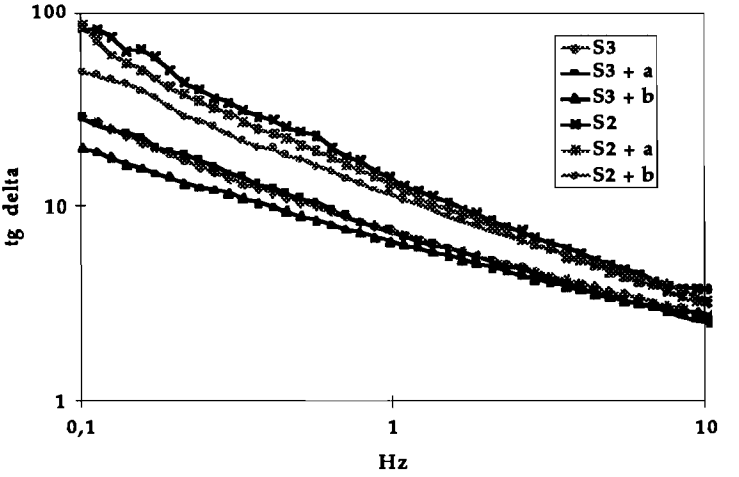

Figure 8: Variations of tgδ of S2 + a, S2 + b, S3 + a and S3 + b, as a function of the frequency, measured on the rheometer, at 20°C.

These measurements were extended to larger ranges of frequencies, by the measurements on the visco-analyser. The results obtained for VT3 and A3 are presented on Figure 9.

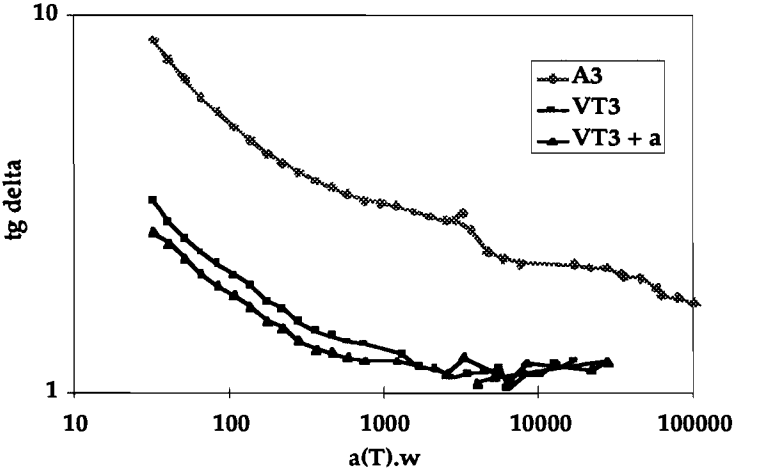

Figure 9: Master curves of tgδ at 20°C, for A3, VT3 and VT3 + a, as a function of the reduced frequency a(T).w, where a(T) is the shift factor and w the pulsation.

III.3. Tack and misting measurements

The tack values are related to the cohesive energy of the samples. Table 6 presents the comparative values of the tack and the misting evaluation for the samples examined. These results suggest that there is a correlation between the cohesive energy and the misting propensy of the systems studied. They also corroborate the previous observations concerning the specific behaviors of the additives, according to the matrix where they intervene.

Sample name	Tack values	Misting (%)
A3	770	10
A3 + a	940	0,3
A3 + b	690	8
VT2	87	31
VT2 + a	130	22
VT2 + b	79	24
VT3	160	22
VT3 + a	220	13
VT3 + b	170	21
S2	13	27
S2 + a	10	25
S2 + b	20	23
S3	13	15
S3 + a	11	16
S3 + b	18	10

Table 6: Tack values (at 2 min) and misting measurements, at 30 °C.

These misting evaluations were compared to the patterns obtained with samples containing carbon black pigments. These observations are consistent with the gravimetric measurements.

Conclusion

Ink misting is an objectionable fact at a time when attention is being increasingly focused on environmental issues. In this work, a special emphasis was made on the study of ink properties, particularly:
- the elastic character of the liquid, which is probabely one of the major causes of misting
- the viscosity, which is obviously not the single parameter,
- the tack, which is related to the cohesive energy.

Some of these properties can be optimized by ink formulation modifications. The influence of some additives on the misting phenomenon was evaluated. The efficiency of these additives depends on the composition of the matrix in which they are incorporated.
Other parameters remain to be thoroughly studied. This work is in progress in our laboratory.

Literature cited

Benjamin D.F., Carvalho M.S., Andersen T.J. and Scriven L.E.
1994 "Forward roll film splitting: theory and experiment",
Coating Conference, San Diego, 1-5 May 1994, TAPPI Press, pp. 109-123.

Blayo A., Gandini A. and J.F. Le Nest
1996 "Rheological Properties of Heatset Inks",
TAGA Proceedings, in press.

Christiansen S.
1995 "Resins Are Gaining Weight"
American Ink Maker, vol.73, no 10, pp. 13,14-60.

Fallani A.
1983 "Current trends in printing ink technology",
Ital. Graph., vol.38, no 3, pp. 4-9.

Gutoff E.B. and Cohen E.D.
1995 "Coating and Drying Defects " John Wiley & Sons, NewYork, pp 92.

Howard J.W. and W.L. Wilbur
1957 "High-speed camera studies of ink misting",
TAGA Proceedings, pp. 153-162, discussion pp 193B-195B.

Kelly E.J., Crouse D.B. and Suspansic R.R.
1974 "Web Offset Operating",
GATF, pp. 152-153.

Leach R.H., R.J.Pierce, E.P.Hickman, M.J.Mackenzie and H.G.Smith,
1993 "The Printing Ink Manual " (Blueprint, London), 5th ed.

McKay R.C.
1994 "Effectiveness of Pigments in Suppression of Misting of Lithographic Printing Inks"
FATIPEC Congress (Paris), vol.22, no 3, pp. 137-150.

MacPhee J. and D.M. Wirth
1989 "Measurements of the Axial Force Required to Drive an Oscillating Roller under a Wide Range of Conditions", TAGA Proceedings, pp. 627-654.

MacPhee J.
1997a "A Unified View of the Film Splitting Process, Part I"
American Ink Maker, vol.75, no1, pp. 42-49.

1997b "A Unified View of the Film Splitting Process, Part II"
American Ink Maker, vol.75, no2, pp. 51-56.

Pugliesi D. and Fabbri I.
1983 "Nebulizzazione negli inchiostri per giornali",
Indicatore Grafico, vol.24, no 6.

Rauenbuehler J.
1966 "Ink misting suppression",
TAGA Proceedings, pp. 410-415.

Reif R.B., L.E. Walkup and C.W.Warner
1964 "Electrostatic control of ink misting on high-speed printing presses", TAGA Proceedings, pp. 279-296.

Southard S.
1958 "Lomist news black inks",
ANPA Mechanical Bulletin no. 660, pp 270-274.

Traber K., Has M. and Dolezalek F.
1993 "Heat Balance in Web Offset Printing Units", TAGA Proceedings, pp. 279-296.

Van der Meulen W.M.
1987 "Misting of Printing Inks ", Am. Ink. Maker., vol. 65, no. 6, pp. 86-88.

Voet A. and C.F. Geffken
1951 "The Nature of Tack ", Ind. Eng. Chem., vol. 43, no. 7, pp. 1614-1624.

Voet A.
1956 "Ink Misting and Its Prevention ", Am. Ink. Maker., vol. 34, no. 2, pp.32.

Volz J
1996 "Rheology modification: Chemically Gelled Vehicles Provide Flexibility in Formulating UV-Cured Inks",
Ink World, October 1996, pp. 48-50.

Anon.
1984 "Ink Fly in Newspaper Pressrooms",
Health and Safety Commission, Printing Industry Advisory Committee.