Study of Rheological Properties and Tack of Offset Printing Inks

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The printability of offset printing inks strongly depends on their rheological properties, tack and water pick-up behaviour. Six process magenta inks drying by oxypolymerization were tested. Two different types of fountain solution were used for preparation of emulsions (one without alcohol and one with the addition of 8 % IPA). The emulsions were characterised by the amount and rate of water pick-up. The rheological properties (shear-load dependent flow and time-dependent bahaviour) of emulsions and unemulsified inks were measured by rotational rheometer HAAKE RotoVisco 1 at different temperatures. The tack and misting of tested inks were measured by Tackmaster-92.

1. Introduction

The quality of offset printing process depends on many chemical and physical specifics of the materials and components involved in the process. The most important are printing inks (e.g. rheological properties, surface tension, temperature behaviour), damping solution (e.g. water hardness, additives, pH value, surface tension), printing plate (e.g. surface tension of printing and nonprinting areas, roughness), inking rollers and its blankets (e.g. surface tension and roughness, viscoelastic properties, ink acceptance and ink transfer behaviour), printing press (e.g. design of the printing, inking and damping unit, temperature control) etc. [1]

Offset printing inks printed on absorbing substrates firstly dry by penetration and afterwards by oxypolymerization. Oxidative drying of offset inks containing drying oils is effected without additional units by molecular linkage with oxygen from the air. Oxidative drying can be accelerated by catalysts such as cobalt or manganese salts of oil soluble acids. Cobalt driers are "surface driers". The drying process is started on the ink surface and slowly proceeds to the substrate. Manganese driers are "through-drier". Addition of small amount of oxygen inhibitors provides that inks do not dry in ink fountain ("semi-fresh inks") or in inking unit ("fresh inks").

One of the most important properties of printing inks are their rheological properties. Their better understanding can determine processibility, help drive technology to better product quality, performance, and eventually growth in consumer acceptance.

2. Experimental part

In this study, six magenta sheetfed offset printing inks (supplied by Flint Group) drying by different speed were tested, three oxidative drying, two semi-fresh and one fresh ink (Table 1). All inks contain vegetable oils and two of them also small amount of mineral oils (Novaboard 2C88 and Novavit 2F1). Emulsions were prepared by using two different types of fountain solutions. First of them is for alcohol free dampening (Dyna Col AC388, PCO Printing Chemicals) and second for alcohol dampening (Dyna Fount 426Ci, PCO Printing Chemicals) with addition of 8 % isopropyl alcohol.

Table 1: Magenta sheetfed offset printing inks tested in this work.

Name of product	Drying	Ink denotation
Novaboard 2C88	oxidation	ox-2C88
Novavit 2F1 Drive	semi-fresh	sf-2F1
Novaboard 2C990 Protect	oxidation	ox-2C990
Novavit 2F100	oxidation	ox-2F100
Novavit 2F918 Supreme Bio	semi-fresh	sf-2F918
Novavit 2X800 SKINEX	fresh	f-2X800

Duke Ink Water Emulsification Tester Model D-10 (HDuke Enterprises, USA) was used for preparation of emulsions. The emulsion properties were defined by the amount of water pick-up and time needed for achievement of saturated emulsion. The method has been described in detail elsewhere [2] and only a brief account is given here. During the test, the 50 g of offset printing ink and 50 g of fountain solution was stirred (90 rpm) and after every 90 turns of stirring tools amount of water pick-up was measured.

Table 2: Duke water pick-up.

	Dyna Col AC388					
	ox-2C88	sf-2F1	ox-2C990	ox-2F100	sf-2F918	f-2X800
E_{max} (%)	76	51	81	50	61	66
t (min)	9	4	10	6	8	7
	Dyna Fount 426Ci					
	ox-2C88	sf-2F1	ox-2C990	ox-2F100	sf-2F918	f-2X800
E_{max} (%)	50	58	76	45	67	51
t (min)	9	5	10	5	7	6

The flow behaviour and the viscosities of unemulsified inks and emulsions were measured on rotational rheometer RotoVisco 1 (HAAKE, Germany). All tests were done with a one cone-plate measuring system (titanium cone with radius 10 mm and angle 1°). Thermostat DC 30 (HAAKE, Germany) was used for temperature control during the tests. Flow characteristics were measured at shear rates from 5 to 800 s^{-1} and at temperatures 20 and 32 °C.

The Tackmaster-92 (Kershaw Instrumentation, USA) was used to measure the tack and misting characteristics of unemulsified inks and their emulsions. The temperature of tackmaster rollers was set to 32 °C for all measurements. The ink was applied to the tackmaster with a small pipette that holds 1.2 cm^3 and left at low speed (300 rpm) for 180 seconds to equilibrate. During the tack measurement (10 minutes), the speed was 1 200 rpm. Misting was performed by way of placing a white paper behind the tackmaster rollers which collects the mist for 10 minutes at 1 200 rpm. Measured parameter was dot area estimated by Image Analysis method. The applied ink volume was triplicated (3.6 cm^3) in comparison with tack measuring. The detailed description of this method is described elsewhere [2].

2.1 Emulsions

In Table 2 are summarized the results of the amount of water pick-up (E_{max}) and time (t) needed to achieve saturated emulsion (1 minute = 90 turns of stirring tools). From the Table 2 is apparent that there are significant differences between magenta inks. The amount of maximum water pick-up E_{max} is between 45 and 81 % (into 100 g of inks is emulsified 45–81 g of fountain solution).Time needed to achieve of saturated emulsion lies between 4 and 10 minutes. Offset inks that pick-up higher amount of fountain solution can have tendency to scumming (mainly Novaboard 2C990 Protect).

2.2 Flow curves

To determine the behaviour of unemulsified inks and emulsions at low and medium flow velocities, rotational tests were run at shear rates 5–800 s^{-1} and curve fitting with rheological model function was applied. Characteristic of tested inks were evaluated by means of Casson model function:

$$\tau^{0.5} = \tau_{0C}{}^{0.5} + \eta_{\infty C}{}^{0.5}\gamma^{0.5} \quad (1)$$

where τ is shear stress (Pa), τ_{0C} Casson yield point (Pa), $\eta_{\infty C}$ Casson viscosity (Pas) and γ shear rate (s^{-1}). [3] In Table 3 are summarized parameters of Casson model for unemulsified and emulsified inks at temperatures 20 and 32°C.

The temperature heavily influences the behaviour of the ink flow. All tested inks show significant decrease of τ_{0C} and $\eta_{\infty C}$. Difference between unemulsified inks and emulsions at 32°C was primarily in parametr $\eta_{\infty C}$. In all cases the estimated values of $\eta_{\infty C}$ were lower for emulsions than unemulsified inks. The parametr $\tau_{0C}/\eta_{\infty C}$ describes the tendency of inks to mist. Inks with higher quotient $\tau_{0C}/\eta_{\infty C}$ has lower tendency to mist than inks with lower $\tau_{0C}/\eta_{\infty C}$. From table 3 is apparent that the quotient $\tau_{0C}/\eta_{\infty C}$ of unemulsified inks decreases with increased temperature (the unemulsified inks will have higher tendency to mist at temperature 32°C than at 20°C) and at the same temperature (32°C) unemulsified inks have lower $\tau_{0C}/\eta_{\infty C}$ than emulsions (emulsion will have lower tendency to mist than unemulsified inks). Results of mist values (dot area of mist droplets) of unemulsified and emulsified inks are summarized in Table 6 (chapter 2.4).

Table 3:
Characteristic of unemulsified and emulsified inks evaluated from flow curves.

		Unemulsified inks		Emulsions	
		20 °C	32 °C	32 °C (D-Col)	32 °C (D- Fount)
ox-2C88	τ_{0C} (Pa)	264.9	85.0	137.5	23.9
	$\eta_{\infty C}$ (Pas)	50.2	24.7	8.0	10.8
	R^2	0.991	0.996	0.983	0.997
	$\tau_{0C} / \eta_{\infty C}$	5.27	3.43	17.02	2.20
sf-2F1	τ_{0C} (Pa)	185.3	38.9	103.1	95.6
	$\eta_{\infty C}$ (Pas)	63.9	27.5	5.6	4.3
	R^2	0.995	0.997	0.987	0.978
	$\tau_{0C} / \eta_{\infty C}$	2.89	1.42	18.09	22.06
ox-2C990	τ_{0C} (Pa)	324.6	123.9	120.8	119.4
	$\eta_{\infty C}$ (Pas)	57.1	21.3	4.8	3.4
	R^2	0.994	0.997	0.975	0.976
	$\tau_{0C} / \eta_{\infty C}$	5.67	5.80	24.73	34.81
ox-2F100	τ_{0C} (Pa)	287.8	47.7	53.7	59.1
	$\eta_{\infty C}$ (Pas)	43.7	31.2	3.6	6.4
	R^2	0.979	0.997	0.992	0.992
	$\tau_{0C} / \eta_{\infty C}$	6.58	1.52	14.65	9.22
sf-2F918	τ_{0C} (Pa)	205.9	90.5	111.1	99.7
	$\eta_{\infty C}$ (Pas)	47.6	24.2	9.4	6.8
	R^2	0.993	0.997	0.993	0.988
	$\tau_{0C} / \eta_{\infty C}$	4.32	3.73	11.75	14.57
f-2X800	τ_{0C} (Pa)	582.2	32.2	109.5	24.5
	$\eta_{\infty C}$ (Pas)	51.3	26.5	2.5	5.5
	R^2	0.974	0.997	0.984	0.997
	$\tau_{0C} / \eta_{\infty C}$	11.34	1.21	42.31	4.46

2.3 Thixotropy

Thixotropic behaviour means the reduction in structural strength during the shear load phase and complete structural regeneration during the subsequent rest phase. Thixotropy is a decrease in the apparent viscosity under shearing, followed by a gradual recovery when the shear is removed. The effect is time dependent. If the viscosity reduces and immediately returns after shearing, the material is not thixotropic but just 'shear thinning'. Substances change from a high viscosity gel to a much lower viscosity sol under exerted high shear during a test period. For real thixotropic substances the transformation from a gel to a sol and conversely is reversible. [4]

In our experiment, thixotropy of unemulsified and emulsified inks was evaluated by method of viscosity regeneration. The test was divided into three intervals, the first interval with $\gamma = 2\ s^{-1}$ for 1 minute, the next interval with $\gamma = 400\ s^{-1}$ for 30 seconds and the last interval with $\gamma = 2\ s^{-1}$ for 3 minutes. From the first interval, when the viscosity was almost constant, η (100%) value was determined. From the third interval (after 3 minutes) the percentage of regeneration was calculated. The temperature during the measurement of viscosity regeneration was 32 °C. Figure 1 shows typical progress and evaluation of viscosity regeneration during the test (unemulsified ink Novaboard 2C88).

The rate of recovery is an essential factor for levelling the ink on the substrate. The results of viscosity regeneration of unemulsified and emulsified inks are summarized in Table 4. Unemulsified inks show faster regeneration of viscosity than emulsions after 180 s. Faster regeneration (Novavit 2X800 SKINEX) facilitates the ability to achieve the required layer thickness, as the ink film strength is reached in shorter time. A slower rate of structural regeneration offer a good levelling behaviour, but too slow rate can cause an increase in dot gain.

Table 4: Percentage of viscosity regeneration for unemulsified and emulsified inks.

Inks	Unemulsified ink (%)	Emulsion D-Col (%)	Emulsion D-Fount (%)
ox-2C88	77.4	41.1	70.2
sf-2F1	75.2	43.3	40.1
ox-2C990	53.6	48.7	43.6
ox-2F100	79.2	53.3	56.3
sf-2F918	57.1	42.8	43.9
f-2X800	73.2	71.0	84.2

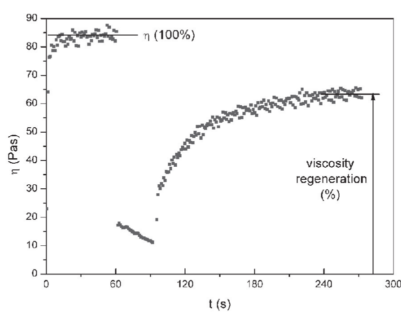


Figure 1: Evaluation of viscosity regeneration (unemulsified ink Novaboard 2C88).

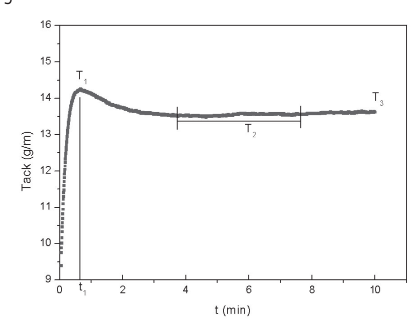
Table 5: Tack of unemulsified and emulsified inks.

Inks	t_1 (s)	T_1 (g/m)	T_2 (g/m)	T_3 (g/m)
ox-2C88	35	14.9	14.0	14.5
ox-2C88 & D-Col	50	14.7	14.6	15.4
ox-2C88 & D-Fount	34	14.1	13.9	14.6
sf-2F1	29	17.4	16.1	16.4
sf-2F1 & D-Col	40	15.3	14.7	15.1
sf-2F1 & D-Fount	41	15.8	15.3	15.4
ox-2C990	34	15.1	13.1	13.1
ox-2C990 & D-Col	44	12.2	11.6	11.7
ox-2C990 & D-Fount	45	14.1	13.9	14.0
ox-2F100	40	14.6	14.2	14.4
ox-2F100 & D-Col	34	13.6	13.0	13.1
ox-2F100 & D-Fount	43	13.4	13.0	13.7
sf-2F918	31	17.9	16.0	16.4
sf-2F918 & D-Col	41	13.4	13.0	13.5
sf-2F918 & D-Fount	40	14.3	13.6	13.6
f-2X800	36	13.2	12.2	12.3
f-2X800 & D-Col	40	10.7	10.5	11.0
f-2X800 & D-Fount	40	10.9	10.5	11.0

Table 6: The comparison of inks misting.

Inks	Dot area of mist droplets (%)		
	Unemulsified ink	Emulsion D-Col	Emulsion D-Fount
ox-2C88	6.28	1.09	1.86
sf-2F1	5.94	1.09	0.98
ox-2C990	4.39	1.40	1.07
ox-2F100	2.44	0.33	0.51
sf-2F918	9.76	4.60	2.22
f-2X800	3.39	1.92	2.11

Figure 2: Evaluation of tack.



2.4 Tack and misting

Tack is the force required to split ink film between two rollers. Tack is an important property in the inking system as well as in the ink/paper interaction and in the ink trapping for multi-colour printing. In order to trap properly, first printed ink should have a higher tack than that of the following one. [4]

Figure 2 shows typical progress and evaluation of tack. The tack of the ink was characterised with three parameters (the maximum at initial stage (T_1), the mean value from the stable middle region (T_2) and the final tack at the end of the test (T_3)). In Table 5 are summarized the results of tack for unemulsified and emulsified inks at 32 °C. High tack is generally desirable, but if the tack is too high it could cause picking (fibres are pulled out of the paper).

Misting, the tendency of ink to fly away from the rollers, was also evaluated on Tackmaster-92. Misting can result in colour contamination and servicing problem for the operator. Papers with misted ink were captured by CCD camera JVC TK-1070E and obtained images were analyzed by Image Analysis method (software AnaTis2). The evaluated parameter was dot area of mist droplets. In Table 6 are summarized the results of misting of unemulsified and emulsified inks at 32 °C.

Emulsified inks misted much less than unemulsified inks (at the same temperature) and the mist droplets were smaller compared to those of unemulsified inks. The lower misting of emulsions is in agreement with results from rheology measurements (parameter $\tau_{0C}/\eta_{\infty C}$, see chapter 2.2). The results of misting of tested inks are similar except ink Novavit 2F918 Supreme Bio. This ink has much higher tendency to mist than the others. The comparision of inks (unemulsified and their emulsions) with the highest (Novavit 2F918 Supreme Bio) and lowest (Novavit 2F100) tendency to mist are shown on Figure 3 (see next page).

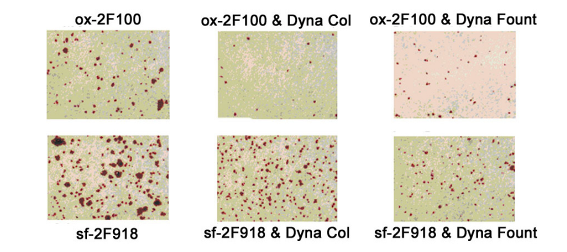


Figure 3:
Misting of unemulsified inks (left column) and their emulsions (middle and right column) for inks Novavit 2F100 and Novavit 2F918 Supreme Bio.

3. Conclusion

The rheological properties, tack and misting of six magenta sheetfed offset printing inks (unemulsified and emulsified) which dry by different mechanism, were investigated. Tested inks contain vegetable oils and two of them also mineral oils. Estimated characteristics were mostly similar and none of the inks have all properties markedly better or worse than the others. From press operators point of view this is a positive result.

Results of fountain solution emulgation into offset printing inks have shown significant differences between tested inks. The variety of maximum water picked-up was from 45 to 81 %. Highest amount of fountain solution picked-up ink Novaboard 2C990 Protect (oxidative, vegetable oil based ink). Offset inks that pick-up larger amount of fountain solution can have tendency to scumming. The rheological study has proved significant decrease of evaluated parameters (τ_{0C}, $\eta_{\infty C}$ and quotient $\tau_{0C}/\eta_{\infty C}$) with increasing temperature. The unemulsified inks have shown higher misting at higher temperature (due to lower quotient $\tau_{0C}/\eta_{\infty C}$). In comparison of unemulsified and emulsified inks, the emulsions will have lower tendency to mist (it was confirmed by measuring of misting droplets on Tackmaster-92, chapter 2.4). The misting of tested inks (at temperature 32 °C) was very similar except ink Novavit 2F918 Supreme Bio. The tack of ink emulsions was in range from 13 to 15 g/m (usual value of tack of offset printing inks), except of fresh ink Novavit 2X800 SKINEX that exhibited lower tack (10.5 g/m).

Acknowledgement

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4. References

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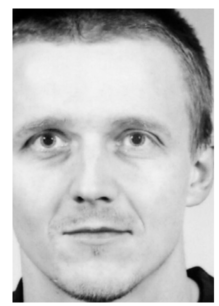

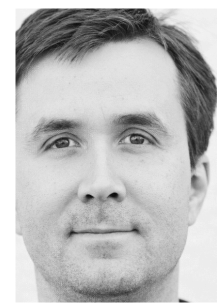

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