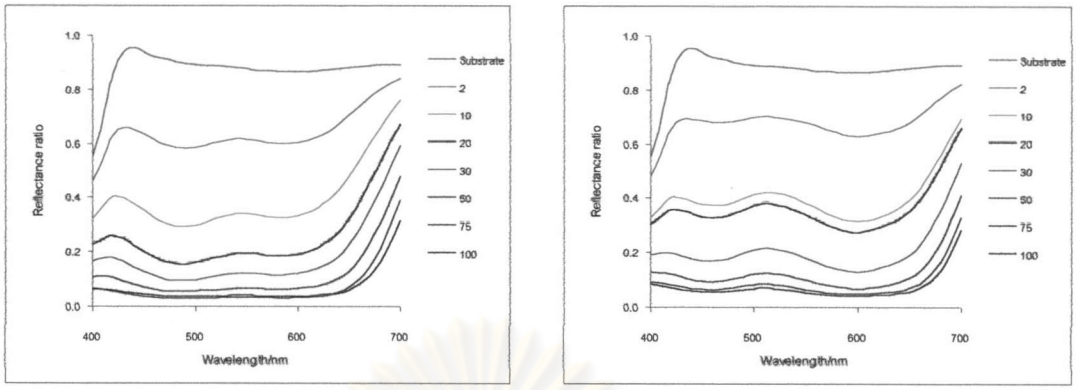
CHAPTER 4

RESULTS AND DISCUSSION

This chapter shows the results and discussions of the experiment. They are divided into four sections: inks calibration, absorption of ink, determination of the optical properties and applications to gamut simulation and gamut comparison.

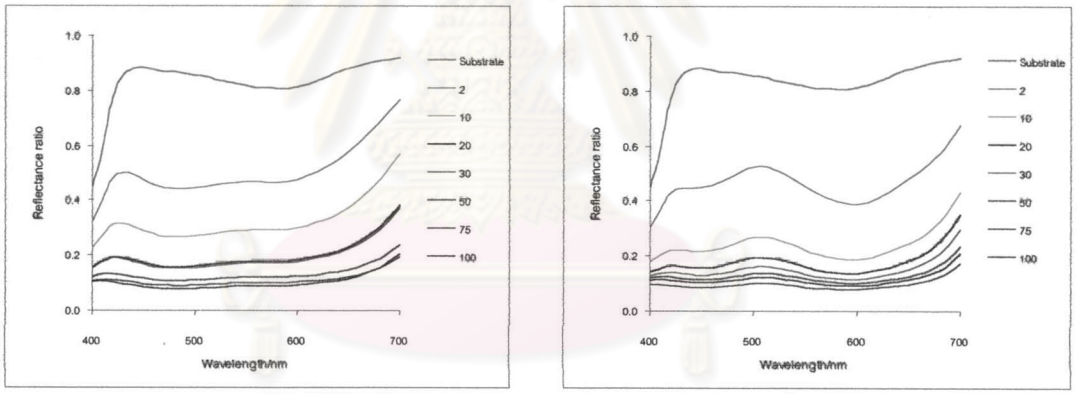
4.1 Inks calibration

Fourteen water-based inkjet inks were calibrated by diluting with water into seven levels. They were then printed onto white and black background coated and uncoated substrates. The reflectance spectrum were measured using a Gretag Macbeth Color Eye 7000 spectrophotometer, they were stored as a database of the ink set. The applications of the database can be used for colorimetric colour matching, spectrophotometric colour matching and gamut matching. The followings are the results of the inks calibration on coated and uncoated papers. Figure 4-1 (a) and Figure 4-1 (b) show the plots of the reflectance spectrum of the Direct Black (reddish) ink and Direct Black (bluish) ink respectively in different levels of concentration printed on coated paper. Figure 4-2 (a) and the figure 4-2 (b) show the plots of the reflectance spectrum of the black inks printed on uncoated paper. The figure 4-2 (a) is reddish black ink and the figure 4-2 (b) is bluish black ink. Figure 4-3 (a-c) show the plots of the reflectance spectrum of the Acid Red 289 ink (a), Basacid Red 510 ink (b) and the reflectance spectrum of Acid Magenta 1 ink (c) printed on coated paper.



(a) (b)

Figure 4-1 The reflectance spectrum of Black (reddish) ink (a) and the reflectance spectrum of Black (bluish) ink (b) printed on coated paper.



(a) (b)

Figure 4-2 The reflectance spectrum of Black (reddish) ink (a) and the reflectance spectrum of Black (bluish) ink (b) printed on uncoated paper.

From Figures 4-1 and 4-2, the reflectance spectra of substrates show that the brightness of coated paper is higher than that of uncoated paper. Both black inks give a darker shade on the coated substrate than on the uncoated substrate. This is because these is less light scattered within the coated layer than within the fiber layer.

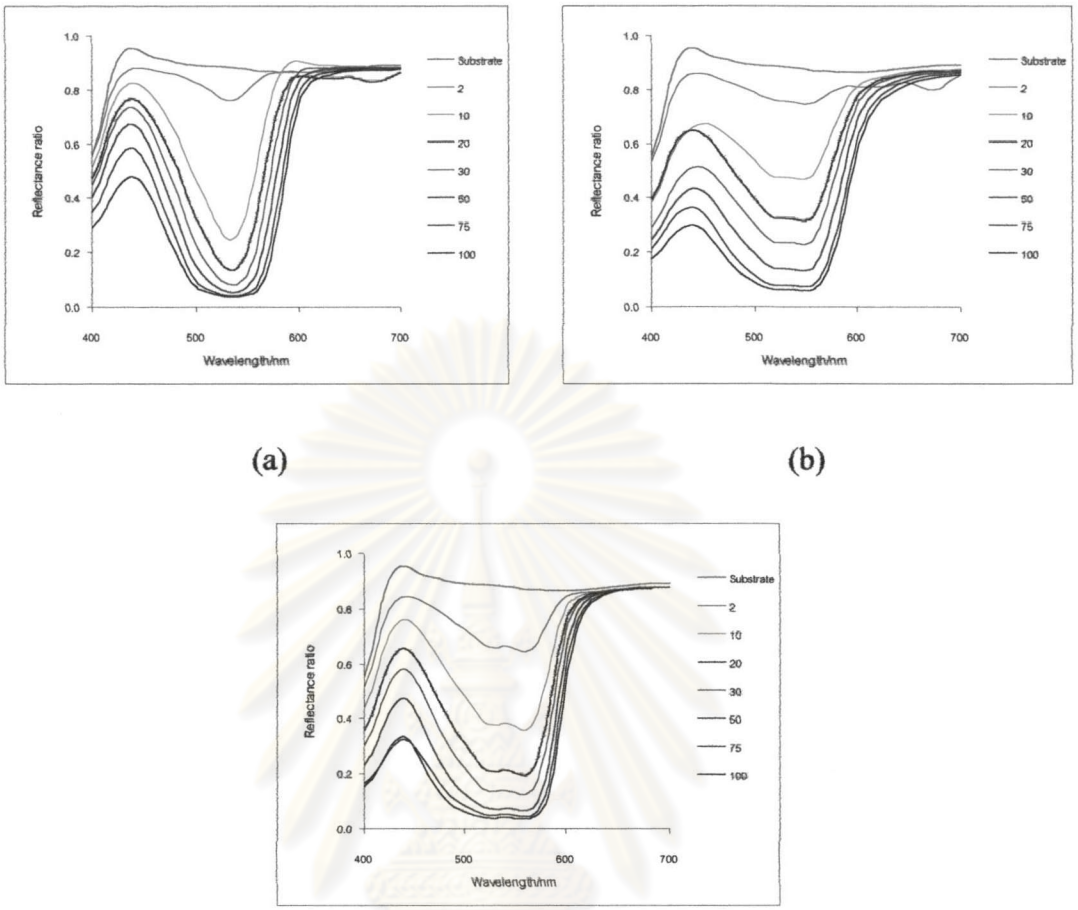


Figure 4-3 The reflectance spectrum of Acid Red 289 ink (a), Basacid Red 510 ink (b) and Acid Magenta 1 (c) printed on coated paper.

Figure 4-4 (a-c) show the plots of the reflectance spectrum of the Acid Red 289 ink (a), Basacid Red 510 ink (b) and the reflectance spectrum of Acid Magenta 1 ink (c) printed on uncoated paper. Figure 4-5 (a-c) show the plots of the reflectance spectrum of the Acid Yellow 23 ink, Direct Yellow 132 ink and Direct Yellow 86 ink printed on coated paper. Figure 4-6 (a-c) show the plots of the reflectance spectrum of the Acid Yellow 23 ink, Direct Yellow 132 ink and Direct Yellow 86 ink printed on uncoated paper.

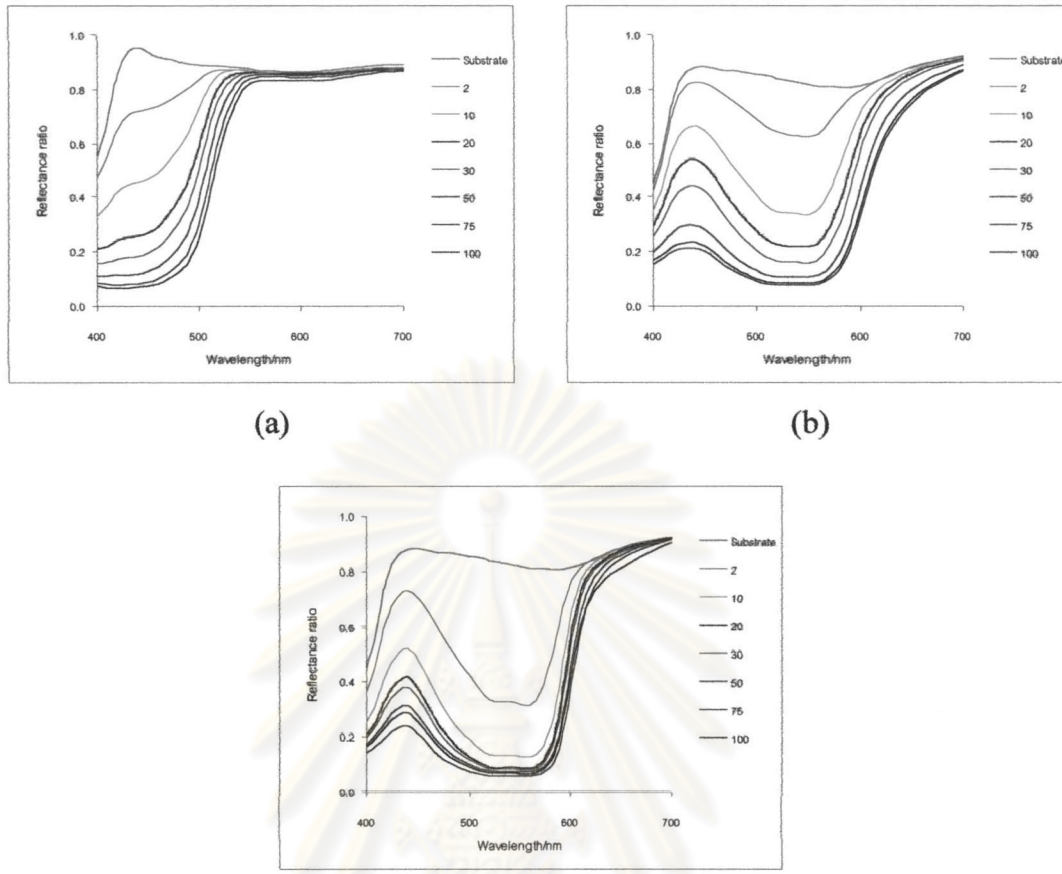


Figure 4-4 The reflectance spectrum of Acid Red 289 ink (a), Basacid Red 510 ink (b) and Acid Magenta 1 ink (c) printed on uncoated paper.

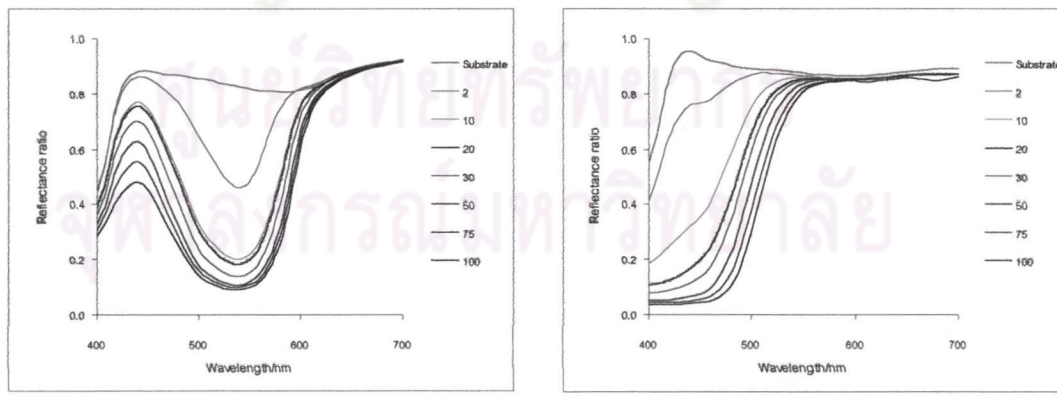
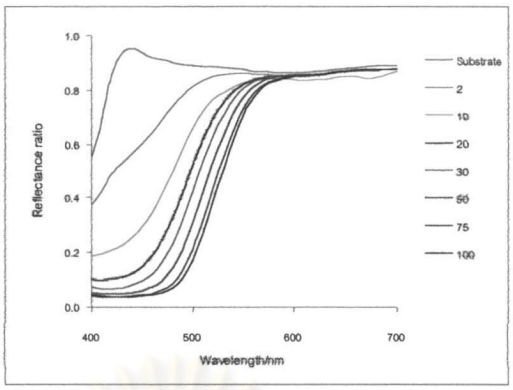
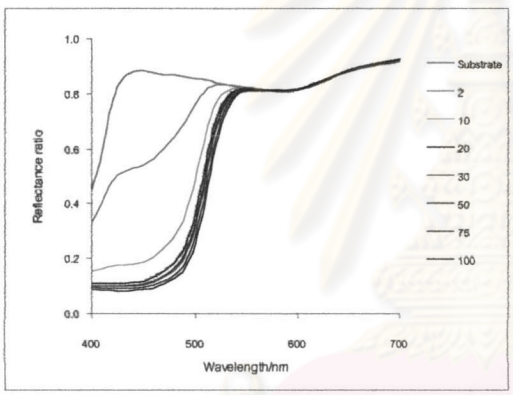


Figure 4-5 The reflectance spectrum of Acid Yellow 23 ink (a) and Direct Yellow 132 ink (b) printed on coated paper.

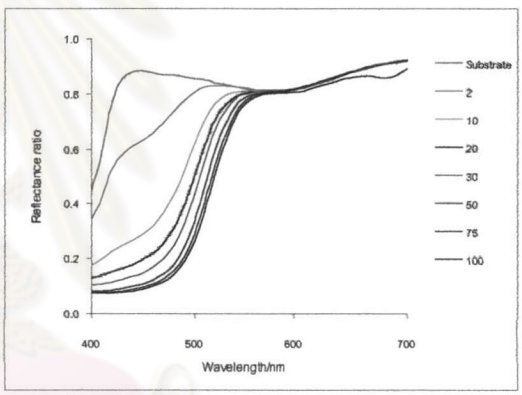


(c)

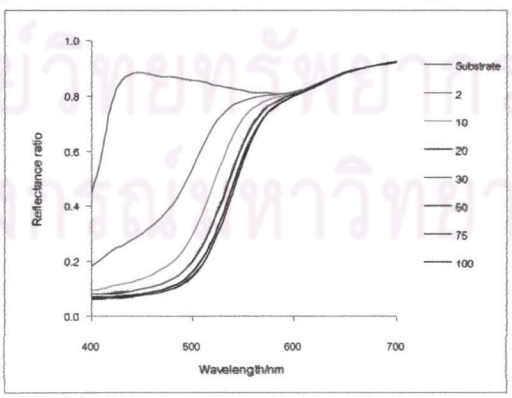
Figure 4-5 (continued) The reflectance spectrum of Direct Yellow 86 ink (c) printed on coated paper.



(a)



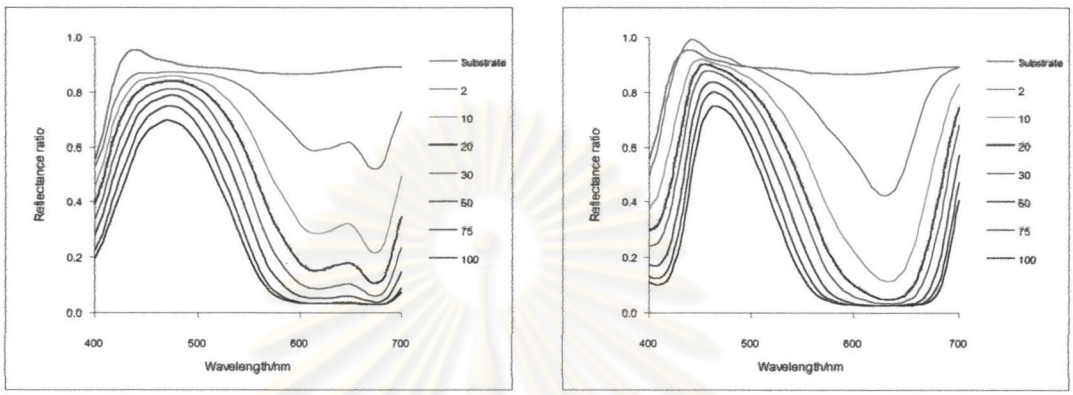
(b)



(c)

Figure 4-6 The reflectance spectrum of Acid Yellow 23 ink (a), Direct Yellow 132 ink (b) and Direct Yellow 86 ink printed on uncoated paper.

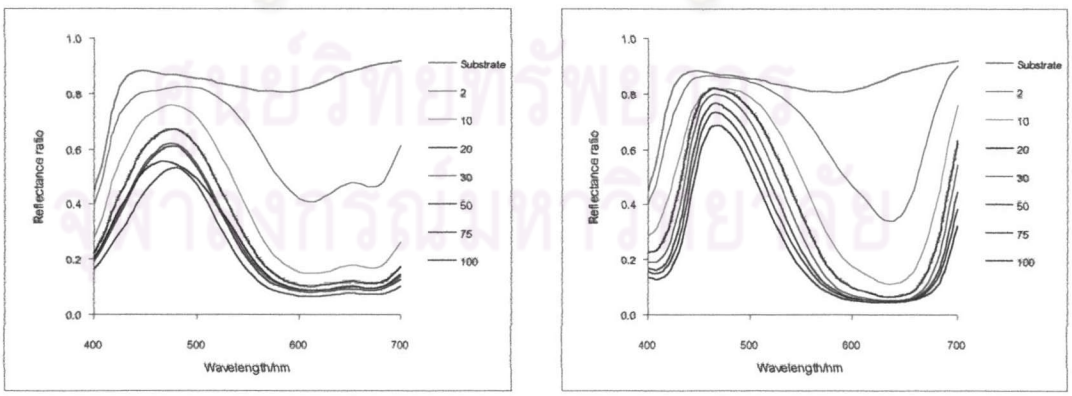
Figure 4-7 (a-b) show the plots of the reflectance spectrum of the Direct Blue 199 ink (a) and Acid Blue 9 ink (b) printed on coated paper.



(a) (b)

Figure 4-7 The reflectance spectrum of the Direct Blue 199 ink (a) and the reflectance spectrum of Acid Blue 9 ink (b) printed on coated paper.

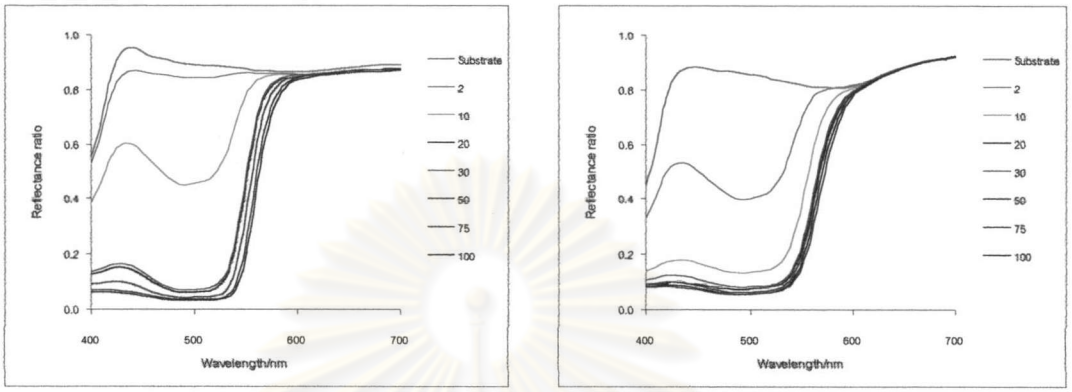
Figure 4-8 (a-b) show the plots of the reflectance spectrum of the Direct Blue 199 ink (a) and Acid Blue 9 ink (b) printed on uncoated paper.



(a) (b)

Figure 4-8 The reflectance spectrum of the Direct Blue 199 ink (a) and the reflectance spectrum of Acid Blue 9 ink (b) printed on uncoated paper.

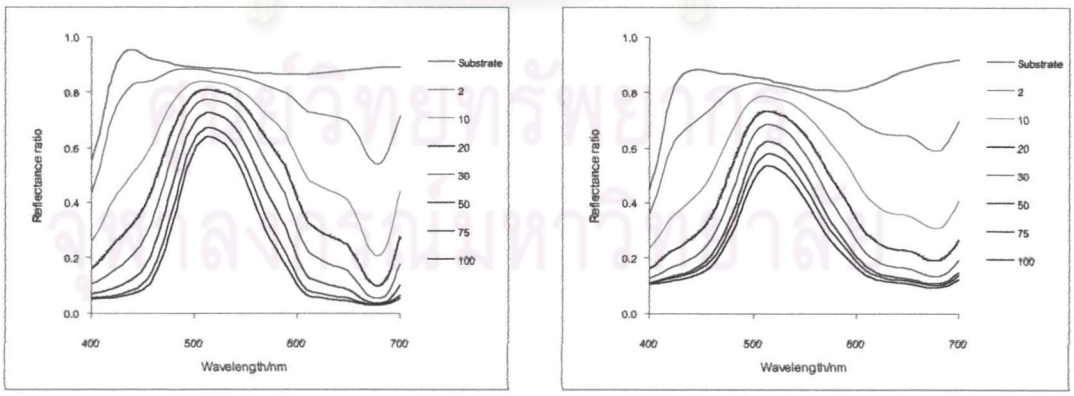
Figure 4-9 show the plots of the reflectance spectrum of the orange ink printed on coated paper (a) and printed on uncoated paper (b).



(a) (b)

Figure 4-9 The reflectance spectrum of the Orange ink printed on coated paper (a) and printed on uncoated paper (b).

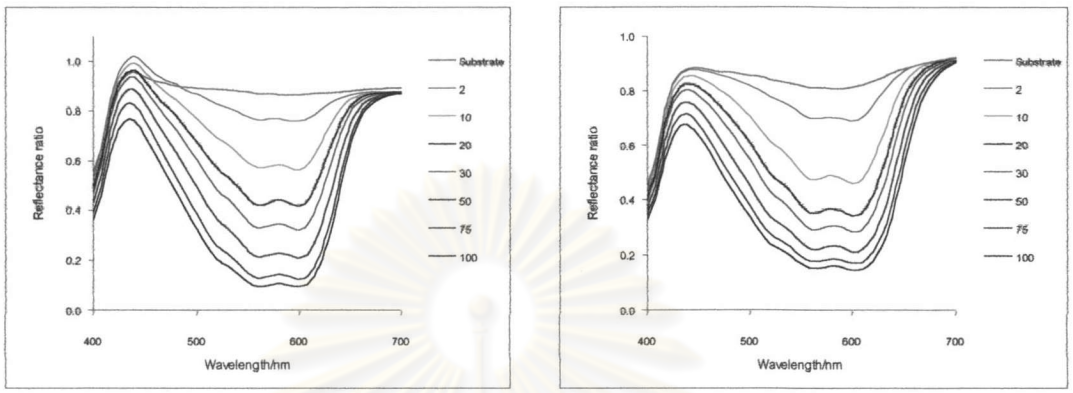
Figure 4-10 (a-b) show the plots of the reflectance spectrum of the green ink printed on coated paper (a) and printed on uncoated paper (b).



(a) (b)

Figure 4-10 The reflectance spectrum of the Green ink printed on coated paper (a) and printed on uncoated paper (b).

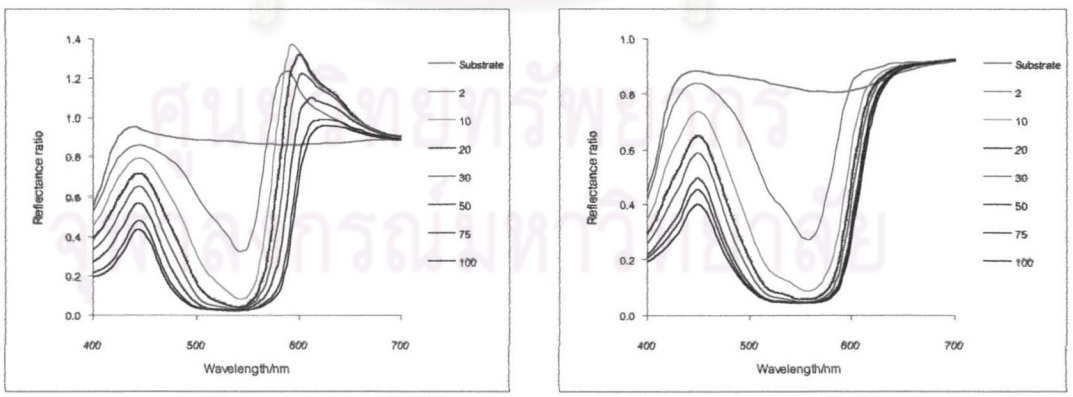
Figure 4-11 (a-b) show the plots of the reflectance spectrum of the violet ink printed on coated paper (a) and printed on uncoated paper (b).



(a) (b)

Figure 4-11 The reflectance spectrum of the Violet ink printed on coated paper (a) and printed on uncoated paper (b).

Figure 4-12 (a-b) show the plots of the reflectance spectrum of the Basonyl Red 540 ink printed on coated paper (a), and printed on uncoated paper (b).



(a) (b)

Figure 4-12 The reflectance spectrum of Basonyl Red 540 ink printed on coated paper (a) and printed on uncoated paper (b).

The fluorescent effect of the Basonyl Red 540 ink is seen remarkably when it is printed on coated paper (Figure 4-12 (a)). At the wavelength of 570-700 nanometers, the reflectance of ink printed on coated substrate is a lot higher than substrate itself, where as the reflectance of ink printed on uncoated substrate is slightly higher than the reflectance of substrate at the wavelength of 590-700 nanometers (Figure 4-12 (b)). The determination of the optical properties of the ink that contains fluorescent dye can cause error values.

The lightness of inks can be rendered very well on coated paper. As seen from the reflectance spectrum of inks on different levels of concentration, the distance of the reflectance spectrum of each ink level printed on uncoated paper is close together compared to that of each ink level printed on coated paper.

4.2 Absorption of the ink

The water dye-based inkjet ink was printed on the substrates that are the coated and uncoated papers. The coated paper has a receiving layer, which is absorbed layer, and a base. The ink penetrates into the receiving layer as shown in Figure 4-13. The depth of ink receiving layer which is equal throughout the sheet is the thickness of ink on the base. In addition the ink absorbed is consistent and the ink receiving material is homogeneous. Therefore, the thickness of the ink layer is known. It was assumed that the ink layer was semitransparent as the ink layer of lithographic ink. Unlike, lithographic printing, various colours in inkjet cause by mixing of inks within the receiving layer.

Figure 4-13 shows the cross-section of coated paper. The photo was taken at magnification of 50 by the light microscope. The scale of the ruler equal 0.0038 mm. The receiving layer was filled with the Direct Blue 199 ink. It was distributed homogeneously since the coated paper used was a micro-porous paper. The characteristic of micro-porous affects the speed of ink absorption. The ink is absorbed into the ink receiving layer so fast that it does not leave the unsmooth gradation as seen in the cross section picture in Figure 4-13.

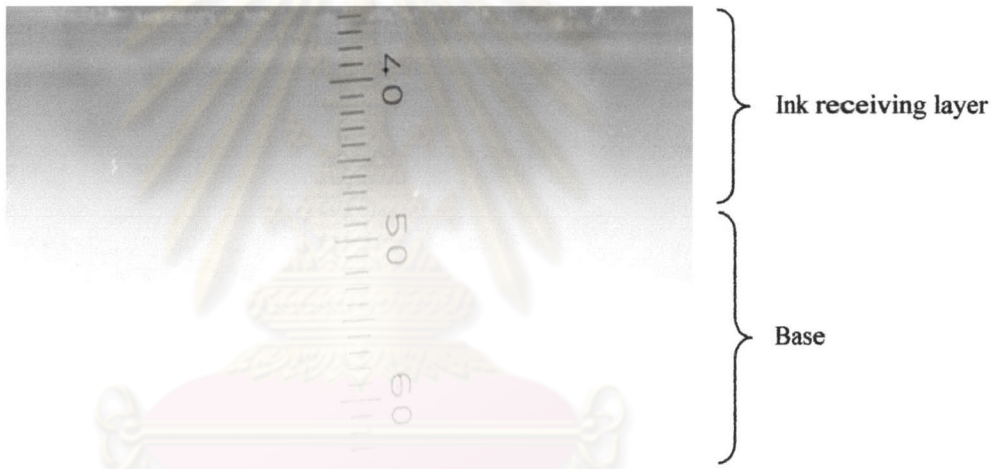


Figure 4-13 The cross-section of coated paper printed using Direct Blue 199 ink.

The colour difference between the print over white and the print over black was above 1. It can be said that the ink layer of inkjet ink is semitransparent. Table 4-1 shows the colour difference between the print over white and the print over black of 6 inks.

Figure 4-14 shows the cross-section of uncoated paper that is printed using Direct Blue 199. The magnification is the same as in Figure 4-13. The ink penetrates into the fibre of paper that is not homogeneous as seen in Figure 4-14. This may affect

the scattering of light entering and the two-contant KM model may be not able to explian this phenomenon very well.

Table 4-1 The colour difference between the print over black and the print over white.

Colourants	dE_{ab}*
Direct Black (reddish)	8
Direct Black (bluish)	4
Direct Blue 199	40
Acid Blue 9	40
Acid Magenta 1	47
Violet	44

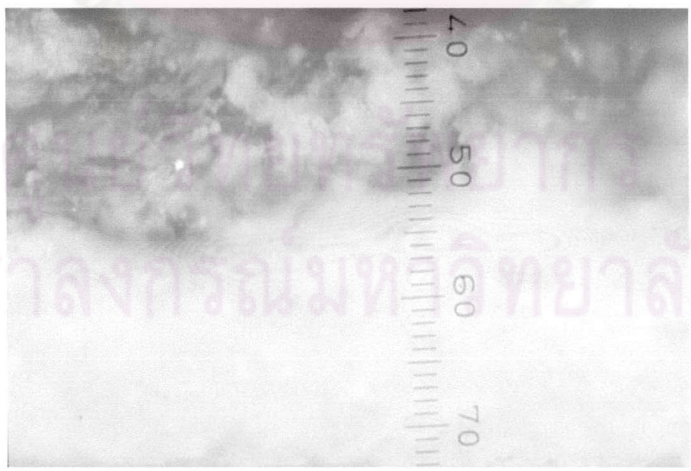


Figure 4-14 The cross-section of uncoated paper printed using Direct Blue 199 ink.

4.3 Determination of the optical properties

4.3.1 Concentration dependence of K and S

The reflectance spectrums obtained were subsequently used to determine the opaque reflectance, absorption coefficients and scattering coefficients. The absorption coefficients of the dyes have a linear relationship with the volume concentrations as shown as an example in Figure 4-15. A range of absorption strengths is shown using the plots of four wavelengths. The degree of linearity of the plots for water-based inkjet ink is similar to that of the plots for lithographic ink. However, the nonlinear dependence of absorption coefficients on concentration often appears as a saturation effect. This causes a plot of absorption coefficient against concentration forming a convex curve rather than a straight line. The nonlinearity then can be characterised by fitting the data to a power series.

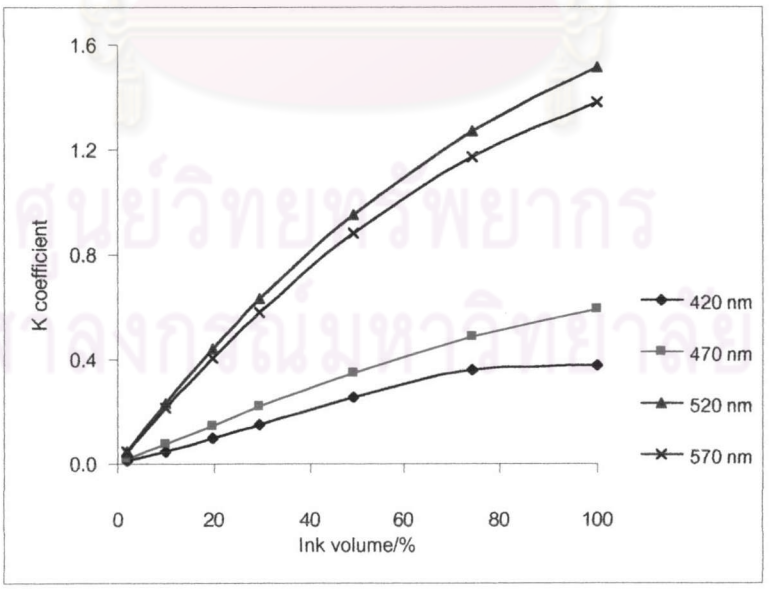


Figure 4-15 Concentration dependence of K for an acid magenta 1 inkjet ink printed on coated paper (PR 101).

The nonlinear dependence of K on C of water-based ink jet ink can be characterised by the following equation:

$$K = aC+bC^2+cC^3 \qquad \textbf{Equation 4-1}$$

4.3.2 Determination of Opaque Reflectance, R_∞

The opaque reflectance was determined in order to be used in the calculation of K and S by using a spreadsheet developed to be easy to use. The flowchart of the calculation is shown in Figure 4-16. An example of calculation of the opaque reflectance of magenta ink is presented in Table 4-2.

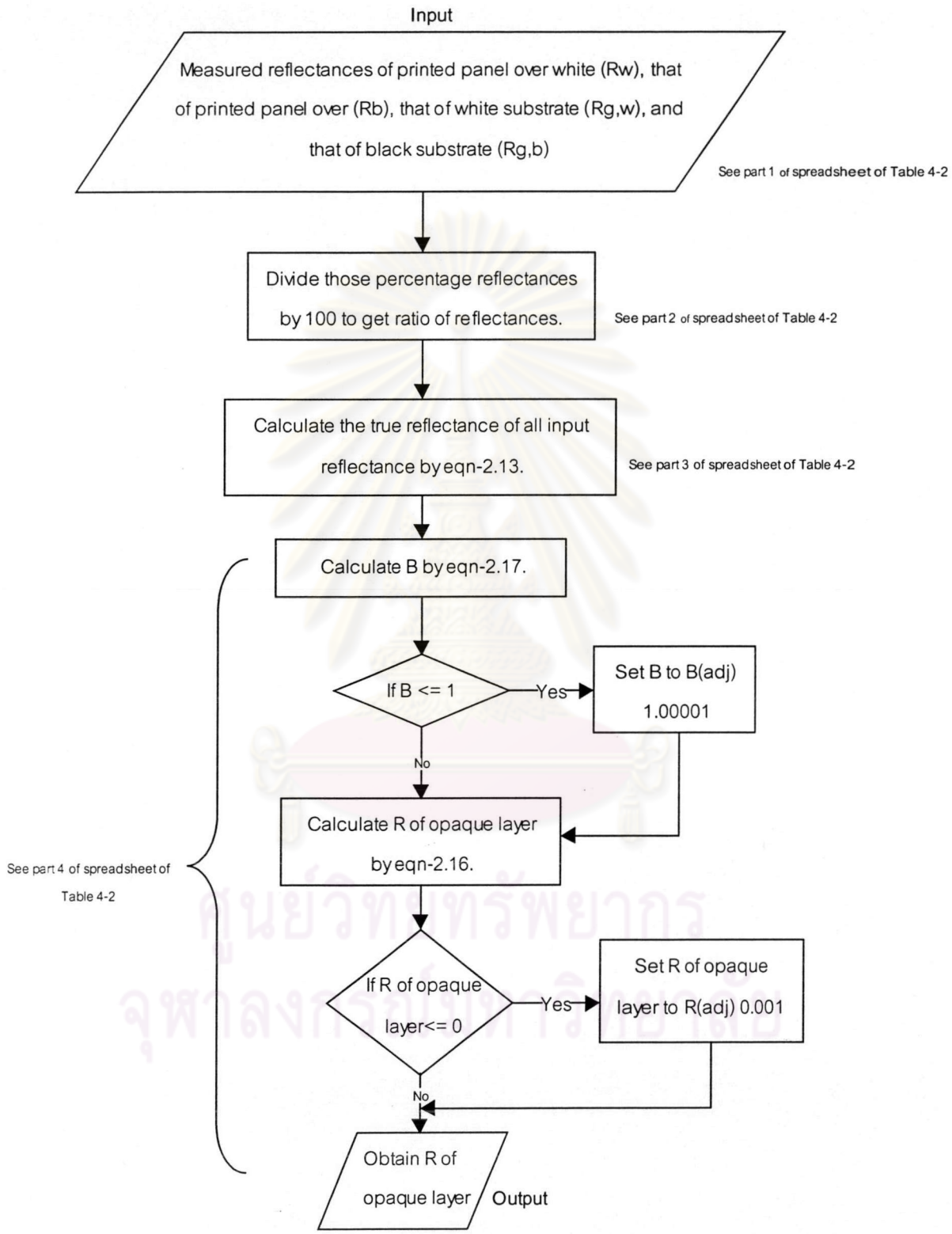


Figure 4-16 Flowchart of the determination of R_{∞}.

Table 4-2 Example of the spreadsheet of determination of R_∞ of Acid Magenta 1.

	Part 1				Part 2				Part 3				Part 4			
Calculation of Infinite Reflectance																
	Measured reflectance				Measured reflectance ratio				Corrected reflectance				Infinite R Calculation			
Wavelength/nm	$\rho_{g,w}$	$\rho_{g,b}$	ρ_w	ρ_b	$\rho_{g,w}$	$\rho_{g,b}$	ρ_w	ρ_b	$\rho_{g,w}$	$\rho_{g,b}$	ρ_w	ρ_b	B	B (adj)	R_∞	R (adj)
400	55.000	5.409	15.398	5.345	0.5500	0.0541	0.1540	0.0535	0.7461	0.0804	0.3028	0.1093	4.2198	4.2198	0.1202	0.1202
410	68.270	4.976	19.111	5.076	0.6827	0.0498	0.1911	0.0508	0.8391	0.0703	0.3627	0.1033	4.2722	4.2722	0.1187	0.1187
420	85.450	4.524	25.625	4.844	0.8545	0.0452	0.2563	0.0484	0.9347	0.0597	0.4559	0.0982	4.1551	4.1551	0.1221	0.1221
430	93.680	4.153	31.933	4.613	0.9368	0.0415	0.3193	0.0461	0.9731	0.0508	0.5343	0.0930	3.9856	3.9856	0.1275	0.1275
440	95.350	3.926	33.677	4.412	0.9535	0.0393	0.3368	0.0441	0.9804	0.0454	0.5542	0.0885	4.0126	4.0126	0.1266	0.1266
450	93.690	3.801	29.274	4.152	0.9369	0.0380	0.2927	0.0415	0.9732	0.0423	0.5025	0.0826	4.5023	4.5023	0.1125	0.1125
460	91.910	3.770	22.252	3.843	0.9191	0.0377	0.2225	0.0384	0.9652	0.0416	0.4093	0.0755	5.4121	5.4121	0.0932	0.0932
470	91.070	3.785	15.964	3.572	0.9107	0.0379	0.1596	0.0357	0.9614	0.0419	0.3123	0.0693	6.4134	6.4134	0.0784	0.0784
480	90.100	3.863	10.969	3.281	0.9010	0.0386	0.1097	0.0328	0.9569	0.0438	0.2238	0.0625	7.5728	7.5728	0.0663	0.0663
490	89.550	4.006	7.798	3.049	0.8955	0.0401	0.0780	0.0305	0.9544	0.0473	0.1614	0.0571	8.6024	8.6024	0.0583	0.0583
500	89.130	4.114	6.140	2.853	0.8913	0.0411	0.0614	0.0285	0.9524	0.0499	0.1266	0.0525	9.5106	9.5106	0.0527	0.0527
510	88.780	4.086	4.835	2.628	0.8878	0.0409	0.0484	0.0263	0.9508	0.0492	0.0980	0.0492	10.1836	10.1836	0.0492	0.0492
520	88.640	3.951	4.024	2.438	0.8864	0.0395	0.0402	0.0244	0.9501	0.0460	0.0797	0.0460	10.9010	10.9010	0.0460	0.0460
530	88.250	3.737	3.819	2.349	0.8825	0.0374	0.0382	0.0235	0.9483	0.0408	0.0750	0.0408	12.2813	12.2813	0.0408	0.0408
540	87.840	3.492	3.894	2.316	0.8784	0.0349	0.0389	0.0232	0.9463	0.0348	0.0767	0.0397	12.5464	12.5464	0.0399	0.0399
550	87.580	3.274	3.740	2.232	0.8758	0.0327	0.0374	0.0223	0.9451	0.0294	0.0732	0.0377	13.1705	13.1705	0.0380	0.0380
560	86.830	3.085	3.599	2.168	0.8683	0.0309	0.0360	0.0217	0.9415	0.0248	0.0699	0.0362	13.6878	13.6878	0.0366	0.0366
570	86.790	2.952	4.268	2.213	0.8679	0.0295	0.0427	0.0221	0.9413	0.0215	0.0852	0.0372	13.1498	13.1498	0.0381	0.0381
580	86.460	2.873	9.017	2.416	0.8646	0.0287	0.0902	0.0242	0.9397	0.0195	0.1860	0.0421	10.8625	10.8625	0.0461	0.0461
590	86.450	2.793	26.053	2.902	0.8645	0.0279	0.2605	0.0290	0.9396	0.0175	0.4615	0.0537	6.2642	6.2642	0.0803	0.0803
600	86.460	2.777	52.666	3.488	0.8646	0.0278	0.5267	0.0349	0.9397	0.0171	0.7330	0.0674	2.8749	2.8749	0.1795	0.1795
610	86.660	2.835	70.850	3.973	0.8666	0.0284	0.7085	0.0397	0.9406	0.0186	0.8575	0.0785	1.6534	1.6534	0.3367	0.3367
620	86.920	2.913	79.822	4.444	0.8692	0.0291	0.7982	0.0444	0.9419	0.0205	0.9074	0.0892	1.2378	1.2378	0.5083	0.5083
630	87.200	3.028	83.625	4.980	0.8720	0.0303	0.8363	0.0498	0.9432	0.0234	0.9268	0.1012	1.1000	1.1000	0.6417	0.6417
640	87.600	3.193	85.482	5.620	0.8760	0.0319	0.8548	0.0562	0.9452	0.0275	0.9359	0.1153	1.0498	1.0498	0.7304	0.7304
650	88.030	3.411	86.401	6.489	0.8803	0.0341	0.8640	0.0649	0.9472	0.0328	0.9403	0.1340	1.0318	1.0318	0.7778	0.7778
660	88.460	3.862	86.963	7.921	0.8846	0.0386	0.8696	0.0792	0.9493	0.0438	0.9430	0.1639	1.0234	1.0234	0.8057	0.8057
670	88.750	4.799	87.224	10.405	0.8875	0.0480	0.8722	0.1041	0.9506	0.0662	0.9442	0.2131	1.0182	1.0182	0.8264	0.8264
680	88.920	6.570	87.364	14.419	0.8892	0.0657	0.8736	0.1442	0.9514	0.1068	0.9449	0.2861	1.0136	1.0136	0.8483	0.8483
690	88.940	10.046	87.497	20.715	0.8894	0.1005	0.8750	0.2072	0.9515	0.1809	0.9455	0.3869	1.0090	1.0090	0.8743	0.8743
700	89.010	15.691	87.600	28.900	0.8901	0.1569	0.8760	0.2890	0.9519	0.2872	0.9460	0.4979	1.0065	1.0065	0.8921	0.8921

4.3.3 Determination of K and S

The K and S are determined using the same spreadsheet as for the calculation of opaque reflectance. The ink can be selected from the dropdown list to determine K and S as shown in Figure 4-17. The flowchart of the calculation is shown in Figure 4-18. An example of the calculation magenta ink is presented in Table 4-3 and Table 4-4.

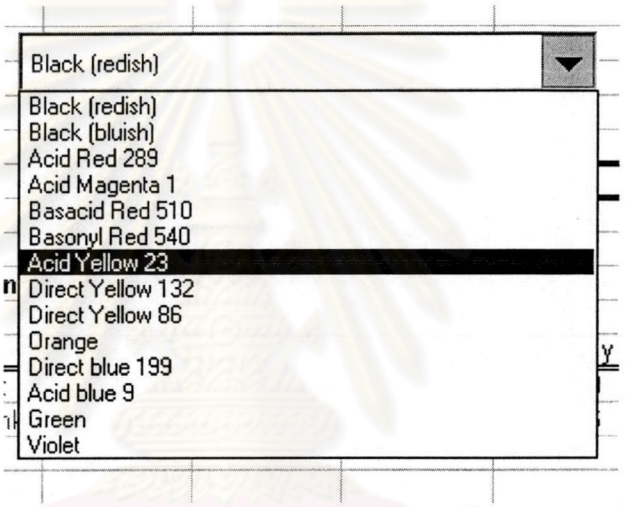


Figure 4-17 The dropdown list of the inks to determine K and S.

The reflectance database consists of reflectance value at seven different concentration levels for each ink stored systematically in the database sheet. By doing this it can locate and obtain the required data correctly when the ink, for which it is desired to determine K and S, is selected from the dropdown list. Once the coloured ink is chosen, K and S are determined. The K and S and R_∞ of the thirteen coloured inks are shown in Table 4-5 (on coated paper) and Table 4-6 (on uncoated paper).

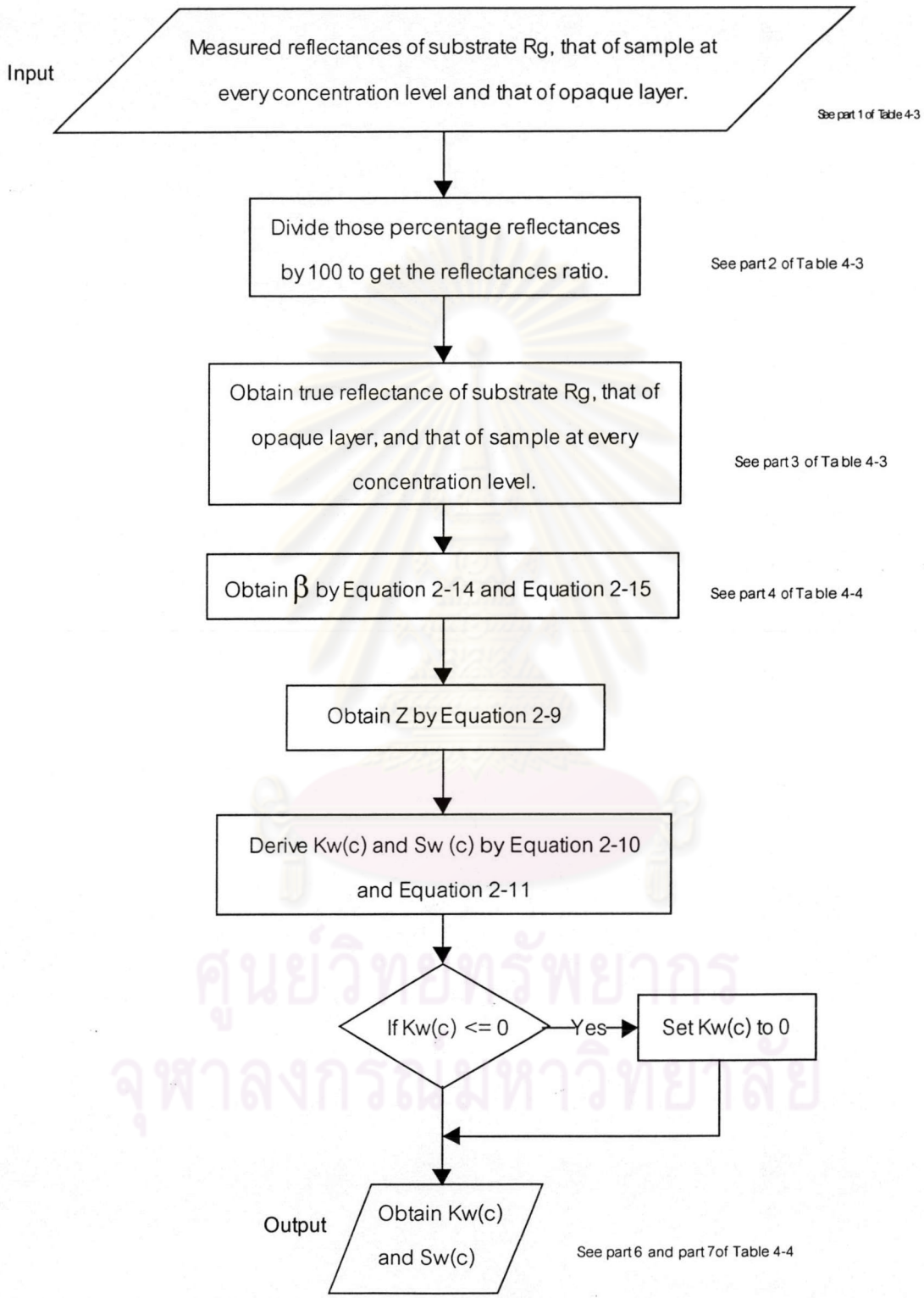


Figure 4-18 Flowchart of calculation of K and S.

Table4-3 1st Spreadsheet of calculation of K and S of Acid Magenta 1 on coated paper.

	Part 1								Part 2								Part 3								
	Measured reflectance								Reflectance ratio								Corrected reflectance								
Wavelength/nm	Subs	2	10	20	30	50	75	100	Subs	2	10	20	30	50	75	100	Subs	2	10	20	30	50	75	100	R_∞
400	55.000	51.597	43.691	35.728	30.434	23.142	16.298	15.398	0.5500	0.5160	0.4369	0.3573	0.3043	0.2314	0.1630	0.1540	0.7461	0.7244	0.6562	0.5767	0.5166	0.4220	0.3178	0.3028	0.1202
410	68.270	61.649	52.888	43.690	37.260	28.710	19.580	19.111	0.6827	0.6165	0.5289	0.4369	0.3726	0.2871	0.1958	0.1911	0.8391	0.7989	0.7347	0.6562	0.5930	0.4955	0.3698	0.3627	0.1187
420	85.450	75.028	65.651	55.329	47.721	37.657	25.189	25.625	0.8545	0.7503	0.6565	0.5533	0.4772	0.3766	0.2519	0.2563	0.9347	0.8815	0.8254	0.7535	0.6922	0.5971	0.4501	0.4559	0.1221
430	93.680	82.335	73.611	63.491	55.712	45.218	30.533	31.933	0.9368	0.8234	0.7361	0.6349	0.5571	0.4522	0.3053	0.3193	0.9731	0.9203	0.8735	0.8113	0.7564	0.6701	0.5178	0.5343	0.1275
440	95.350	84.413	75.870	65.872	58.088	47.418	32.623	33.677	0.9535	0.8441	0.7587	0.6587	0.5809	0.4742	0.3262	0.3368	0.9804	0.9307	0.8862	0.8268	0.7739	0.6896	0.5422	0.5542	0.1266
450	93.690	83.927	73.978	62.927	54.698	43.361	30.102	29.274	0.9369	0.8393	0.7398	0.6293	0.5470	0.4336	0.3010	0.2927	0.9732	0.9283	0.8756	0.8076	0.7487	0.6531	0.5126	0.5025	0.1125
460	91.910	82.277	69.638	56.909	48.012	36.026	24.965	22.252	0.9191	0.8228	0.6964	0.5691	0.4801	0.3603	0.2497	0.2225	0.9652	0.9200	0.8502	0.7653	0.6947	0.5799	0.4470	0.4093	0.0932
470	91.070	80.302	64.584	50.096	40.681	28.540	19.537	15.964	0.9107	0.8030	0.6458	0.5010	0.4068	0.2854	0.1954	0.1596	0.9614	0.9099	0.8185	0.7122	0.6276	0.4934	0.3692	0.3123	0.0784
480	90.100	77.708	58.521	42.548	33.010	21.403	14.349	10.969	0.9010	0.7771	0.5852	0.4255	0.3301	0.2140	0.1435	0.1097	0.9569	0.8962	0.7770	0.6455	0.5466	0.3971	0.2849	0.2238	0.0663
490	89.550	74.920	52.816	35.988	26.619	16.065	10.579	7.798	0.8955	0.7492	0.5282	0.3599	0.2662	0.1607	0.1058	0.0780	0.9544	0.8809	0.7341	0.5795	0.4689	0.3140	0.2164	0.1614	0.0583
500	89.130	72.640	48.504	31.322	22.289	12.754	8.361	6.140	0.8913	0.7264	0.4850	0.3132	0.2229	0.1275	0.0836	0.0614	0.9524	0.8680	0.6989	0.5271	0.4099	0.2567	0.1729	0.1266	0.0527
510	88.780	69.759	43.541	26.276	17.872	9.749	6.481	4.835	0.8878	0.6976	0.4354	0.2628	0.1787	0.0975	0.0648	0.0484	0.9508	0.8509	0.6548	0.4645	0.3433	0.2004	0.1339	0.0980	0.0492
520	88.640	66.618	38.756	21.903	14.305	7.593	5.196	4.024	0.8864	0.6662	0.3876	0.2190	0.1431	0.0759	0.0520	0.0402	0.9501	0.8316	0.6084	0.4043	0.2841	0.1572	0.1060	0.0797	0.0460
530	88.250	65.653	37.500	20.818	13.449	7.076	4.900	3.819	0.8825	0.6565	0.3750	0.2082	0.1345	0.0708	0.0490	0.0382	0.9483	0.8254	0.5955	0.3884	0.2691	0.1464	0.0994	0.0750	0.0408
540	87.840	66.257	38.447	21.604	14.036	7.359	5.039	3.894	0.8784	0.6626	0.3845	0.2160	0.1404	0.0736	0.0504	0.0389	0.9463	0.8293	0.6052	0.4000	0.2795	0.1523	0.1025	0.0767	0.0399
550	87.580	65.342	37.258	20.569	13.225	6.900	4.773	3.740	0.8758	0.6534	0.3726	0.2057	0.1323	0.0690	0.0477	0.0374	0.9451	0.8234	0.5929	0.3847	0.2652	0.1427	0.0966	0.0732	0.0380
560	86.830	64.108	35.758	19.411	12.365	6.461	4.530	3.599	0.8683	0.6411	0.3576	0.1941	0.1237	0.0646	0.0453	0.0360	0.9415	0.8154	0.5770	0.3673	0.2497	0.1334	0.0912	0.0699	0.0366
570	86.790	66.488	39.893	23.349	15.594	8.344	5.580	4.268	0.8679	0.6649	0.3989	0.2335	0.1559	0.0834	0.0558	0.0427	0.9413	0.8307	0.6198	0.4249	0.3061	0.1725	0.1144	0.0852	0.0381
580	86.460	73.727	53.367	37.746	28.796	18.129	12.283	9.017	0.8646	0.7373	0.5337	0.3775	0.2880	0.1813	0.1228	0.0902	0.9397	0.8742	0.7385	0.5980	0.4966	0.3473	0.2482	0.1860	0.0461
590	86.450	80.725	69.790	59.099	51.593	40.356	31.899	26.053	0.8645	0.8073	0.6979	0.5910	0.5159	0.4036	0.3190	0.2605	0.9396	0.9121	0.8511	0.7812	0.7244	0.6244	0.5339	0.4615	0.0803
600	86.460	84.172	80.193	75.396	71.454	64.529	57.873	52.666	0.8646	0.8417	0.8019	0.7540	0.7145	0.6453	0.5787	0.5267	0.9397	0.9295	0.9094	0.8836	0.8610	0.8181	0.7724	0.7330	0.1795
610	86.660	85.279	83.912	82.104	80.504	77.361	73.803	70.850	0.8666	0.8528	0.8391	0.8210	0.8050	0.7736	0.7380	0.7085	0.9406	0.9349	0.9282	0.9192	0.9110	0.8944	0.8746	0.8575	0.3367
620	86.920	85.782	85.308	84.672	84.048	82.828	81.103	79.822	0.8692	0.8578	0.8531	0.8467	0.8405	0.8283	0.8110	0.7982	0.9419	0.9373	0.9351	0.9320	0.9289	0.9228	0.9141	0.9074	0.5083
630	87.200	86.158	86.017	85.799	85.526	85.079	84.144	83.625	0.8720	0.8616	0.8602	0.8580	0.8553	0.8508	0.8414	0.8363	0.9432	0.9392	0.9385	0.9374	0.9361	0.9339	0.9294	0.9268	0.6417
640	87.600	86.677	86.612	86.540	86.422	86.262	85.708	85.482	0.8760	0.8668	0.8661	0.8654	0.8642	0.8626	0.8571	0.8548	0.9452	0.9416	0.9413	0.9410	0.9404	0.9397	0.9370	0.9359	0.7304
650	88.030	87.005	86.989	86.984	86.925	86.896	86.486	86.401	0.8803	0.8701	0.8699	0.8698	0.8693	0.8690	0.8649	0.8640	0.9472	0.9432	0.9431	0.9431	0.9428	0.9427	0.9407	0.9403	0.7778
660	88.460	87.310	87.321	87.330	87.304	87.344	86.979	86.963	0.8846	0.8731	0.8732	0.8733	0.8730	0.8734	0.8698	0.8696	0.9493	0.9446	0.9447	0.9447	0.9446	0.9448	0.9431	0.9430	0.8057
670	88.750	87.465	87.473	87.480	87.458	87.523	87.233	87.224	0.8875	0.8747	0.8747	0.8748	0.8746	0.8752	0.8723	0.8722	0.9506	0.9454	0.9454	0.9454	0.9453	0.9456	0.9443	0.9442	0.8264
680	88.920	87.521	87.514	87.546	87.506	87.608	87.338	87.364	0.8892	0.8752	0.8751	0.8755	0.8751	0.8761	0.8734	0.8736	0.9514	0.9456	0.9456	0.9458	0.9456	0.9460	0.9448	0.9449	0.8483
690	88.940	87.574	87.560	87.584	87.574	87.674	87.423	87.497	0.8894	0.8757	0.8756	0.8758	0.8757	0.8767	0.8742	0.8750	0.9515	0.9459	0.9458	0.9459	0.9459	0.9464	0.9452	0.9455	0.8743
700	89.010	87.656	87.630	87.673	87.661	87.763	87.548	87.600	0.8901	0.8766	0.8763	0.8767	0.8766	0.8776	0.8755	0.8760	0.9519	0.9463	0.9461	0.9463	0.9463	0.9468	0.9458	0.9460	0.8921

Table 4-4 2nd Spreadsheet of calculation of K and S of Acid Magenta 1 ink printed on coated paper.

	Part 4							Part 5							Part 6							Part 7						
	2	10	20	30	50	75	100	2	10	20	30	50	75	100	2	10	20	30	50	75	100	2	10	20	30	50	75	100
Wavelength/nm	β	β	β	β	β	β	β	Z	Z	Z	Z	Z	Z	Z	Kw(c)	Kw(c)	Kw(c)	Kw(c)	Kw(c)	Kw(c)	Kw(c)	Sw(c)	Sw(c)	Sw(c)	Sw(c)	Sw(c)	Sw(c)	Sw(c)
400	0.039	0.182	0.402	0.627	1.163	2.347	2.628	0.019	0.083	0.169	0.243	0.386	0.604	0.644	0.015	0.066	0.133	0.191	0.303	0.474	0.506	0.005	0.020	0.041	0.059	0.094	0.147	0.157
410	0.065	0.185	0.373	0.568	0.998	2.046	2.138	0.031	0.085	0.158	0.225	0.346	0.557	0.572	0.025	0.067	0.125	0.177	0.273	0.439	0.450	0.008	0.020	0.038	0.054	0.083	0.134	0.138
420	0.078	0.173	0.319	0.473	0.790	1.644	1.596	0.038	0.080	0.138	0.194	0.291	0.486	0.477	0.029	0.062	0.108	0.152	0.228	0.380	0.373	0.009	0.020	0.034	0.048	0.072	0.121	0.118
430	0.075	0.150	0.266	0.387	0.627	1.310	1.212	0.036	0.070	0.118	0.164	0.243	0.419	0.397	0.028	0.054	0.091	0.127	0.188	0.324	0.307	0.009	0.018	0.031	0.042	0.063	0.109	0.103
440	0.070	0.139	0.246	0.358	0.580	1.184	1.120	0.034	0.065	0.110	0.153	0.229	0.391	0.376	0.026	0.051	0.085	0.119	0.177	0.303	0.291	0.009	0.017	0.028	0.039	0.059	0.101	0.097
450	0.061	0.142	0.264	0.391	0.656	1.276	1.338	0.030	0.066	0.117	0.165	0.252	0.411	0.425	0.024	0.053	0.094	0.132	0.201	0.328	0.339	0.007	0.015	0.027	0.038	0.057	0.094	0.097
460	0.060	0.165	0.324	0.490	0.862	1.595	1.915	0.029	0.077	0.140	0.199	0.311	0.477	0.535	0.024	0.064	0.116	0.165	0.258	0.396	0.444	0.005	0.014	0.026	0.037	0.058	0.090	0.101
470	0.067	0.208	0.423	0.653	1.212	2.189	2.984	0.032	0.094	0.176	0.251	0.397	0.580	0.691	0.028	0.081	0.151	0.215	0.339	0.496	0.591	0.005	0.015	0.028	0.040	0.063	0.092	0.109
480	0.078	0.269	0.572	0.908	1.800	3.269	4.948	0.037	0.119	0.226	0.323	0.515	0.726	0.892	0.033	0.104	0.198	0.283	0.451	0.635	0.781	0.005	0.016	0.030	0.043	0.069	0.097	0.119
490	0.094	0.344	0.759	1.248	2.644	4.926	8.119	0.045	0.148	0.282	0.405	0.647	0.890	1.105	0.040	0.132	0.251	0.360	0.575	0.792	0.983	0.005	0.017	0.033	0.047	0.076	0.104	0.129
500	0.109	0.412	0.941	1.595	3.580	6.812	11.743	0.052	0.173	0.332	0.477	0.761	1.028	1.272	0.046	0.155	0.298	0.429	0.685	0.925	1.145	0.005	0.018	0.035	0.050	0.080	0.109	0.135
510	0.130	0.511	1.226	2.162	5.193	10.101	18.301	0.061	0.207	0.400	0.576	0.912	1.204	1.480	0.055	0.187	0.362	0.522	0.826	1.091	1.341	0.006	0.020	0.039	0.057	0.090	0.119	0.146
520	0.157	0.634	1.589	2.918	7.440	14.673	26.935	0.073	0.246	0.476	0.683	1.066	1.376	1.665	0.067	0.224	0.434	0.623	0.973	1.255	1.519	0.007	0.023	0.044	0.063	0.098	0.127	0.153
530	0.163	0.661	1.672	3.088	7.882	15.030	26.508	0.075	0.254	0.491	0.704	1.092	1.387	1.657	0.069	0.234	0.453	0.649	1.006	1.279	1.527	0.006	0.021	0.040	0.058	0.089	0.113	0.135
540	0.154	0.626	1.574	2.889	7.329	13.985	24.522	0.072	0.243	0.473	0.679	1.060	1.354	1.620	0.066	0.224	0.437	0.627	0.979	1.250	1.495	0.006	0.019	0.038	0.054	0.085	0.108	0.130
550	0.160	0.657	1.674	3.100	7.937	15.002	25.687	0.074	0.253	0.492	0.706	1.095	1.386	1.642	0.069	0.234	0.456	0.654	1.015	1.285	1.522	0.006	0.019	0.037	0.054	0.083	0.106	0.125
560	0.167	0.697	1.796	3.357	8.629	16.115	27.032	0.077	0.265	0.514	0.736	1.132	1.420	1.667	0.072	0.246	0.478	0.684	1.052	1.320	1.549	0.006	0.019	0.038	0.054	0.083	0.104	0.122
570	0.144	0.572	1.383	2.454	5.922	11.216	18.801	0.067	0.226	0.434	0.620	0.967	1.251	1.493	0.063	0.210	0.402	0.574	0.896	1.160	1.383	0.005	0.017	0.033	0.047	0.074	0.095	0.114
580	0.082	0.303	0.646	1.026	2.051	3.570	5.619	0.040	0.132	0.249	0.353	0.558	0.760	0.945	0.036	0.121	0.227	0.322	0.509	0.693	0.862	0.004	0.012	0.023	0.033	0.052	0.070	0.087
590	0.036	0.123	0.243	0.359	0.623	0.961	1.348	0.017	0.058	0.109	0.153	0.242	0.337	0.427	0.015	0.050	0.093	0.131	0.206	0.287	0.363	0.003	0.009	0.018	0.025	0.039	0.054	0.069
600	0.016	0.048	0.093	0.134	0.222	0.329	0.435	0.008	0.024	0.044	0.063	0.100	0.142	0.181	0.005	0.016	0.031	0.044	0.070	0.099	0.126	0.003	0.009	0.016	0.023	0.037	0.053	0.067
610	0.012	0.027	0.048	0.067	0.108	0.159	0.207	0.006	0.013	0.023	0.032	0.051	0.074	0.094	0.003	0.007	0.012	0.016	0.025	0.037	0.047	0.005	0.010	0.018	0.025	0.039	0.056	0.072
620	0.015	0.023	0.033	0.044	0.065	0.098	0.123	0.007	0.011	0.016	0.022	0.032	0.047	0.058	0.002	0.004	0.005	0.007	0.010	0.015	0.019	0.010	0.015	0.023	0.030	0.043	0.064	0.079
630	0.021	0.024	0.029	0.036	0.047	0.072	0.086	0.010	0.012	0.014	0.018	0.023	0.035	0.041	0.002	0.003	0.003	0.004	0.005	0.008	0.009	0.022	0.026	0.032	0.039	0.051	0.076	0.090
640	0.025	0.027	0.030	0.034	0.040	0.060	0.068	0.012	0.014	0.015	0.017	0.019	0.029	0.033	0.002	0.002	0.002	0.003	0.003	0.005	0.005	0.039	0.042	0.046	0.052	0.061	0.091	0.103
650	0.037	0.037	0.037	0.040	0.041	0.060	0.064	0.018	0.018	0.018	0.020	0.020	0.029	0.031	0.002	0.002	0.002	0.002	0.003	0.004	0.004	0.071	0.072	0.072	0.077	0.080	0.114	0.122
660	0.050	0.049	0.049	0.050	0.048	0.067	0.068	0.024	0.024	0.024	0.024	0.023	0.033	0.033	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.111	0.110	0.109	0.112	0.107	0.149	0.151
670	0.065	0.065	0.064	0.066	0.062	0.080	0.080	0.032	0.031	0.031	0.032	0.030	0.038	0.039	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.165	0.164	0.163	0.166	0.156	0.200	0.201
680	0.087	0.087	0.085	0.088	0.080	0.100	0.098	0.042	0.042	0.041	0.042	0.039	0.048	0.047	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.251	0.253	0.246	0.254	0.233	0.289	0.284
690	0.111	0.112	0.110	0.111	0.101	0.126	0.118	0.052	0.053	0.052	0.052	0.048	0.059	0.056	0.004	0.004	0.003	0.004	0.003	0.004	0.004	0.389	0.394	0.386	0.389	0.356	0.440	0.415
700	0.139	0.143	0.137	0.139	0.126	0.154	0.147	0.065	0.067	0.064	0.065	0.059	0.071	0.068	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.570	0.583	0.562	0.568	0.517	0.624	0.598

Table 4-5 K, S and R_∞ of the dye-based inks printed on coated paper.

	Black (reddish)			Black (bluish)			Acid Magenta 1			Acid Red 289			Basacid Red 510			Acid Yellow 23		
Wavelength/nm	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S
400	0.0804	1.1968	0.2276	0.0820	0.8965	0.1745	0.1202	0.5364	0.1666	0.1980	0.2135	0.1315	0.1054	0.3992	0.1052	0.0873	1.0036	0.2102
410	0.0703	1.2372	0.2014	0.0735	0.9870	0.1691	0.1187	0.4802	0.1467	0.1881	0.2097	0.1197	0.1039	0.3696	0.0956	0.0800	1.0821	0.2046
420	0.0624	1.3436	0.1908	0.0661	1.0963	0.1662	0.1221	0.4022	0.1275	0.1849	0.1909	0.1063	0.1027	0.3376	0.0861	0.0728	1.1164	0.1892
430	0.0567	1.4791	0.1885	0.0605	1.1922	0.1634	0.1275	0.3352	0.1123	0.1841	0.1678	0.0928	0.1022	0.3146	0.0798	0.0680	1.1177	0.1750
440	0.0531	1.6186	0.1918	0.0575	1.2557	0.1625	0.1266	0.3163	0.1050	0.1812	0.1584	0.0856	0.1018	0.3101	0.0783	0.0656	1.0939	0.1644
450	0.0503	1.7382	0.1938	0.0560	1.2859	0.1617	0.1125	0.3597	0.1027	0.1662	0.1753	0.0838	0.0971	0.3362	0.0801	0.0647	1.0398	0.1537
460	0.0480	1.8591	0.1967	0.0550	1.2893	0.1587	0.0932	0.4577	0.1037	0.1379	0.2276	0.0844	0.0885	0.4006	0.0854	0.0655	0.9562	0.1434
470	0.0471	2.0204	0.2097	0.0552	1.2748	0.1575	0.0784	0.5960	0.1101	0.1098	0.3195	0.0885	0.0789	0.5045	0.0939	0.0691	0.8384	0.1337
480	0.0460	2.0727	0.2093	0.0554	1.2250	0.1520	0.0663	0.7786	0.1185	0.0850	0.4650	0.0944	0.0699	0.6377	0.1031	0.0754	0.7099	0.1252
490	0.0473	2.2155	0.2309	0.0563	1.1623	0.1468	0.0583	0.9748	0.1282	0.0660	0.7035	0.1064	0.0638	0.7742	0.1127	0.0888	0.5645	0.1207
500	0.0499	2.3673	0.2617	0.0559	1.1142	0.1397	0.0527	1.1328	0.1331	0.0545	0.9897	0.1208	0.0586	0.9092	0.1203	0.1186	0.3910	0.1194
510	0.0492	2.1529	0.2344	0.0546	1.0920	0.1335	0.0492	1.3219	0.1439	0.0492	1.2246	0.1334	0.0534	1.0585	0.1261	0.1807	0.2287	0.1231
520	0.0460	1.9171	0.1936	0.0517	1.1023	0.1269	0.0460	1.4913	0.1506	0.0460	1.3888	0.1403	0.0500	1.1460	0.1271	0.2751	0.1186	0.1242
530	0.0446	1.8299	0.1790	0.0493	1.1414	0.1245	0.0408	1.4972	0.1327	0.0416	1.4682	0.1330	0.0493	1.1486	0.1253	0.3890	0.0562	0.1171
540	0.0442	1.7859	0.1727	0.0465	1.1969	0.1225	0.0399	1.4697	0.1273	0.0415	1.4782	0.1336	0.0477	1.1515	0.1212	0.4993	0.0261	0.1039
550	0.0430	1.7525	0.1647	0.0440	1.2646	0.1216	0.0380	1.4948	0.1228	0.0439	1.3973	0.1342	0.0463	1.1726	0.1194	0.5777	0.0137	0.0888
560	0.0420	1.7591	0.1610	0.0418	1.3341	0.1214	0.0366	1.5182	0.1197	0.0482	1.1226	0.1193	0.0470	1.0818	0.1120	0.6297	0.0088	0.0812
570	0.0409	1.7700	0.1574	0.0402	1.3968	0.1221	0.0381	1.3625	0.1121	0.0619	0.6637	0.0934	0.0524	0.7747	0.0904	0.6267	0.0078	0.0705
580	0.0408	1.7933	0.1588	0.0395	1.4551	0.1245	0.0461	0.8490	0.0861	0.1065	0.2915	0.0778	0.0689	0.4298	0.0683	0.6271	0.0074	0.0671
590	0.0407	1.7996	0.1591	0.0392	1.4997	0.1275	0.0803	0.3573	0.0679	0.2127	0.1090	0.0748	0.1067	0.2160	0.0578	0.6203	0.0076	0.0655
600	0.0407	1.7627	0.1559	0.0389	1.4992	0.1263	0.1795	0.1241	0.0662	0.3861	0.0355	0.0727	0.1709	0.1050	0.0522	0.6148	0.0078	0.0650
610	0.0415	1.7250	0.1559	0.0400	1.4879	0.1293	0.3367	0.0459	0.0703	0.5503	0.0117	0.0639	0.2466	0.0574	0.0498	0.6134	0.0081	0.0662
620	0.0421	1.6461	0.1512	0.0407	1.4344	0.1269	0.5083	0.0182	0.0764	0.6595	0.0042	0.0481	0.3207	0.0351	0.0488	0.6229	0.0081	0.0707
630	0.0429	1.5391	0.1443	0.0418	1.3762	0.1254	0.6417	0.0083	0.0830	0.7248	0.0014	0.0258	0.3811	0.0243	0.0483	0.6394	0.0079	0.0775
640	0.0441	1.3904	0.1344	0.0425	1.3021	0.1209	0.7304	0.0044	0.0887	0.7667	0.0001	0.0024	0.4299	0.0182	0.0481	0.6625	0.0074	0.0863
650	0.0462	1.1999	0.1218	0.0441	1.2010	0.1158	0.7778	0.0030	0.0939	0.7789	0.0000	-0.0016	0.4729	0.0143	0.0487	0.6889	0.0070	0.0996
660	0.0491	0.9862	0.1070	0.0467	1.0614	0.1092	0.8057	0.0025	0.1056	0.7938	-0.0005	-0.0203	0.5105	0.0114	0.0485	0.7233	0.0064	0.1200
670	0.0662	0.7818	0.1187	0.0662	0.9006	0.1367	0.8264	0.0023	0.1276	0.8076	-0.0014	-0.0625	0.5421	0.0092	0.0474	0.7634	0.0056	0.1538
680	0.1068	0.5994	0.1605	0.1068	0.7204	0.1929	0.8483	0.0023	0.1687	0.8284	-0.0013	-0.0744	0.5756	0.0078	0.0497	0.8045	0.0050	0.2101
690	0.1809	0.4393	0.2369	0.1809	0.5345	0.2882	0.8743	0.0021	0.2377	0.8559	0.0000	0.0037	0.6152	0.0071	0.0587	0.8441	0.0043	0.3004
700	0.2872	0.3161	0.3574	0.2872	0.3826	0.4326	0.8921	0.0022	0.3304	0.8803	0.0013	0.1589	0.6509	0.0065	0.0693	0.8730	0.0039	0.4193

Table 4-5 (continued) K, S and R_∞ of the dye-based inks printed on coated paper.

	Direct Yellow 132			Direct Yellow 86			Direct Blue 199			Acid Blue 9			Orange			Green		
Wavelength/nm	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S
400	0.0643	1.7326	0.3296	0.0804	3.1448	0.5982	0.1158	0.3806	0.1127	0.1074	0.6897	0.1860	0.0817	1.0791	0.2091	0.0804	1.4096	0.2681
410	0.0703	2.5824	0.4204	0.0703	2.3824	0.3878	0.1210	0.2840	0.0890	0.0920	0.7985	0.1781	0.0762	1.1472	0.2049	0.0706	1.3195	0.2158
420	0.0597	1.7995	0.2429	0.0597	1.9098	0.2578	0.1303	0.2130	0.0734	0.0900	0.7081	0.1540	0.0708	1.1780	0.1933	0.0682	1.2983	0.2040
430	0.0508	1.5962	0.1801	0.0508	1.6693	0.1883	0.1449	0.1539	0.0610	0.1146	0.4111	0.1202	0.0662	1.2054	0.1831	0.0671	1.2361	0.1904
440	0.0463	1.4911	0.1518	0.0487	1.6079	0.1731	0.1736	0.1044	0.0531	0.1857	0.1820	0.1020	0.0630	1.2612	0.1810	0.0681	1.1304	0.1772
450	0.0480	1.4386	0.1525	0.0506	1.5848	0.1781	0.2028	0.0766	0.0489	0.2941	0.0811	0.0958	0.0596	1.3645	0.1838	0.0721	0.9736	0.1631
460	0.0509	1.3212	0.1492	0.0531	1.5012	0.1778	0.2248	0.0624	0.0467	0.3689	0.0494	0.0916	0.0562	1.4980	0.1892	0.0809	0.7433	0.1423
470	0.0571	1.0963	0.1407	0.0579	1.3522	0.1765	0.2405	0.0554	0.0462	0.3845	0.0460	0.0934	0.0537	1.6427	0.1972	0.1044	0.4835	0.1259
480	0.0693	0.8039	0.1287	0.0653	1.1091	0.1659	0.2378	0.0574	0.0470	0.3690	0.0537	0.0995	0.0513	1.7549	0.1999	0.1555	0.2777	0.1212
490	0.0969	0.5249	0.1247	0.0798	0.8269	0.1560	0.2179	0.0683	0.0487	0.3302	0.0716	0.1054	0.0502	1.8188	0.2026	0.2354	0.1573	0.1267
500	0.1499	0.3194	0.1325	0.1057	0.5673	0.1499	0.1894	0.0874	0.0504	0.2815	0.1011	0.1103	0.0503	1.8189	0.2027	0.3098	0.1017	0.1322
510	0.2292	0.1865	0.1440	0.1460	0.3671	0.1470	0.1571	0.1173	0.0518	0.2266	0.1464	0.1110	0.0499	1.7800	0.1967	0.3497	0.0808	0.1336
520	0.3188	0.1067	0.1466	0.1983	0.2295	0.1416	0.1253	0.1627	0.0533	0.1700	0.2148	0.1060	0.0495	1.7279	0.1893	0.3458	0.0796	0.1286
530	0.4115	0.0589	0.1399	0.2592	0.1385	0.1308	0.0984	0.2301	0.0557	0.1199	0.3183	0.0986	0.0514	1.5301	0.1746	0.3148	0.0901	0.1208
540	0.4956	0.0323	0.1257	0.3251	0.0815	0.1163	0.0772	0.3300	0.0599	0.0834	0.4665	0.0926	0.0564	1.0422	0.1321	0.2644	0.1125	0.1099
550	0.5685	0.0179	0.1092	0.3966	0.0464	0.1010	0.0613	0.4830	0.0671	0.0614	0.6651	0.0926	0.0708	0.5150	0.0845	0.2051	0.1526	0.0991
560	0.6369	0.0099	0.0959	0.4815	0.0249	0.0892	0.0500	0.7043	0.0779	0.0482	0.9217	0.0980	0.1120	0.2118	0.0602	0.1490	0.2191	0.0901
570	0.6711	0.0063	0.0787	0.5598	0.0134	0.0773	0.0438	0.9763	0.0935	0.0409	1.2333	0.1096	0.1995	0.0810	0.0504	0.1086	0.3096	0.0846
580	0.7037	0.0043	0.0687	0.6417	0.0069	0.0692	0.0401	1.2416	0.1081	0.0364	1.5279	0.1197	0.3343	0.0303	0.0456	0.0816	0.4175	0.0807
590	0.7134	0.0035	0.0610	0.7009	0.0038	0.0589	0.0385	1.4659	0.1221	0.0346	1.7237	0.1281	0.4778	0.0122	0.0428	0.0654	0.5510	0.0825
600	0.7148	0.0033	0.0580	0.7442	0.0020	0.0457	0.0372	1.6514	0.1327	0.0338	1.8037	0.1307	0.5827	0.0057	0.0384	0.0513	0.7957	0.0907
610	0.6992	0.0037	0.0566	0.7539	0.0015	0.0362	0.0374	1.7727	0.1431	0.0334	1.8361	0.1315	0.6208	0.0039	0.0336	0.0452	1.0561	0.1048
620	0.7038	0.0037	0.0588	0.7702	0.0011	0.0326	0.0381	1.7887	0.1473	0.0330	1.8453	0.1301	0.6424	0.0031	0.0314	0.0439	1.1719	0.1124
630	0.7129	0.0036	0.0624	0.7861	0.0009	0.0310	0.0388	1.7686	0.1487	0.0326	1.8471	0.1286	0.6567	0.0028	0.0310	0.0429	1.2520	0.1171
640	0.7266	0.0035	0.0690	0.8078	0.0007	0.0321	0.0395	1.7226	0.1474	0.0332	1.8845	0.1340	0.6662	0.0026	0.0307	0.0423	1.3055	0.1205
650	0.7302	0.0038	0.0766	0.8192	0.0007	0.0331	0.0395	1.7043	0.1459	0.0352	1.9321	0.1460	0.6715	0.0025	0.0309	0.0419	1.3782	0.1257
660	0.7242	0.0049	0.0938	0.8284	0.0005	0.0279	0.0438	1.9906	0.1908	0.0438	2.1636	0.2074	0.6585	0.0028	0.0318	0.0438	1.6214	0.1554
670	0.7234	0.0066	0.1248	0.8396	0.0002	0.0116	0.0407	2.1420	0.3252	0.0662	2.1789	0.3308	0.6370	0.0034	0.0333	0.0468	2.0077	0.3048
680	0.7479	0.0073	0.1727	0.8550	0.0003	0.0283	0.0434	2.1299	0.5705	0.1068	1.2281	0.3289	0.6423	0.0035	0.0350	0.0465	1.9785	0.5299
690	0.7985	0.0063	0.2466	0.8780	0.0010	0.1150	0.0703	2.0180	1.0881	0.1809	0.5209	0.2808	0.6788	0.0028	0.0374	0.0587	1.9927	1.0745
700	0.8458	0.0047	0.3350	0.8949	0.0016	0.2642	0.1383	1.6999	1.9224	0.3612	0.2323	0.4112	0.7116	0.0022	0.0376	0.0994	1.8345	2.0746

Table 4-6 K, S and R_∞ of the dye-based inks printed on coated paper and printed on uncoated paper.

	Violet on coated paper			Black (reddish) on uncoated paper			Black (bluish) on uncoated paper			Acid Magenta 1 on uncoated paper			Acid Red 289 on uncoated paper			Basacid Red 510 on uncoated paper		
Wavelength/nm	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S
400	0.2790	0.1370	0.1471	0.1860	2.2542	1.6493	0.2034	2.8099	2.0554	0.2213	1.5188	1.1089	0.2200	0.1657	0.1198	0.2213	0.7835	0.5720
410	0.3291	0.0958	0.1401	0.1901	2.1767	1.6993	0.2073	2.7841	2.1730	0.2305	1.3016	1.0137	0.2294	0.1835	0.1417	0.2306	0.7027	0.5474
420	0.3878	0.0631	0.1305	0.1853	2.1886	1.7029	0.2028	2.7869	2.1681	0.2300	1.0829	0.8401	0.2289	0.1918	0.1477	0.2301	0.6359	0.4936
430	0.4098	0.0505	0.1187	0.1736	2.2726	1.6469	0.1929	2.8830	2.0889	0.2197	0.9148	0.6603	0.2186	0.1637	0.1173	0.2199	0.5999	0.4336
440	0.3890	0.0541	0.1127	0.1601	2.3664	1.6269	0.1864	2.9540	2.0305	0.2124	0.8801	0.6025	0.2112	0.1549	0.1051	0.2126	0.6033	0.4136
450	0.3392	0.0708	0.1100	0.1482	2.4555	1.6562	0.1842	2.9701	2.0028	0.2098	1.0351	0.6958	0.2088	0.1874	0.1250	0.2100	0.6593	0.4436
460	0.2856	0.0956	0.1070	0.1379	2.5315	1.7262	0.1856	2.9373	2.0022	0.2115	1.3582	0.9239	0.2107	0.2757	0.1864	0.2115	0.7833	0.5330
470	0.2409	0.1295	0.1083	0.1305	2.5808	1.8253	0.1904	2.8661	2.0262	0.2167	1.8270	1.2903	0.2161	0.4194	0.2951	0.2167	0.9797	0.6919
480	0.2056	0.1737	0.1132	0.1286	2.5937	1.9795	0.2006	2.7348	2.0861	0.2275	2.5462	1.9417	0.2272	0.6251	0.4755	0.2275	1.2248	0.9339
490	0.1759	0.2280	0.1181	0.1289	2.5850	2.1440	0.2121	2.5994	2.1547	0.1932	3.1556	2.6161	0.2394	0.9374	0.7761	0.2127	1.4728	1.2209
500	0.1484	0.2930	0.1199	0.1321	2.5580	2.2585	0.2209	2.4981	2.2043	0.1615	3.6251	3.2000	0.2488	1.3366	1.1790	0.1819	1.7098	1.5091
510	0.1191	0.3843	0.1180	0.1366	2.5221	2.2736	0.2240	2.4694	2.2248	0.1329	4.1365	3.7290	0.2188	1.6683	1.5031	0.1575	1.9517	1.7592
520	0.0973	0.4745	0.1133	0.1413	2.4795	2.1661	0.2199	2.5083	2.1900	0.1141	4.5469	3.9728	0.1866	1.9047	1.6634	0.1449	2.1013	1.8356
530	0.0834	0.5436	0.1079	0.1461	2.4369	1.9999	0.2114	2.6022	2.1345	0.1106	4.6497	3.8167	0.1644	2.0963	1.7201	0.1431	2.1343	1.7515
540	0.0702	0.6327	0.1027	0.1512	2.3976	1.8089	0.2006	2.7308	2.0595	0.1124	4.6060	3.4760	0.1621	2.1299	1.6068	0.1430	2.1474	1.6203
550	0.0590	0.7553	0.1007	0.1541	2.3756	1.6275	0.1882	2.8732	1.9679	0.1078	4.7193	3.2343	0.1809	1.9648	1.3458	0.1429	2.1498	1.4730
560	0.0532	0.8295	0.0985	0.1563	2.3587	1.4786	0.1775	3.0010	1.8809	0.1074	4.7239	2.9623	0.2003	1.5929	0.9979	0.1562	1.9937	1.2498
570	0.0527	0.8052	0.0945	0.1572	2.3557	1.3723	0.1691	3.1027	1.8072	0.1324	4.1353	2.4094	0.1905	1.0872	0.6323	0.1907	1.5765	0.9180
580	0.0520	0.7673	0.0888	0.1573	2.3497	1.2945	0.1629	3.1646	1.7433	0.1835	2.5986	1.4308	0.1830	0.6055	0.3321	0.1834	1.0184	0.5603
590	0.0497	0.8001	0.0882	0.1589	2.3382	1.2514	0.1599	3.1851	1.7046	0.1795	1.1766	0.6276	0.1784	0.2651	0.1402	0.1795	0.5785	0.3085
600	0.0486	0.8430	0.0906	0.1629	2.3112	1.2401	0.1606	3.1434	1.6867	0.1788	0.4496	0.2385	0.1882	0.0696	0.0397	0.1792	0.2940	0.1564
610	0.0528	0.7551	0.0889	0.1690	2.2696	1.2665	0.1654	3.0539	1.7042	0.2029	0.1687	0.1078	0.2098	0.0073	0.0049	0.1895	0.1490	0.0859
620	0.0687	0.5381	0.0853	0.1758	2.2215	1.3247	0.1730	2.9307	1.7477	0.2535	0.0546	0.0497	0.2215	0.0000	0.0000	0.2148	0.0782	0.0545
630	0.1114	0.3065	0.0865	0.1846	2.1675	1.3992	0.1826	2.7960	1.8050	0.3083	0.0136	0.0176	0.2331	0.0000	0.0000	0.2416	0.0457	0.0384
640	0.2040	0.1513	0.0974	0.1962	2.1010	1.4822	0.1936	2.6619	1.8779	0.3516	0.0000	0.0000	0.2256	0.0000	0.0000	0.2673	0.0288	0.0287
650	0.3514	0.0694	0.1160	0.2109	2.0090	1.5609	0.2057	2.5129	1.9525	0.3844	0.0000	0.0000	0.3963	0.0000	0.0000	0.2945	0.0197	0.0233
660	0.5173	0.0320	0.1418	0.2316	1.8906	1.6592	0.2218	2.3320	2.0468	0.4289	0.0000	0.0000	0.7811	0.0000	0.0000	0.3328	0.0130	0.0195
670	0.6628	0.0157	0.1827	0.2572	1.7470	1.7957	0.2436	2.1053	2.1641	0.4934	0.0000	0.0000	0.9464	0.0000	0.0000	0.3926	0.0088	0.0186
680	0.7648	0.0086	0.2386	0.2887	1.5828	2.0102	0.2746	1.8416	2.3391	0.5829	0.0000	0.0000	0.9499	0.0000	0.0000	0.4662	0.0055	0.0180
690	0.8316	0.0054	0.3146	0.3286	1.3992	2.3645	0.3191	1.5446	2.6103	0.6949	0.0000	0.0000	0.9535	0.0000	0.0000	0.5600	0.0030	0.0175
700	0.8699	0.0040	0.4076	0.3743	1.2093	2.8812	0.3755	1.2517	2.9822	0.8015	0.0000	0.0000	0.9565	0.0000	0.0000	0.6478	0.0016	0.0167

Table 4-6 (continued) K, S and R_∞ of the dye-based inks printed on uncoated paper.

	Acid Yellow 23			Dirfect Yellow 132			Direct Yellow 86			Direct Blue 199			Acid Blue 9			Orange		
Wavelength/nm	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S	Opaque R	K	S
400	0.1537	4.2531	3.1131	0.1230	2.8517	2.0880	0.1111	4.5582	3.3379	0.2211	1.4907	1.0862	0.2215	1.4032	1.0257	0.1453	6.2943	4.6076
410	0.1468	4.4473	3.4733	0.1197	2.9258	2.2855	0.1101	4.7023	3.6735	0.2301	1.1472	0.8908	0.2308	1.6415	1.2808	0.1491	6.6364	5.1828
420	0.1435	4.5653	3.5532	0.1235	2.9041	2.2606	0.1139	4.8863	3.8039	0.2295	0.9076	0.7016	0.2303	1.3728	1.0672	0.1552	6.8514	5.3321
430	0.1419	4.5971	3.3320	0.1312	2.8044	2.0328	0.1191	4.8703	3.5306	0.2190	0.7063	0.5072	0.2199	0.7785	0.5626	0.1533	6.7843	4.9169
440	0.1440	4.5480	3.1271	0.1420	2.6437	1.8177	0.1287	4.7989	3.3000	0.2263	0.5132	0.3881	0.2118	0.3296	0.2248	0.1442	6.5572	4.5086
450	0.1511	4.4043	2.9707	0.1565	2.4627	1.6610	0.1410	4.6646	3.1465	0.2331	0.3822	0.3029	0.2214	0.1275	0.0931	0.1287	6.3312	4.2710
460	0.1662	4.0956	2.7922	0.1771	2.2281	1.5188	0.1555	4.5143	3.0778	0.2365	0.3111	0.2524	0.2461	0.0655	0.0568	0.1118	6.2071	4.2333
470	0.1934	3.6215	2.5602	0.2168	1.9274	1.3624	0.1733	4.2777	3.0246	0.2414	0.2714	0.2277	0.2537	0.0603	0.0549	0.0967	6.1523	4.3523
480	0.2275	3.0086	2.2944	0.2275	1.4971	1.1414	0.2004	3.9842	3.0393	0.2455	0.2763	0.2383	0.2520	0.0764	0.0689	0.0862	6.1222	4.6737
490	0.2395	2.1106	1.7480	0.2394	1.0603	0.8778	0.2396	3.5686	2.9575	0.2459	0.3235	0.2797	0.2468	0.1056	0.0919	0.0825	6.0990	5.0599
500	0.2485	1.2190	1.0730	0.2485	0.6816	0.5998	0.2488	2.6528	2.3392	0.2472	0.4139	0.3610	0.2467	0.1586	0.1379	0.0861	5.9937	5.2932
510	0.2509	0.5529	0.4943	0.2512	0.3959	0.3546	0.2518	1.9271	1.7337	0.2506	0.5529	0.4936	0.2506	0.2364	0.2110	0.0912	5.9172	5.3355
520	0.2941	0.2038	0.2406	0.2824	0.2105	0.2308	0.2469	1.3449	1.1706	0.2463	0.7550	0.6546	0.2464	0.3554	0.3085	0.0983	5.8335	5.0974
530	0.4127	0.0503	0.1204	0.3424	0.0936	0.1483	0.2372	0.8836	0.7202	0.2373	1.0330	0.8430	0.2376	0.5373	0.4391	0.1217	5.5204	4.5310
540	0.6053	0.0000	0.0000	0.4284	0.0342	0.0897	0.2651	0.5460	0.5359	0.2254	1.3881	1.0430	0.2256	0.7936	0.5973	0.1868	4.6461	3.5044
550	0.9066	0.0000	0.0000	0.5411	0.0046	0.0235	0.2949	0.3137	0.3722	0.2121	1.8402	1.2572	0.2123	1.1324	0.7746	0.2122	2.5893	1.7710
560	0.9073	0.0000	0.0000	0.6896	0.0000	0.0000	0.3359	0.1684	0.2565	0.2002	2.4181	1.5131	0.2003	1.5850	0.9929	0.1996	1.2704	0.7916
570	0.9072	0.0000	0.0000	0.9016	0.0000	0.0000	0.3885	0.0876	0.1820	0.1906	3.1285	1.8206	0.1690	2.2060	1.2850	0.2383	0.5635	0.4629
580	0.9068	0.0000	0.0000	0.9030	0.0000	0.0000	0.4664	0.0353	0.1156	0.1835	3.9325	2.1654	0.1187	2.9380	1.6191	0.3117	0.2155	0.2836
590	0.9076	0.0000	0.0000	0.9040	0.0000	0.0000	0.5872	0.0073	0.0506	0.1799	4.7952	2.5658	0.0877	3.6500	1.9546	0.4303	0.0734	0.1946
600	0.9100	0.0000	0.0000	0.9055	0.0000	0.0000	0.8261	0.0000	0.0000	0.1617	5.0655	2.7180	0.0718	4.1645	2.2362	0.6131	0.0154	0.1260
610	0.9143	0.0000	0.0000	0.9080	0.0000	0.0000	0.9093	0.0000	0.0000	0.1556	5.1589	2.8791	0.0635	4.4890	2.5071	0.8395	0.0000	0.0000
620	0.9214	0.0000	0.0000	0.6243	0.0000	0.0000	0.9177	0.0000	0.0000	0.1584	5.1391	3.0650	0.0553	4.9043	2.9272	0.9173	0.0000	0.0000
630	0.9289	0.0000	0.0000	0.4530	0.0000	0.0000	0.9262	0.0000	0.0000	0.1668	5.0340	3.2502	0.0500	5.2608	3.3993	0.9262	0.0000	0.0000
640	0.9361	0.0000	0.0000	0.2839	0.0000	0.0000	0.9340	0.0000	0.0000	0.1779	4.8956	3.4542	0.0513	5.3480	3.7765	0.9341	0.0000	0.0000
650	0.9415	0.0000	0.0000	0.0436	0.0000	0.0000	0.9400	0.0000	0.0000	0.1850	4.8081	3.7365	0.0587	5.0521	3.9292	0.9403	0.0000	0.0000
660	0.9465	0.0000	0.0000	0.1630	0.0000	0.0000	0.9453	0.0000	0.0000	0.1798	4.8727	4.2779	0.0758	4.3369	3.8098	0.9457	0.0000	0.0000
670	0.9501	0.0000	0.0000	0.2317	0.0000	0.0000	0.9491	0.0000	0.0000	0.1720	4.9683	5.1094	0.1119	3.2145	3.3069	0.9496	0.0000	0.0000
680	0.9531	0.0000	0.0000	0.3583	0.0000	0.0000	0.9526	0.0000	0.0000	0.1799	4.8534	6.1680	0.1895	1.9985	2.5398	0.9530	0.0000	0.0000
690	0.9562	0.0000	0.0000	0.5001	0.0000	0.0000	0.9560	0.0000	0.0000	0.2169	4.3834	7.4122	0.3411	1.0215	1.7260	0.9559	0.0000	0.0000
700	0.9589	0.0000	0.0000	0.6657	0.0000	0.0000	0.9586	0.0000	0.0000	0.2702	3.8034	9.0672	0.4117	0.4679	1.1131	0.9586	0.0000	0.0000

Table 4-6 (continue) K, S and R_∞ of the dye-based inks printed on uncoated paper.

	Green			Violet		
Wavelength/nm	Opaque R	K	S	Opaque R	K	S
400	0.1919	2.4580	1.7983	0.2552	0.1024	0.0942
410	0.2038	2.3856	1.8621	0.2718	0.0910	0.0933
420	0.2174	2.2544	1.7536	0.2790	0.0745	0.0799
430	0.2202	2.1037	1.5238	0.2684	0.0623	0.0625
440	0.2128	1.8975	1.3036	0.2387	0.0699	0.0576
450	0.2102	1.6414	1.1060	0.2128	0.0930	0.0639
460	0.2116	1.3126	0.8935	0.2088	0.1277	0.0852
470	0.2165	0.9419	0.6644	0.2147	0.1770	0.1233
480	0.2270	0.5972	0.4537	0.2261	0.2448	0.1849
490	0.2386	0.3501	0.2881	0.2386	0.3220	0.2651
500	0.2472	0.2227	0.1943	0.2482	0.4160	0.3653
510	0.2640	0.1725	0.1681	0.2515	0.5472	0.4914
520	0.2608	0.1658	0.1582	0.2470	0.6808	0.5930
530	0.2455	0.1847	0.1593	0.2378	0.7742	0.6338
540	0.2242	0.2286	0.1703	0.2257	0.8835	0.6652
550	0.2111	0.3002	0.2037	0.2122	1.0558	0.7222
560	0.1994	0.4129	0.2569	0.2002	1.1875	0.7434
570	0.1901	0.5708	0.3307	0.1906	1.1710	0.6812
580	0.1831	0.7641	0.4193	0.1834	1.1093	0.6102
590	0.1796	0.9852	0.5258	0.1798	1.1465	0.6127
600	0.1801	1.2846	0.6881	0.1801	1.2463	0.6679
610	0.1851	1.6148	0.9002	0.1851	1.1933	0.6651
620	0.1937	1.8911	1.1271	0.1936	0.9433	0.5615
630	0.2043	2.1177	1.3668	0.2039	0.6141	0.3952
640	0.2054	2.2333	1.5753	0.2156	0.3347	0.2346
650	0.2010	2.2652	1.7602	0.2282	0.1585	0.1215
660	0.1892	2.3779	2.0875	0.2437	0.0634	0.0540
670	0.1730	2.5694	2.6424	0.2882	0.0203	0.0231
680	0.1706	2.6141	3.3224	0.4687	0.0020	0.0067
690	0.1895	2.3671	4.0033	0.6711	0.0000	0.0000
700	0.2272	1.9561	4.6643	0.8149	0.0000	0.0000

The R_∞, K and S determined and shown in Tables 4-3 to 4-6 were carried out after the surface correction. The method of determining the correction coefficients used for surface correction according to Saunderson correction was to minimise the average colour difference, dE_{ab}* between the predicted reflectance and the measured reflectance. The database a, b, c, K and S obtained were transferred to another spreadsheet to achieve the predicted reflectance (the detail given in 4.4). Then the average dE_{ab}* was calculated (Table 4-7). Moreover, the spectral shape of predicted spectrum and measured spectrum were compared (Figure 4-19). In this research, the correction coefficients for inkjet ink on Canon PR-101 paper and uncoated photocopying paper when measured by an integrating shpere instrument are shown in Table 4-8

Table 4-7 The colour difference between the measured reflectance and the predicted reflectance of 13 dye-based inks on coated and uncoated paper.

Dye-based inks	ΔE^*_{ab}	
	Coated paper	Uncoated paper
Black (redish)	4	No match under the specified dE*
Black (bluish)	1	1
Acid Red 289	5	53
Basacid Red 510	3	34
Acid Magenta 1	4	No match under the specified dE*
Acid Yellow 23	3	77
Direct Yellow 132	3	78
Direct Yellow 86	7	No match under the specified dE*
Direct Blue 199	1	97
Acid Blue 9	5	74
Orange	4	26
Green	3	43
Violet	7	47
Average	4	53

Table 4-8 The corrected coefficients for inkjet ink on Canon PR-101 and photocopying paper.

Substrates		r_e	r_i	t_e	t_i
Canon PR-101	Print	0.007	0.600	0.993	0.400
	Subtrate	0.021	0.600	0.979	0.400
Photo copying Paper	Print	0.020	0.625	0.980	0.375
	Subtrate	0.025	0.600	0975	0.400

The average colour difference between the predicted R and the measured R on Canon PR-101 was 4. It was found that the coloured inks that gave the high colour difference were the single colour inks or the mixture of the inks that contained fluorescent dyes. These dyes were the Acid Red 289 and the Basonyl Red 540 which appeared the fluorescent effect in the 590 to 700 nm (Figure 4-3 and Figure 4-12). This cause high dE_{ab}* because KM theory does not take into account for fluorescence.

The two-constant KM theory does not suitable for prediction of the optical property on uncoated paper because the average colour difference between the predicted R and the measured R on uncoated paper was very poor (Table 4-7).

Figures 4-20 (a-f) shows the plot of K and S values of some colour inks on uncoated paper. The S values of inks are high since the fibres of the uncoated paper scatter the incident light. The uncoated paper is a heterogeneous as shown in Figure 4-14. This characteristic lead to higher the S value also.

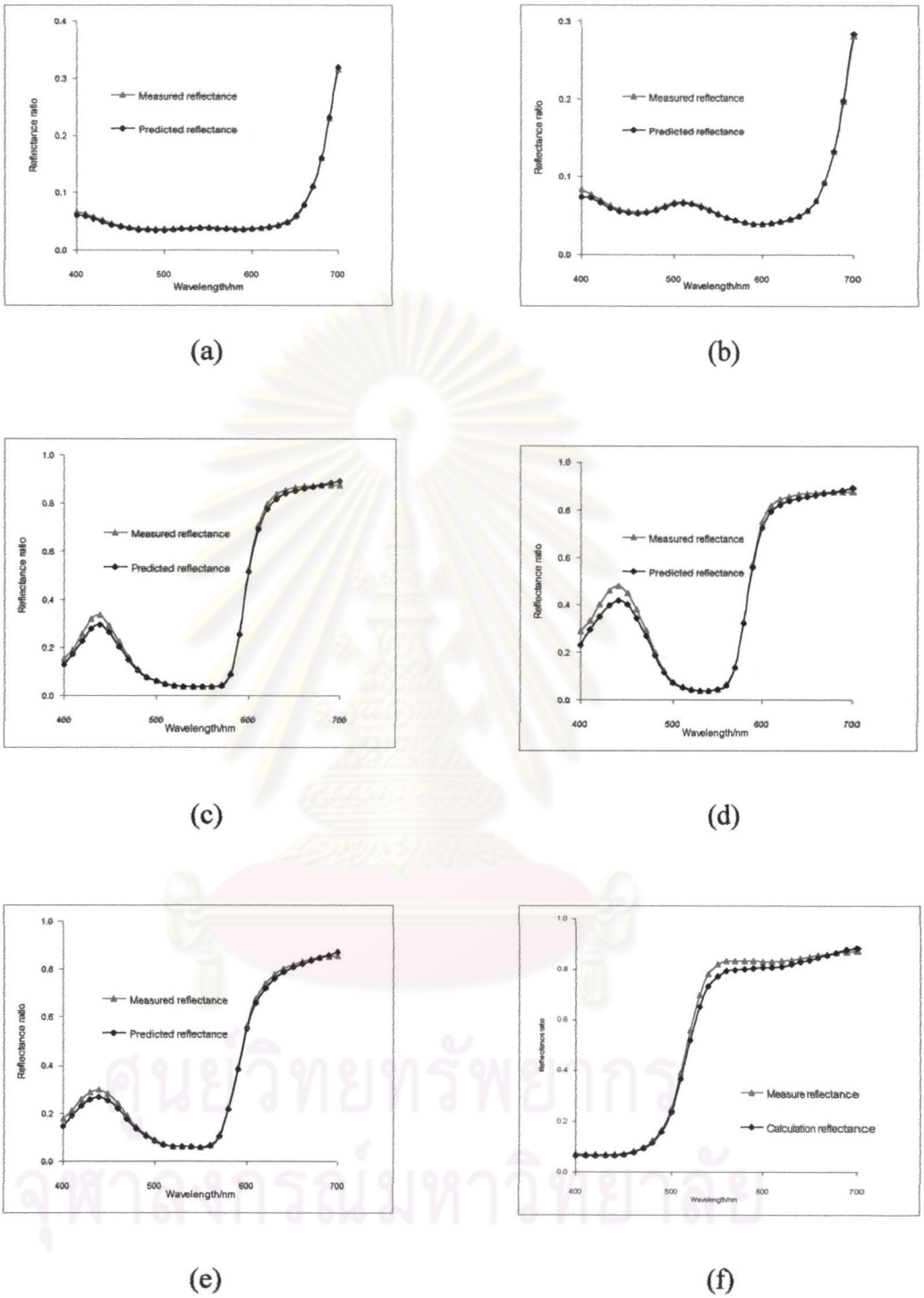
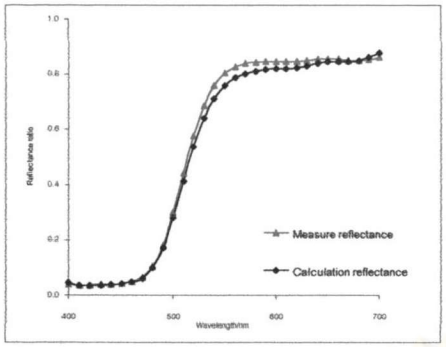
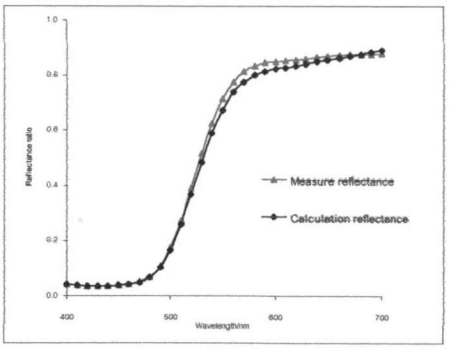


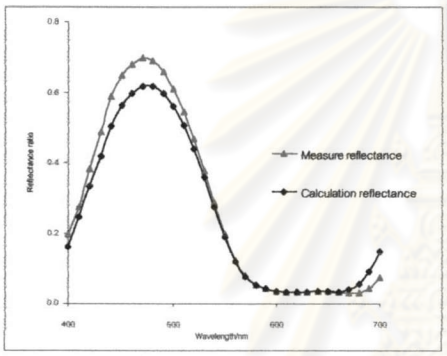
Figure 4-19 Comparison of the reflectance spectrum between the prediction and the measuring of the Direct Black (reddish) ink (a), the Direct Black (bluish) ink (b), the Acid Magenta 1 ink (c), the Acid Red 289 ink (d), the Basacid Red 510 ink (e) and the Acid Yellow 23 ink (f) printed on coated paper.



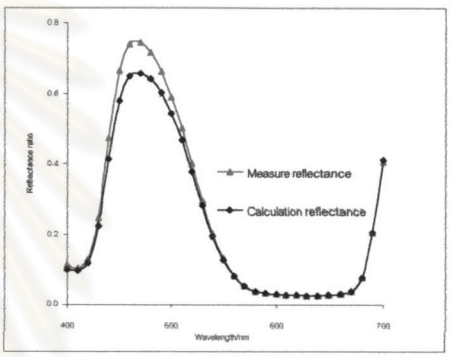
(g)



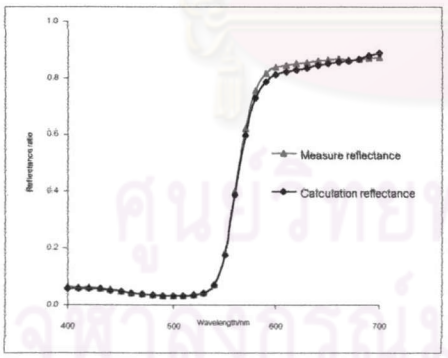
(h)



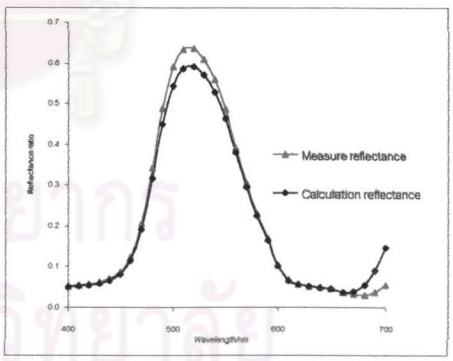
(i)



(j)

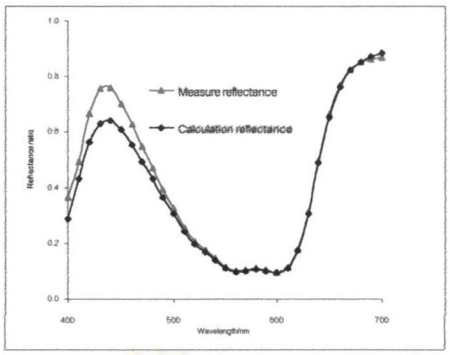


(k)



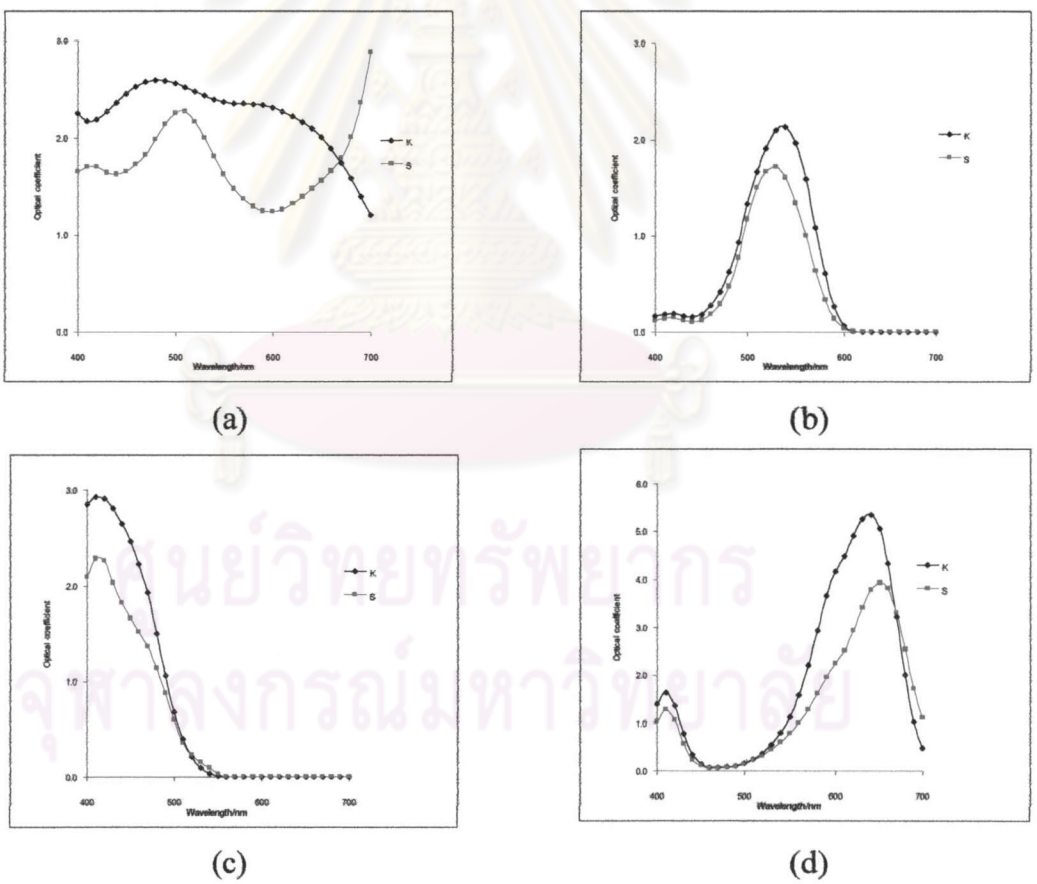
(l)

Figure 4-19 (continued) Comparison of the reflectance spectrum between the prediction and the measuring of the Direct Yellow 132 ink (g), the Direct Yellow 86 ink (h), the Direct Blue 199 ink (i), the Acid Blue 9 ink (j), the Orange ink (k) and the Green ink (l) printed on coated paper.



(m)

Figure 4-19 (continued) Comparison of the reflectance spectrum between the prediction and the measuring of the Violet ink (m) printed on coated paper.



(a) (b)

(c) (d)

Figure 4-20 Absorption and scattering coeffcients of the Direct Black (reddish) ink (a), the Acid Red 289 ink (b), the Direct Yellow 132 ink (c) and the Acid Blue 9 ink (d) printed on uncoated paper.

4.4 Applications

4.4.1 Application to gamut simulation

The database of inks including K and S, *a*, *b*, and *c* from the K and S determination spreadsheet is used to determine the predicted reflectance of inks when they are mixed and printed on a substrate. The steps of calculation of the predicted reflectance can be defined as follows:

1. Select the table corresponding to the number of inks to be used in the formulation from the table list (figure 4-21). Each table already contains the various amount for each component in the formulation.
2. Select the inks to be used in the formulation from the database list.

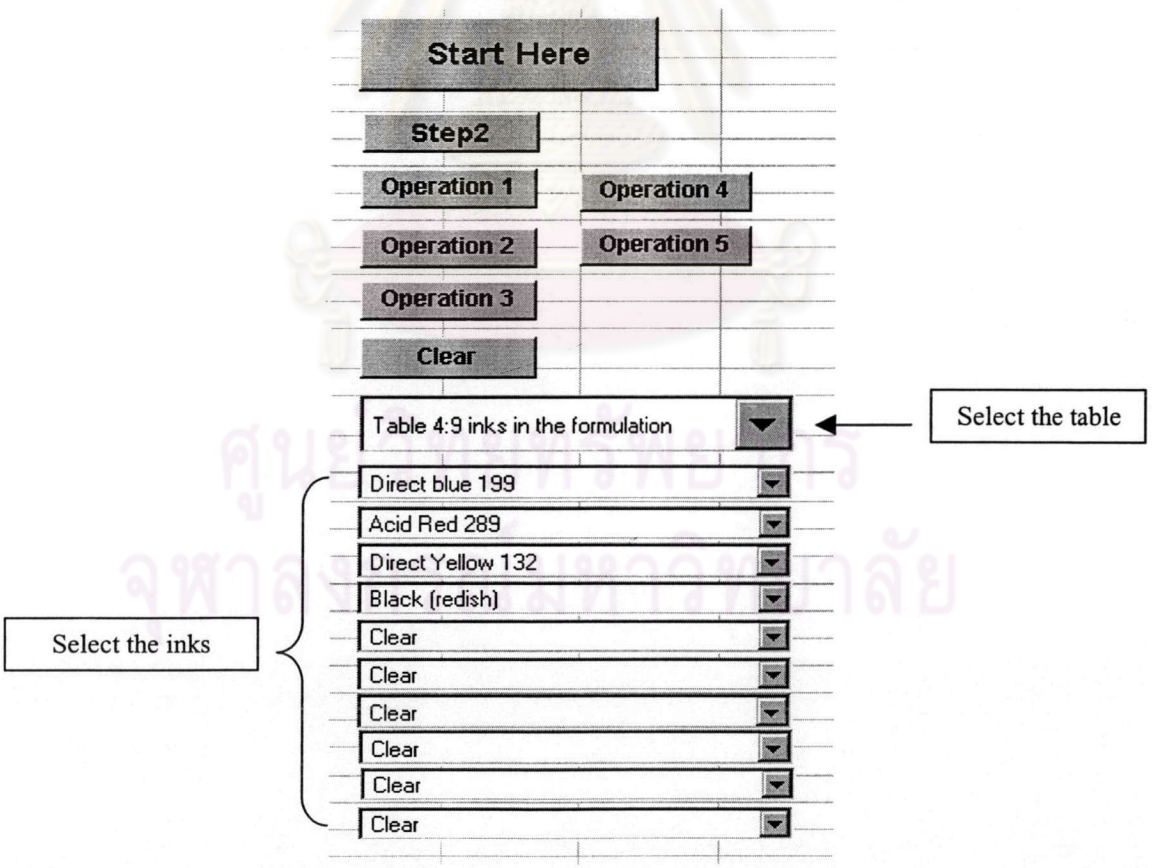


Figure 4-21 The front page of the spreadsheet used to determine the predicted reflectance of inks.

3. Calculate the total absorption, K_M and total scattering S_M coefficients by summing the contributions from each component in the formulation, taking into account the relative thickness D of the layer, at each wavelength in the spectrum (Equation 4-2)

$$\omega = \frac{K_1 + K_2 + ... + K_n}{S_1 + S_2 + ... + S_n} \qquad \textbf{Equation 4-2}$$

4. Calculate the reflectance of the layer R_M which depends on K_M, S_M and the reflectance of the substrate R_g via Equation-2.5 (rewritten to Equation 4-3),

$$R_M = \frac{\alpha R_g + \beta R_\infty}{\alpha + \beta} \qquad \textbf{Equation 4-3}$$

where α is a function of both the opaque reflectance R_∞ and R_g (Equation 2-6) and R_∞ is given by Equation 4-4.

$$R_\infty = 1 + \omega - \sqrt{(1+\omega)^2 - 1} \qquad \textbf{Equation 4-4}$$

β is a function of the K_M and S_M values of the layer and the thickness D of the layer relative to that used for the calibration print.

$$\beta = \exp(2Z) - 1 \qquad \textbf{Equation 4-5}$$

where Z is defined by Equation 4-6

$$Z = D\sqrt{K_M\left(K_M + 2S_M\right)} \qquad \textbf{Equation 4-6}$$

5. Correct the R_M value by taking into account the effect of the coating-to-air interface (Equation 2-13)
6. Calculate the colour coordinates from the recipe reflectance spectrum.

For more detail about the calculations in the worksheet, the flowchart of the calculations is shown in Figure 4-22. From this flowchart, it gives the tristimulus values and CIEL*a*b* coordinates of each ink formulation that are stored continuously row by row in the spreadsheet.

The amount of inks to be input in the first step in Figure 4-21 is set as shown in Table 4-9. The total amount of the inks to be mixed is 100 and the increased step is 25. This five levels was found that it gave sufficient combinations of mixtures to observe the colour gamut.[11] Table 4-9 is an example of amounts of each ink in the test formulations that consists of the mixture of any of 5 inks in the recipe. Therefore, the total of unique formulation is 70 recipes (5 inks in the recipe), 126 recipes (6 inks in the recipe), 210 recipes (7 inks in the recipe), 495 recipes (9 inks in the recipe) and 715 recipes (10 inks in the recipe). The detail of recipes is presented in Appendix (Tables B-1 to B-3).

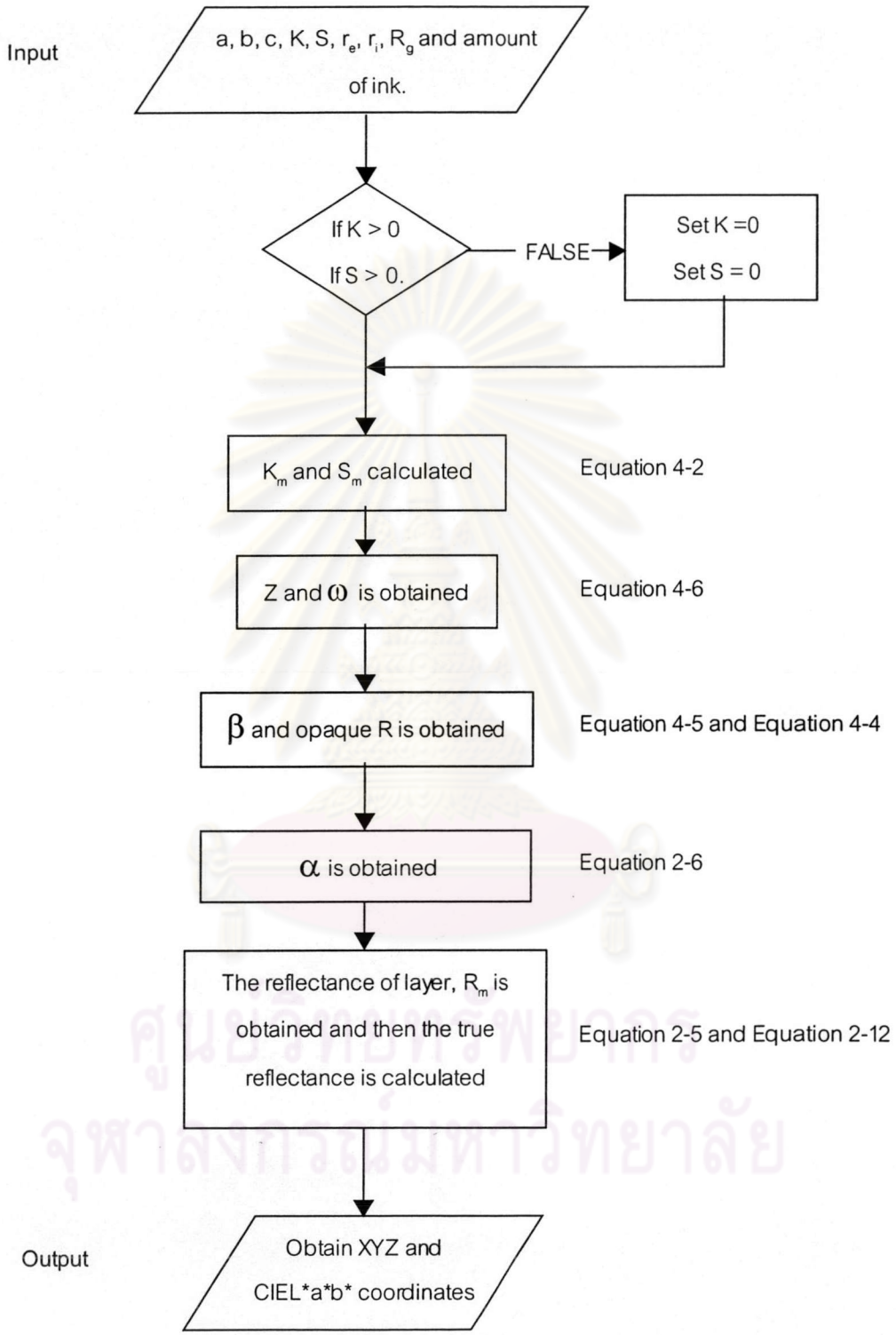


Figure 4-22 Flowchart of the calculation of reflectance spectrum and the tristimulus values from the specified amounts of the components in the formulation.

Table 4-9 Type of recipe in the 5-ink test set.

Type of recipe	Number of unique formulation
100, 0, 0, 0, 0	5
75, 25, 0, 0, 0	20
50, 50, 0, 0, 0	10
50, 25, 25, 0, 0	30
25, 25, 25, 25, 25	5
Total	70

From Figure 4-21, the user can select the number of components and the inks in the formulation. The K and S value from the K and S determination spreadsheet were used in the gamut simulation. The colour gamut of the Pantone Formula Guide 747XR is used to represent gamut in order to estimate the colour gamut of each ink set. Therefore, it can be used to investigate how a limited number of inks could be used to cover a large part of the gamut produced by several inks.

The colour gamut was simulated using different inks in the set. The ink can be selected freely but in this thesis, set of 4 inks, set of 6 inks and set of 7 inks were chosen in the formulation to investigate which dye based ink set gave the widest colour gamut. It was found that the ink set consists of four inks (Direct Blue 199, Acid Magenta 1, Direct Yellow 86 and Black (reddish)) give the widest colour gamut on coated paper (Figures 4-23 to 4-25). Figures 4-23 to 4-25 show the a*b* colour gamut of four inks in the formulation under the different illuminations: D65, D50 and A on coated. Figures 4-26 to 4-31 show the L*a* colour gamut and the L*b* colour

gamut on coated paper at the different illuminations. The colour gamut of this ink set printed on coated paper almost covers the gamut of the Pantone book, under different illuminations. Figures 4-32 to 4-49 show the colour gamut of six inks and seven inks that were printed on coated paper. The six inks consist of four inks from the best set shown above and two inks of orange and green. Seven inks consist of four inks from the best set shown above, and orange, green as well as violet inks. It is obvious that using the extra inks extends the colour gamut significantly. The colour gamut of six inks extends the gamut in the orange region and the green region greatly, as seen in Figure 4-23 and Figure 4-36. However, when the violet ink is added the gamut of the Pantone book can be covered completely.

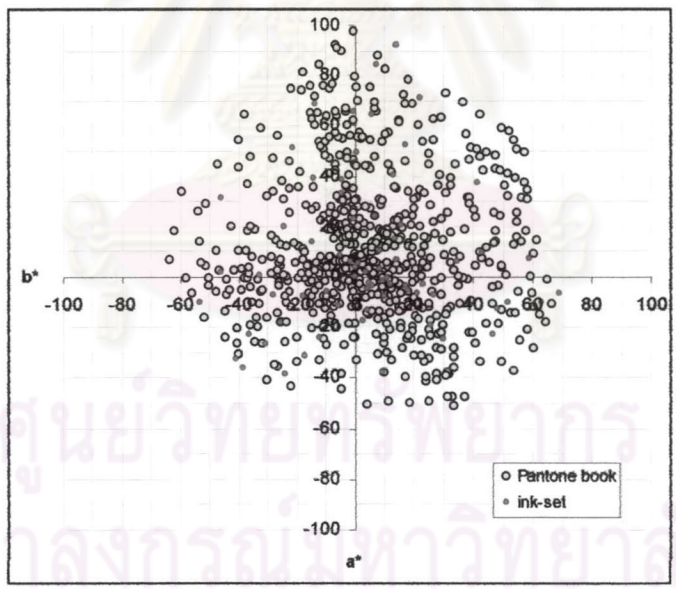


Figure 4-23 The a*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/10.

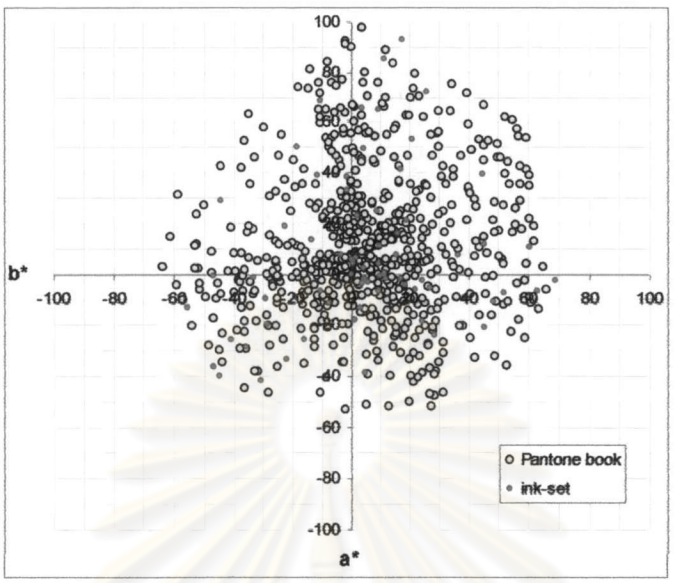


Figure 4-24 The a*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D50/10.

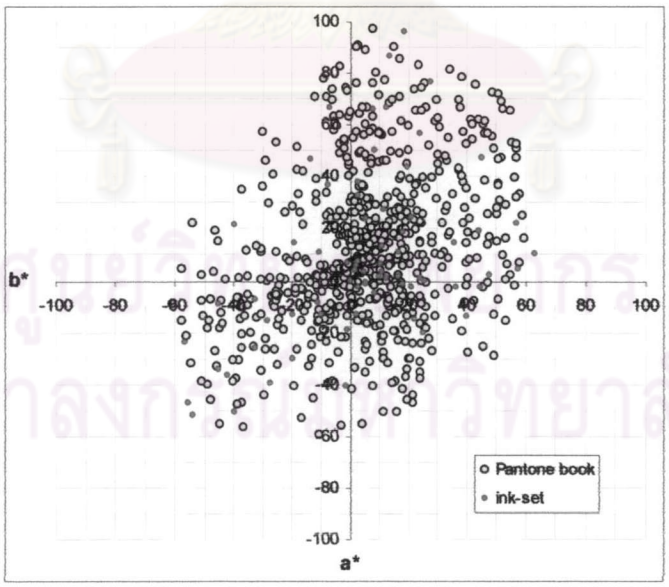


Figure 4-25 The a*b*colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1ink, Direct Yellow 86 ink and Black (reddish)ink, printed on coated paper, A/10.

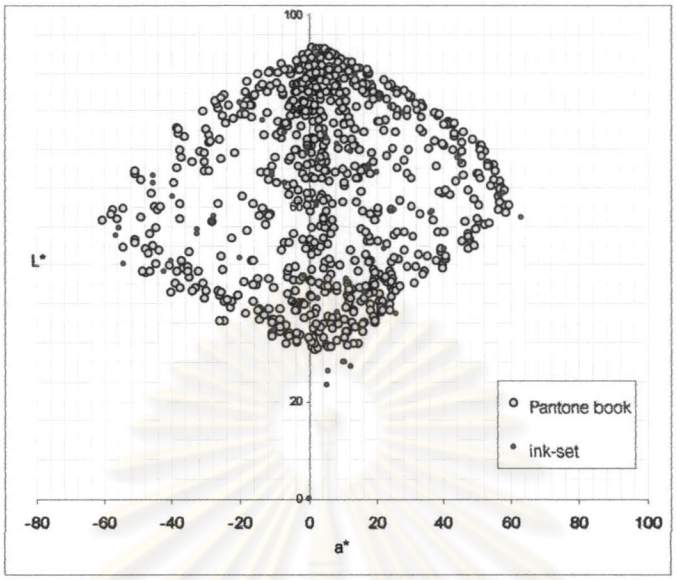


Figure 4-26 The L*a* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, A/10.

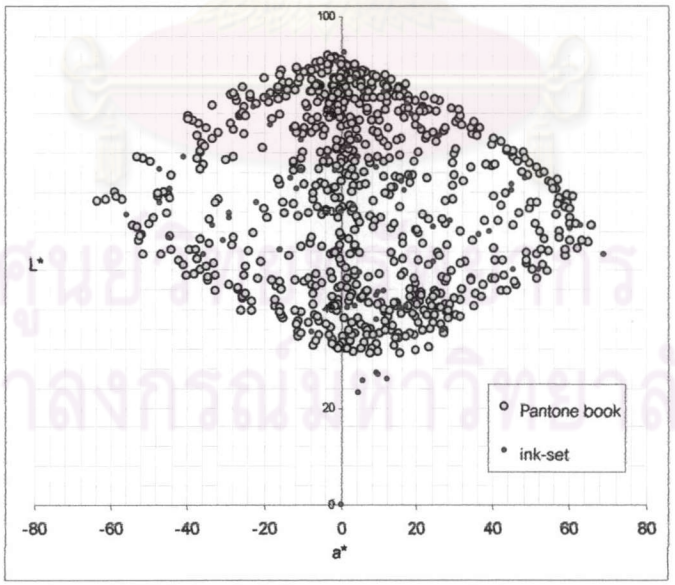


Figure 4-27 The L*a* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D50/10.

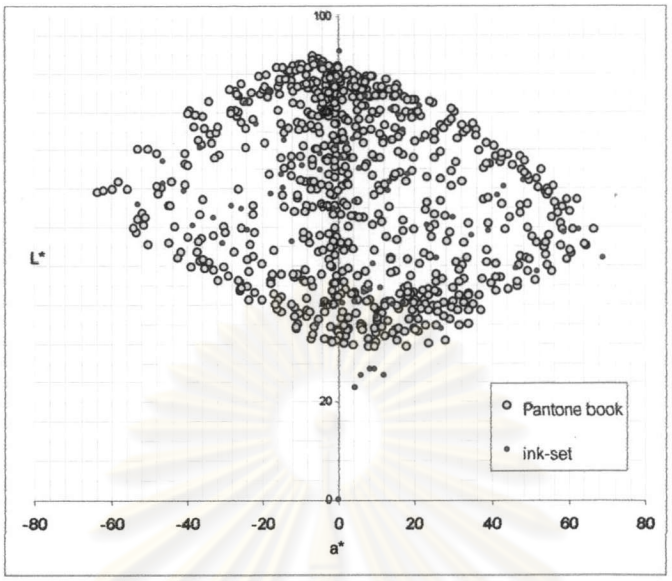


Figure 4-28 The L*a* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/10.

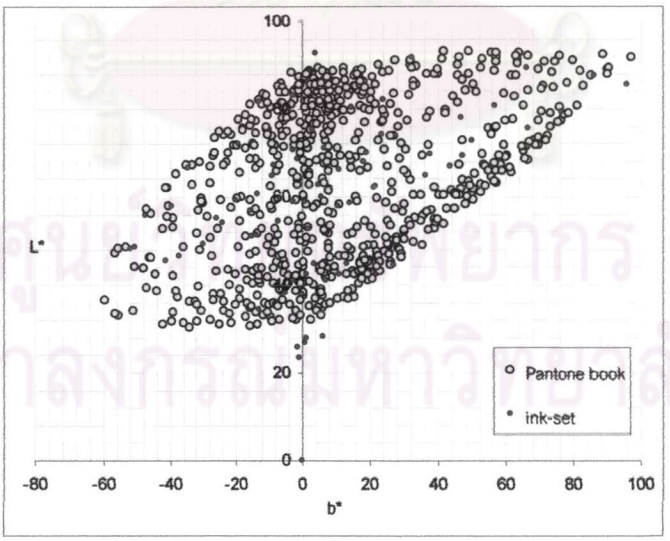


Figure 4-29 The L*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, A/10.

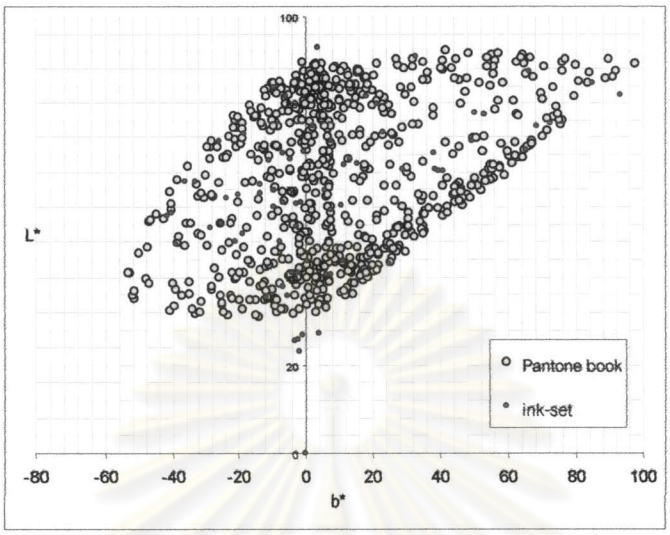


Figure 4-30 The L*b*colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish)ink, printed on coated paper. D50/10.

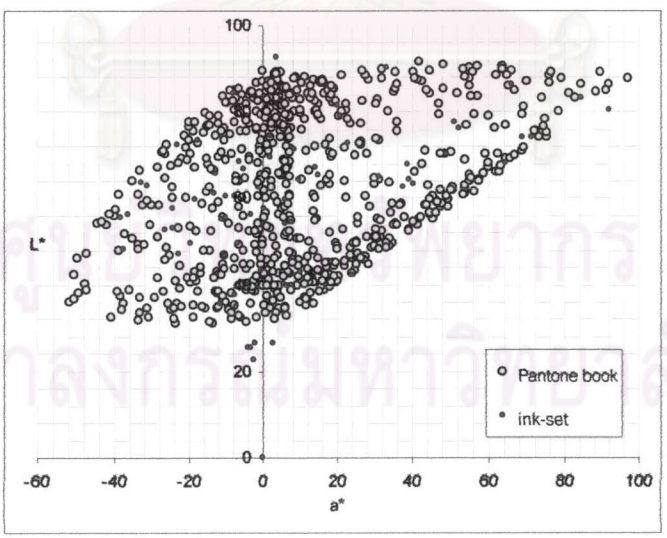


Figure 4-31 The L*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/10.

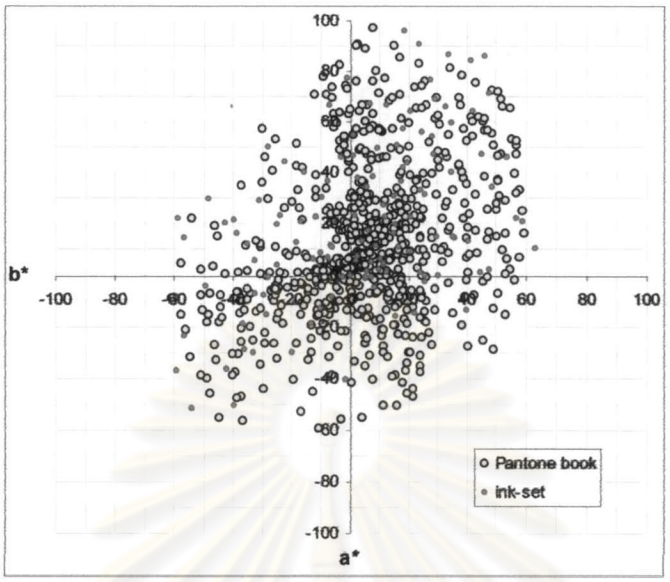


Figure 4-32 The a*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, A/10.

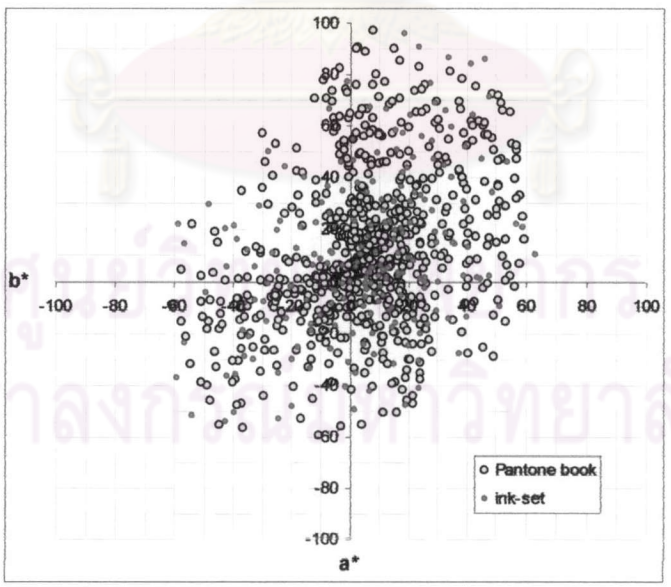


Figure 4-33 The a*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, A/10.

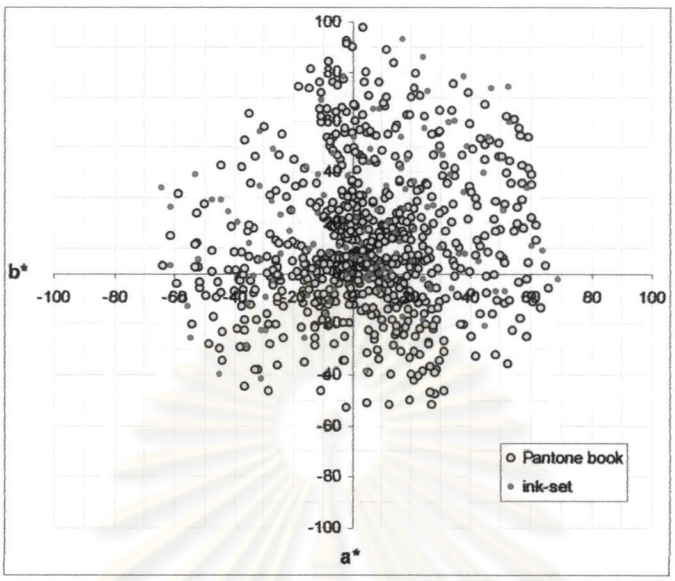


Figure 4-34 The a*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D50/10.

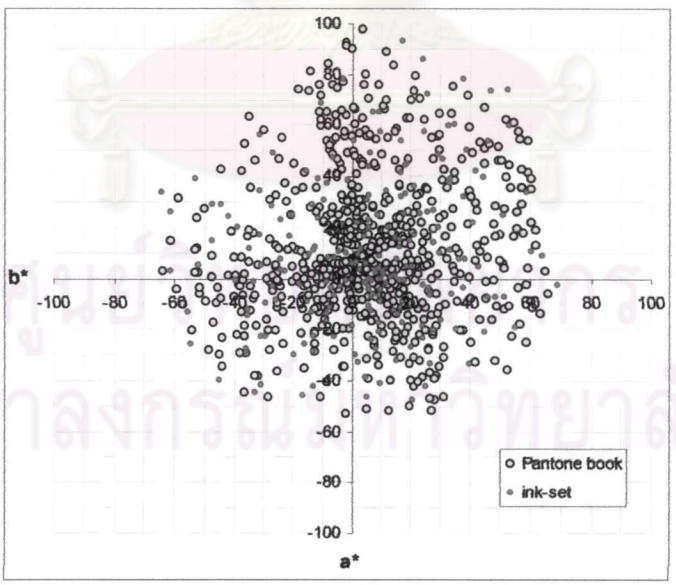


Figure 4-35 The a*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D50/10.

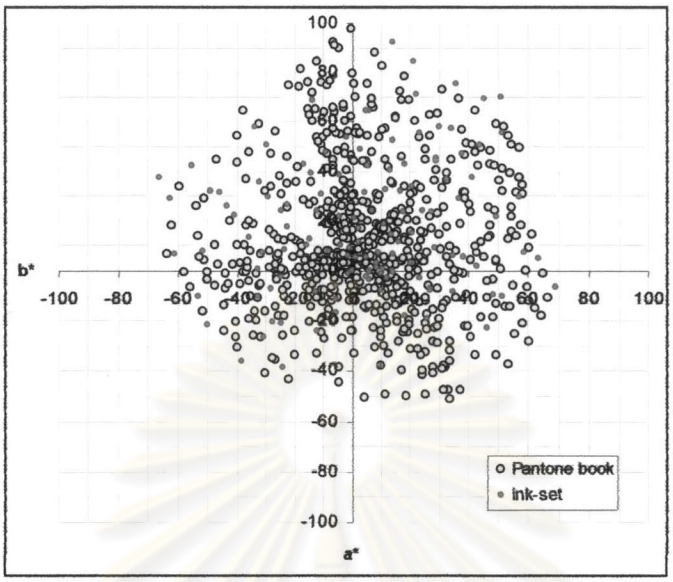


Figure 4-36 The a*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/10.

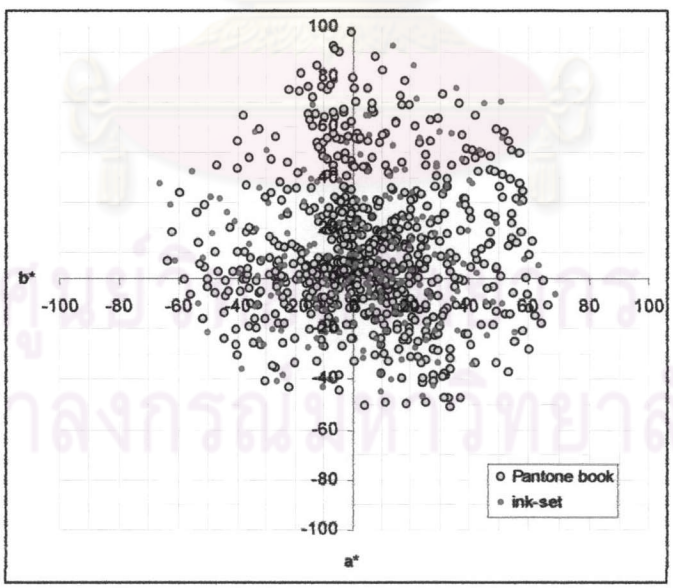


Figure 4-37 The a*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/10.

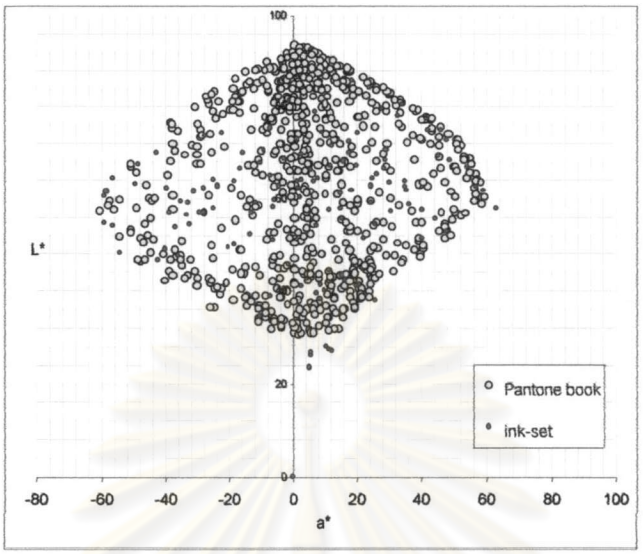


Figure 4-38 The L*a* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, A/10.

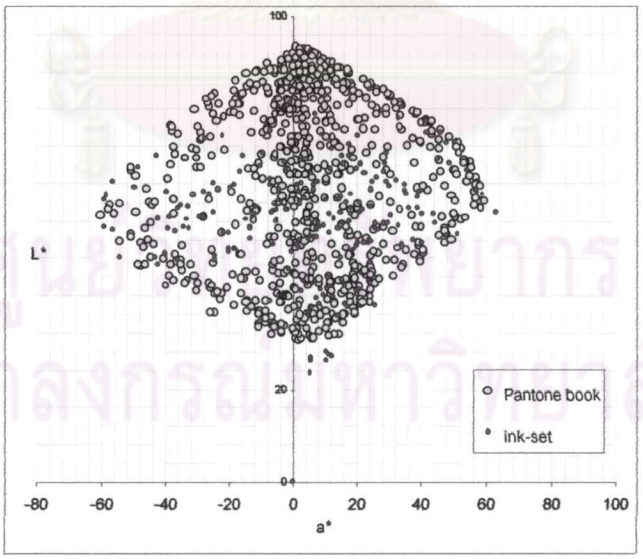


Figure 4-39 The L*a* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, A/10.

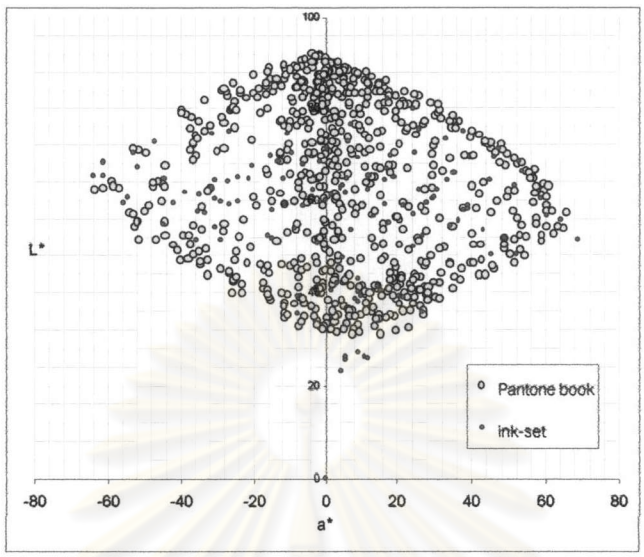


Figure 4-40 The L*a* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D50/10.

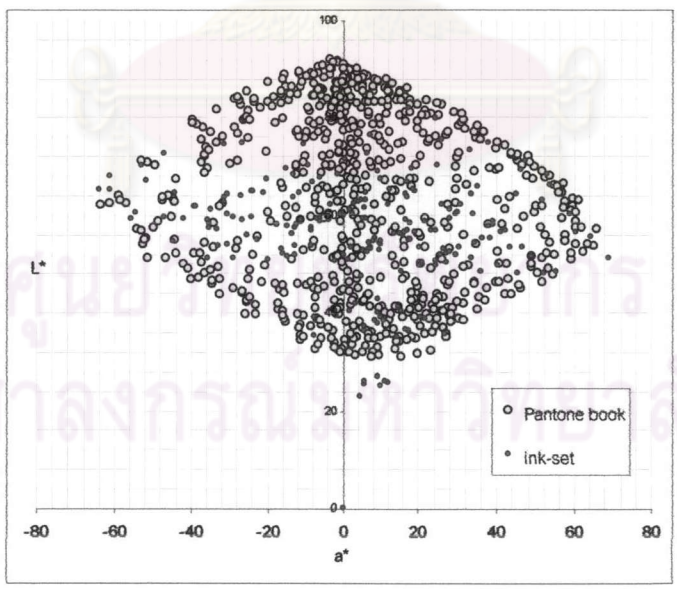


Figure 4-41 The L*a* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D50/10.

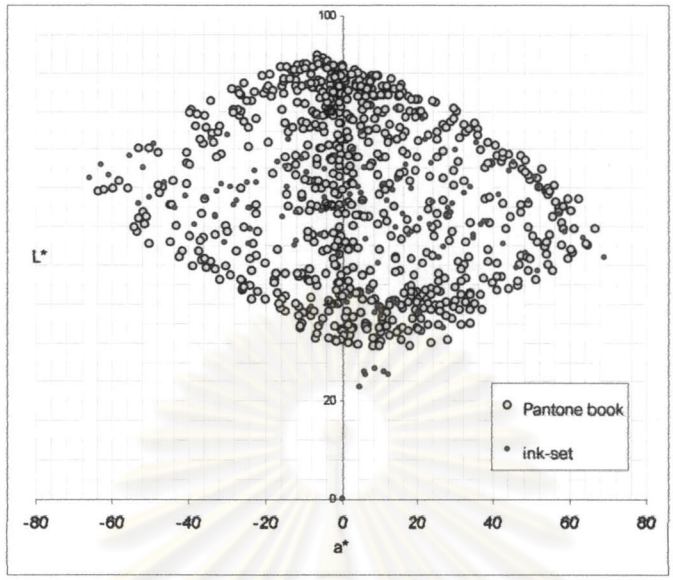


Figure 4-42 The L*a* colour gamut of six inks: Direct Blue 199 ink Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/10.

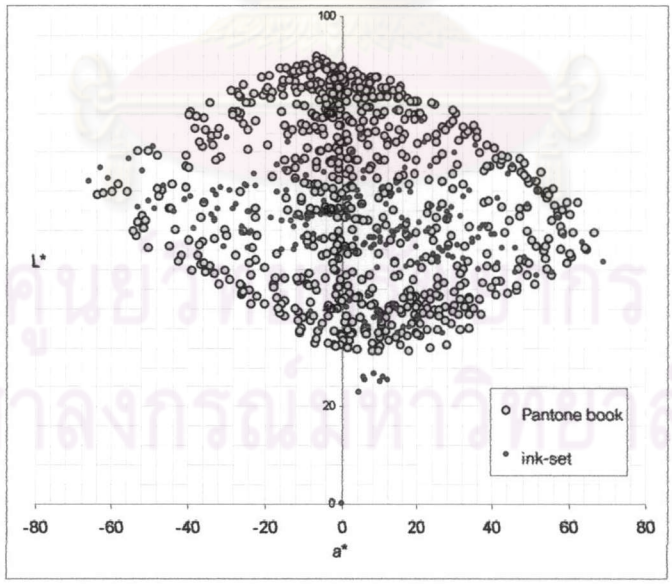


Figure 4-43 The L*a* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/10.

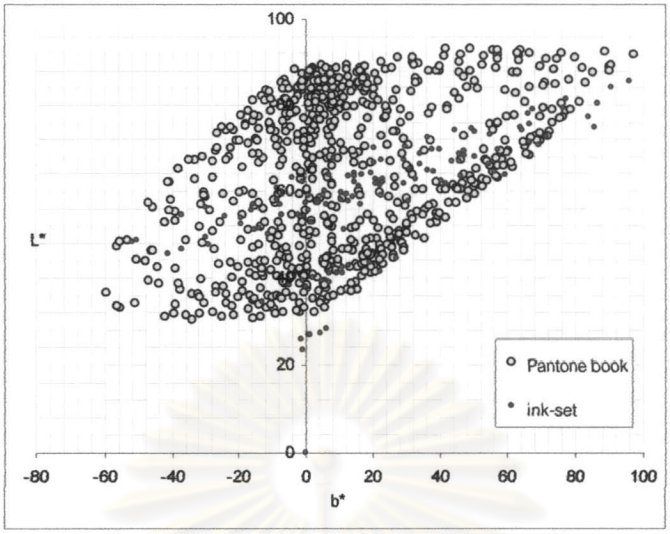


Figure 4-44 The L*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, A/10.

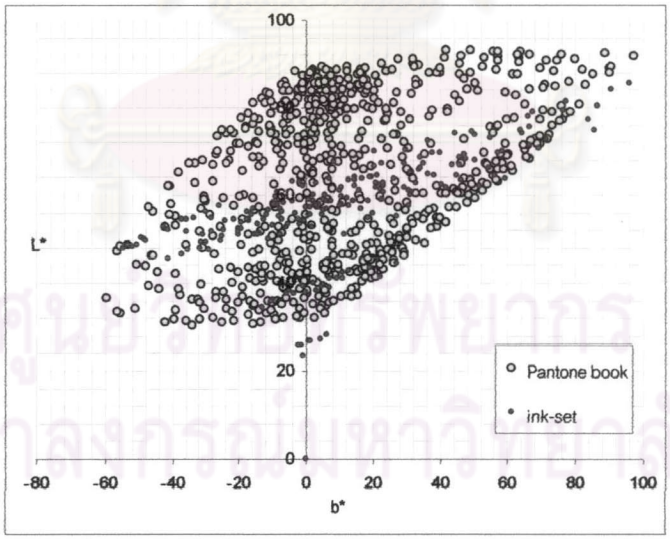


Figure 4-45 The L*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, A/10.

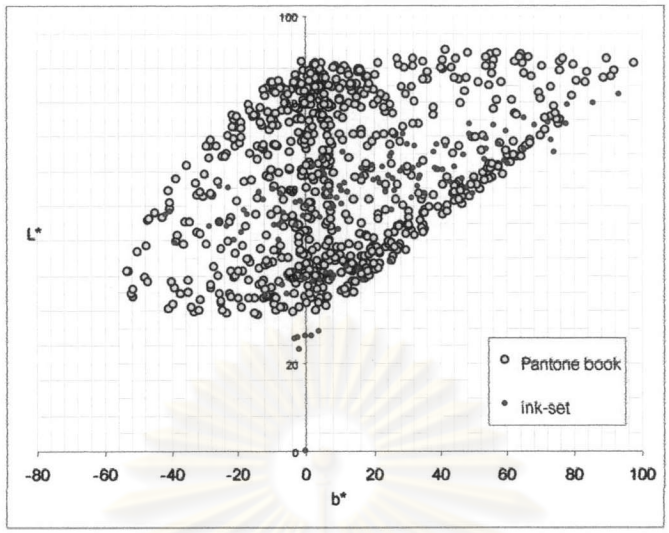


Figure 4-46 The L*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, D50/10.

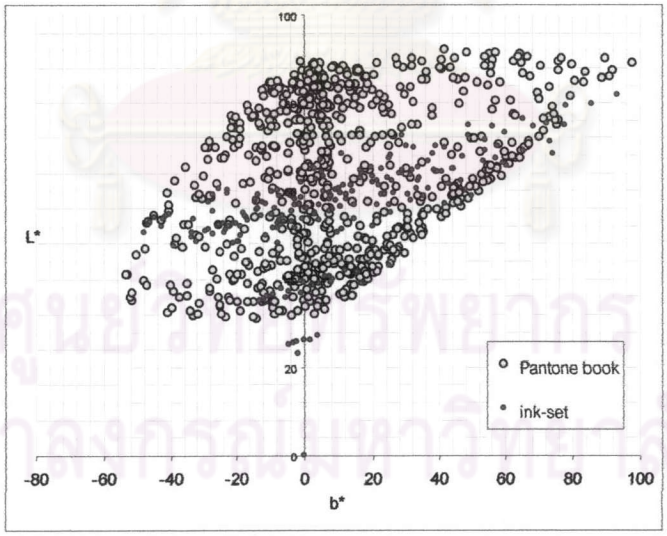


Figure 4-47 The L*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D50/10.

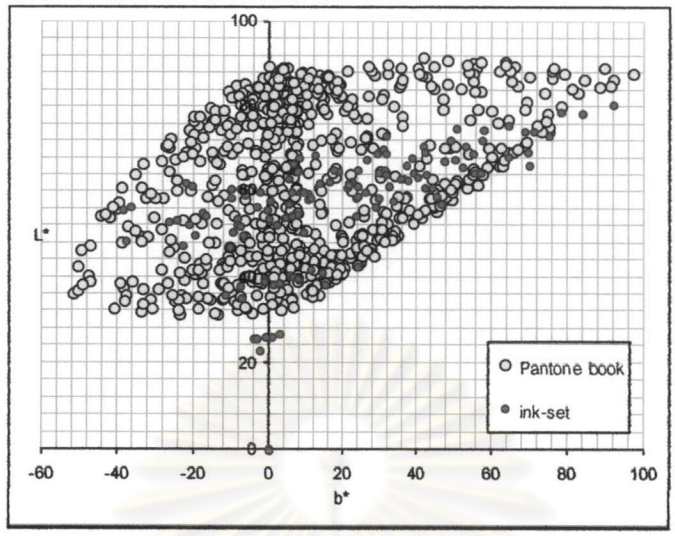


Figure 4-48 The L*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/10.

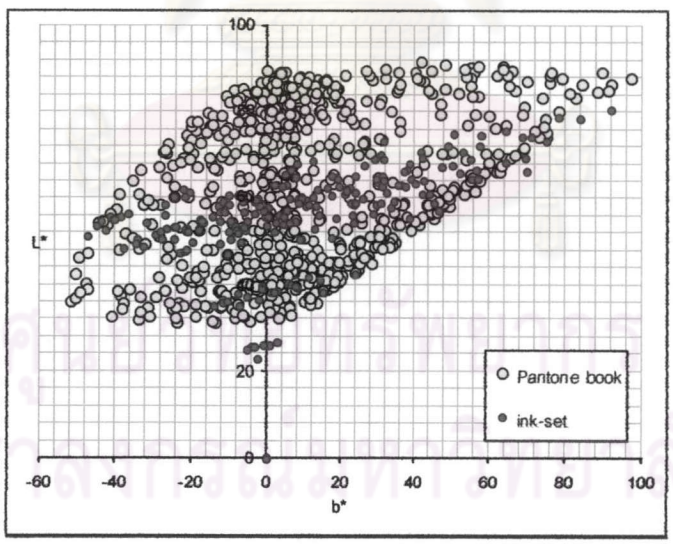


Figure 4-49 The L*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/10.

The reason for this is that the uncoated paper is not designed for inkjet printing. The inkjet ink is designed for coated paper where the ink will be deposited within the coated layer. The two-constant KM model probably cannot describe the effect of ink absorbed into paper. Generally, in lithographic printing, that the two-constant KM model can describe very well, the lithographic paste ink does not absorb remarkably into a substrate as the inkjet ink does on the uncoated substrate. Therefore, the optical properties of the inks printed on uncoated paper that are determined using the KM model may not be sufficiently accurate. This causes a high performance colour difference on uncoated paper. It follows that the characteristic curve shape of inkjet inks printed on uncoated paper are not representative of all concentration levels.

4.4.2 Application to gamut comparison

The colour gamut of a colourful picture name 'Wool', used for the original digital image in this study, (Figure 4-50) was compared with the colour gamut of three ink set that consist of four inks, six inks and seven inks in formulation. Sukkaew [12] developed the MATLAB code to read the RGB colour values of digital images. The RGB values then were transformed to CIEL*a*b* co-ordinates using the standard matrix transform under illumination/observer of D65/2. The CIEL*a*b* co-ordinates were taken from her study for the application of gamut comparison. It can be investigated that which inks in the formulation that can cover the colour gamut of the original.

Figure 4-50 The wool picture was used to comparison.

Figures 4-51 to 4-59 show the colour gamut of the ink set and the colour gamut of the wool picture on coated paper at illumination/observer: D65/2. It was found that the colour gamut of four inks in the formulation can cover the colour gamut of the wool picture. However, at a lightness of lower than 10, the colour gamut of this picture can not be reached by four inks, six inks and seven inks.

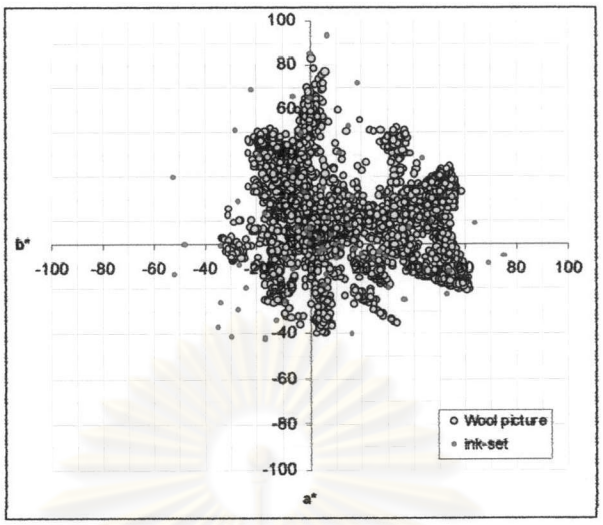


Figure 4-51 The a*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/2.

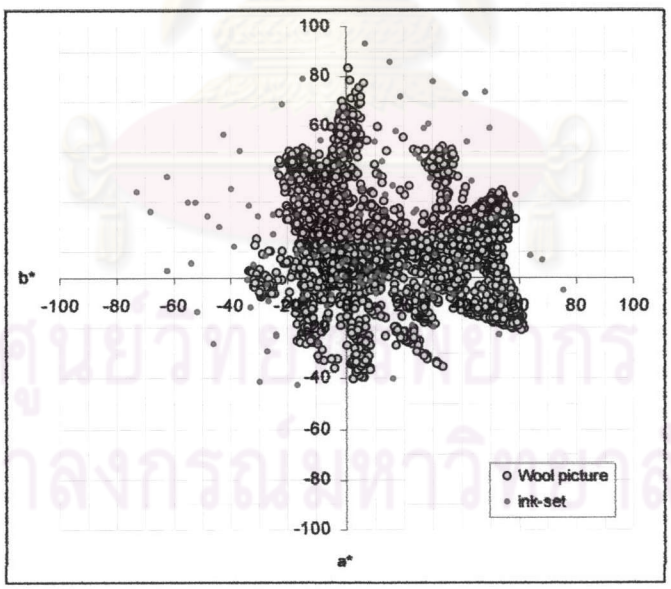


Figure 4-52 The a*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/2.

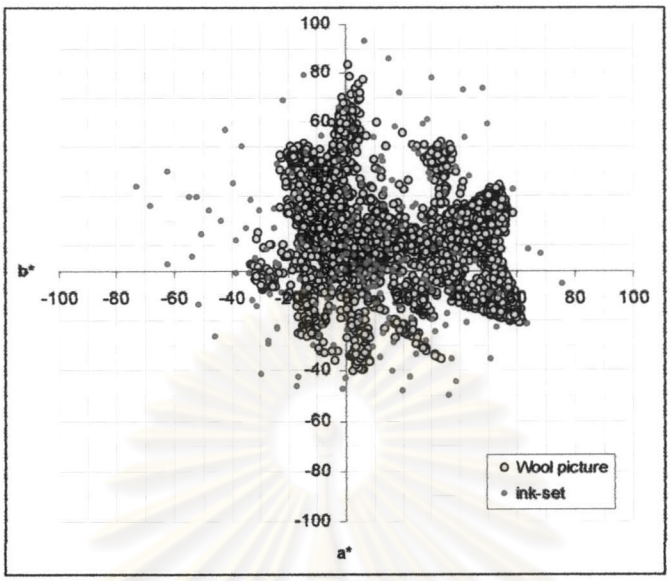


Figure 4-53 The a*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/2.

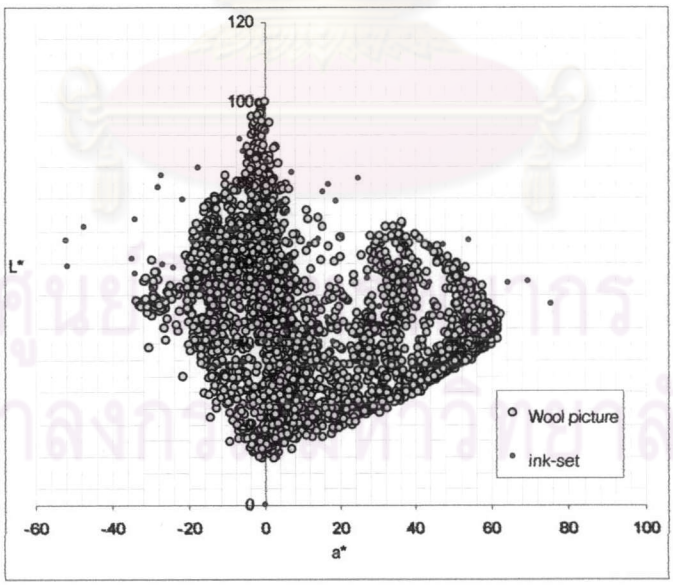


Figure 4-54 The L*a* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/2.

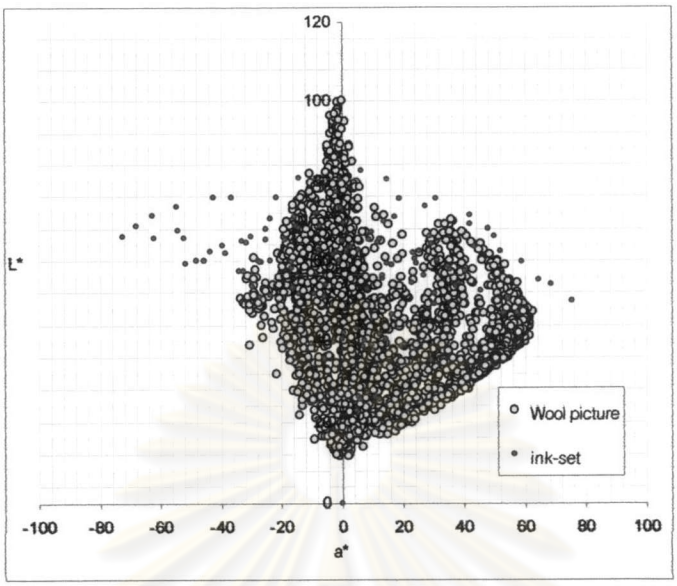


Figure 4-55 The L*a* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/2.

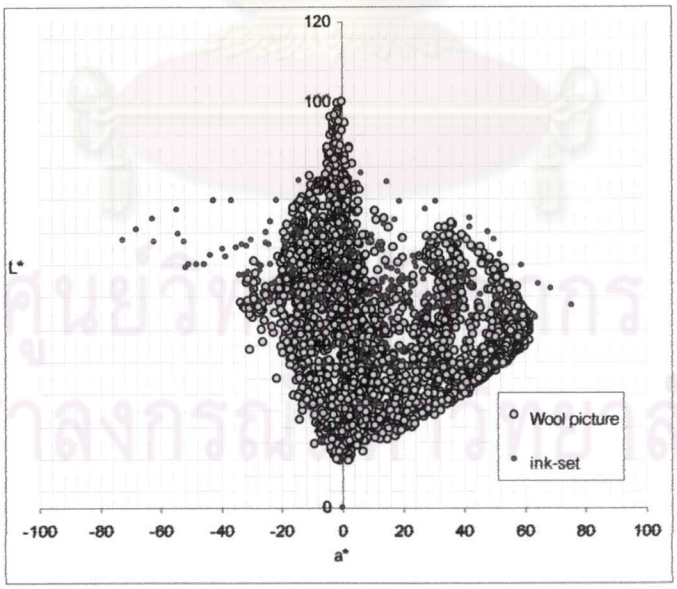


Figure 4-56 The L*a* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/2.

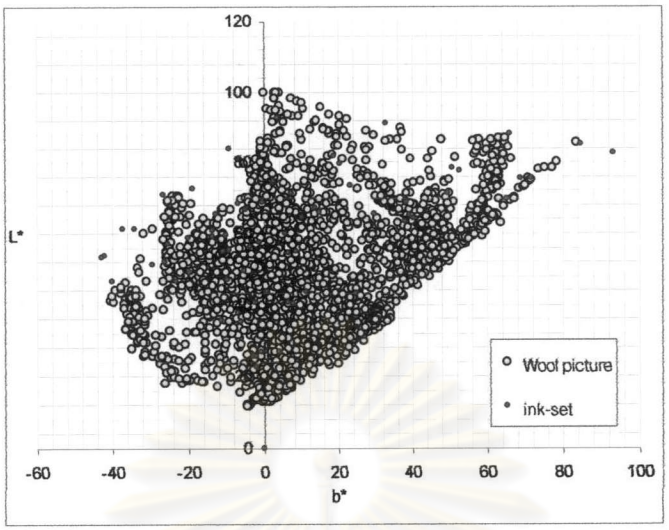


Figure 4-57 The L*b* colour gamut of four inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink and Black (reddish) ink, printed on coated paper, D65/2.

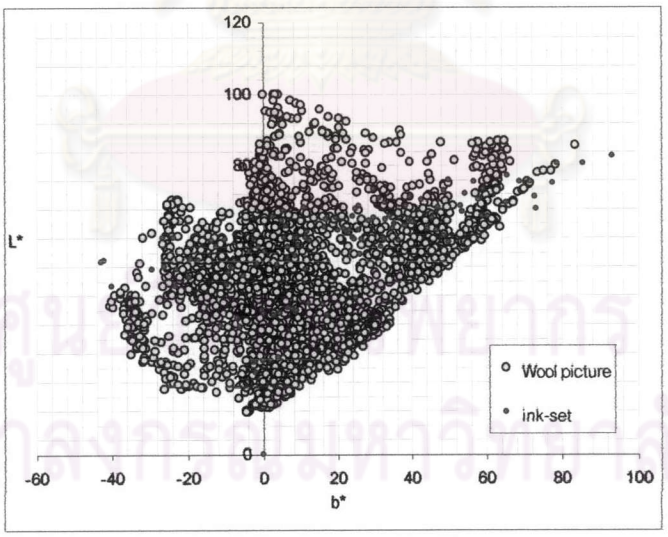


Figure 4-58 The L*b* colour gamut of six inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink and Green ink, printed on coated paper, D65/2.

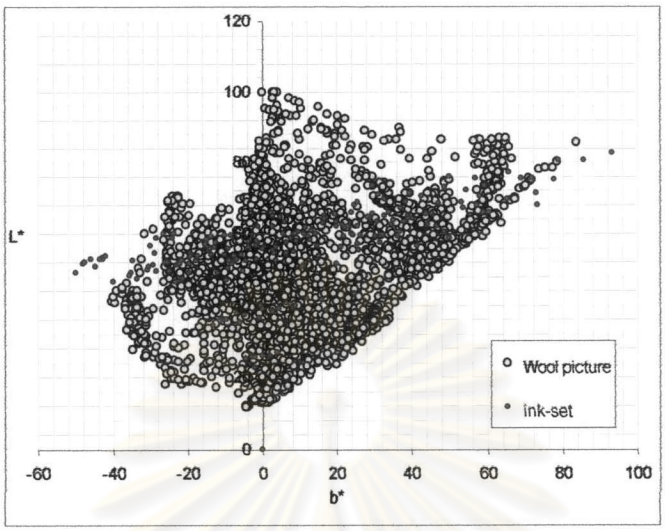


Figure 4-59 The L*b* colour gamut of seven inks: Direct Blue 199 ink, Acid Magenta 1 ink, Direct Yellow 86 ink, Black (reddish) ink, Orange ink, Green ink and Violet ink, printed on coated paper, D65/2.