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Achievement of highest brightness and whiteness in paper in a cost effective manner through selective addition of OWA at wet-end and size press

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Particulars of the Project

1	Project No.	:	ACIRD/IPMA/0914-24/165
2	Project Title	:	Achievement of highest brightness and whiteness in paper in a cost effective manner through selective addition of OWA at wet-end and size press
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6	Participating Agency	:	Tamil Nadu Newsprint & Papers Limited
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8	Duration of the Project	:	24 + 6 months

Contents

Nomenclature

OWA	:	Optical whitening agent
DSA	:	Dry strength additive
CFA	:	Cationic fixing agent
RA	:	Retention aid
DS1	:	Di-sulhonated 1
DS2	:	Di-sulphonated 2
TS1	:	Tetra-sulphonated 1
TS2	:	Tetra-sulphonated 2
TS3	:	Tetra-sulphonated 3
HS1	:	Hexa-sulphonated 1
MHW	:	Mixed hardwood
BBS	:	Bleached bagasse
RCL	:	Recycled
GCC	:	Grounded calcium carbonate
PCC	:	Precipitated calcium carbonate
CPPRI	:	Central Pulp and Paper Research Institute

1. EXECUTIVE SUMMARY

Optical whitening agent (OWA) is a chemical designed specifically to increase the perceived brightness and whiteness of paper. According to the number of sulphonic acid groups present in the molecule, OWAs are distinguished as di, tetra and hexa-sulphonic OWA. The higher the number of sulphonic groups, higher the solubility of OWA and lesser the affinity to cellulose. The selection of OWAs for wet-end application is critical. The interaction of OWA with cellulosic fibers and wet-end additives, primarily fillers, is not well studied. This, in turn, makes a gap between knowledge and application part. This project was proposed to select the appropriate OWAs for addition in wet-end, and understand their effect on brightness and whiteness of paper. In the present study, the effect of these sulphonic groups on optical properties of paper sheets was studied. For understanding the impact for commercial papermaking, three types of fillers, GCC, PCC and talc, were added in paper sheets to get about 21% ash level. The sequential addition of wet-end chemicals was also studied to analyse their impact on optical properties of paper. Optimization study for the dose of different OWAs at wet-end using different fillers and furnishes was studied followed by split addition of different OWAs at wet-end as well as at size press to reduce the cost without compromising the optical properties of paper. Effect of broke addition (ranging from 5-30% in paper making furnish) on efficiency of OWAs was also studied. Two new OWAs other than commercially available OWAs were identified and characterization was done. Optimization of dose at wet-end along with split addition of these OWAs at surface sizing was studied. Different combinations of OWAs at wet -end and surface sizing were studied. Comparable optical properties could be achieved by splitting the OWAs at wet-end and size press along with significant reduction in cost. Validation of results was done at CPPRI on set of selected experiments using mixed hardwood pulp along with GCC and talc filler. All sets of experiments carried out at CPPRI show better results than experiments carried out at ACIRD. It was recommended that the plant trial with the use of selected OWA with suitable filler may be carried out at selected mills. Based on encouraging lab results, the plant trials were conducted at. BILT SGU, Yamunanagar and Satia Industries Ltd., Muktsar. Improvement in optical properties of paper along with reduction in cost of paper was observed during the trial at BILT SGU, Yamunanagar. The reduction in the dose of OWA at wet end was observed along with comparable optical properties of paper during the plant trial taken at Satia Industries Ltd., Muktsar.

2. BACKGROUND

Paper and paperboard are generally available in a wide range of appearance, colour, brightness and whiteness. The natural colours of cellulosic fibres and mineral fillers normally do not meet customer's requirements, so optical whitening agent (OWA)/ optical brightening agent (OBA)/ fluorescent whitening agents (FWA) and dyes/ pigments are added for the paper to get the desired shade. OWAs are designed specifically to increase the perceived whiteness of a given substrate. They are the fluorescent molecule i.e. they absorb light in certain region of the wavelength (typically 340-360 nm) and emit it in a different one (mainly 430 to 460 nm). Fluorescence is thus blue light that is added on a substrate (normally yellow) increasing the perceived whiteness. OWA is characterized by its absorption and fluorescence maxima, its quantum yield and its affinity for a substrate. Using OWAs is a convenient way to increase the reflectance (and thus the lightness) of paper and simultaneously to move the shade from yellow to blue. This subtle tint change makes the paper look even whiter.

In general, there are two families for paper applications: stilbene and di-stiryl-biphenyl types. Traditionally, the first family is better known and is divided according to the number of sulphonic acid groups present in the molecule. One distinguishes di-tetra- and hexa-sulphonated OWA and their field of application is related to their solubility and affinity. The structures of these compounds are given in Figure 1-3.

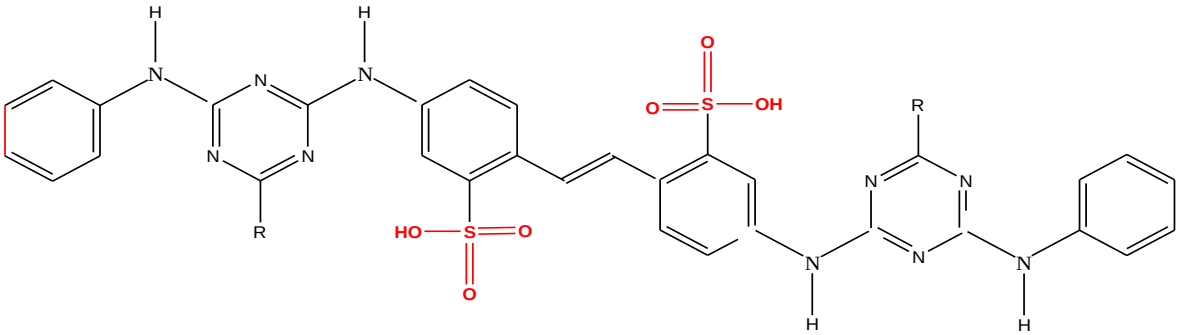

Figure 1: Di-sulphonated (Diamino-stilbene disulphonic acid) OWA

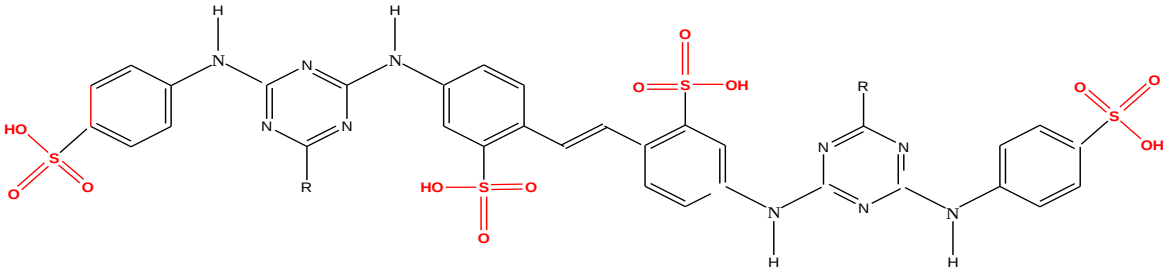

Figure 2: Tetra-sulphonated (Diamino-stilbene tetrasulphonic acid) OWA

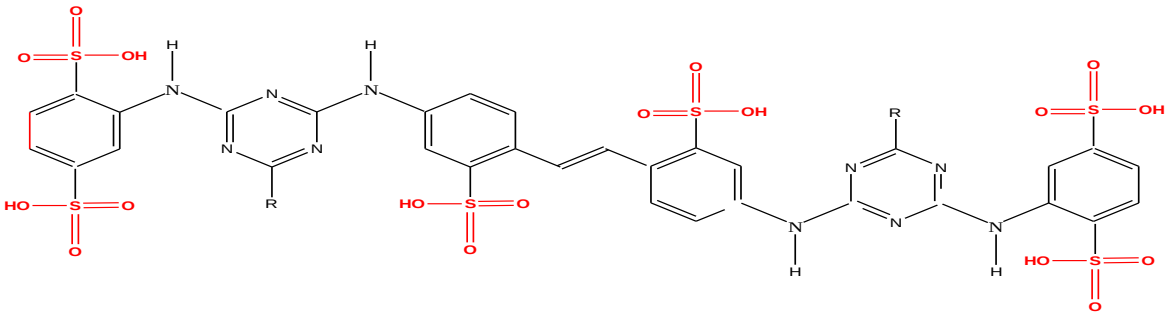

Figure 3: Hexa-sulphonated (Diamino-stilbene hexasulphonic acid) OWA

The larger the number of sulphonic acid groups, higher the solubility and lesser the affinity. Di-sulphonic and tetra-sulphonic types are better for applications in furnish, while hexa-sulphonic is better suited for surface applications such as size press and coating. Di-sulphonic OWA has high affinity with cellulose, but is extremely sensitive to alum and cationic auxiliaries. Because of low compatibility with starch, it can't be used effectively in the size press. Tetra-sulpho OWAs are all rounder. It has adequate affinity and is compatible with starch and alum, making it suitable for a wide range of applications. Hexa-sulphonic OWA is applied only at the size press or in coating application for high whiteness levels, due to its low affinity to fibers (1&2). The effects of OWAs on paper and papermaking process are summarised in the following table:

Di-sulphonated	High affinity	Sensitive to alum, low stability in the presence of cations, not compatible with starch
Tetra-sulphonated	Intermediate affinity	Good stability in the presence of cations, good compatibility with alum, good compatibility with starch
Hexa-sulphonated	Low affinity	High stability in the presence of cations, high greening limit

Roughly one-third of the OWA is added in the wet-end and the remaining two-third is added on paper surface through size press. The OWA requires good acid and alum stability, compatibility with fillers, and good affinity with fibers, since any unabsorbed OWA is lost in the white water fibers (3&4).

Some of the critical factors in the use of OWAs include retention, quenching and competition with other UV absorbers. OWA retention can be increased by addition of a coagulant to the pulp stream, either before or after the whitener. It is necessary to note that highly charged cationic polyelectrolytes can easily destroy the fluorescent character of the molecule. The effect is called quenching. The coagulants used for the retention of filler, fines and fibers have a negative effect on efficacy of OWA (5). OWAs can be considered to be anionic direct dyes. They are substantive, capable of hydrogen bonding, and can bind to cellulosic fibers without assistance from cationic additives to affect retention. However, strongly cationic chemicals (including alum) which act as quenching agents should be avoided since they adversely affect fluorescent properties and reduce brightness. Low pH and presence of trivalent aluminum are unfavorable as far as the efficiency of an OWA is concerned. If the pH is low enough, some of the sulphonic groups can occur in acid form. This lowers the solubility of OWAs. Aluminum salts of OWAs are insoluble and impart a greenish shade to the paper, in addition to reducing the effectiveness of OWAs (6-9). In higher white shades, a hexa-sulphonic OWA is additionally applied at the size press to obtain the required whiteness level. Moreover, colouring/tinting dyes and pigments have also been used for increasing whiteness further as well as to adjust chromaticity co-ordinates (1). The tinting dyes can increase the whiteness but decrease the brightness due to their masking effect.

The selection and dosage of OWAs for wet-end application are critical. The chemistry of interaction of OWA with cellulosic fibers and wet-end additives, primarily fillers, is not well known to papermakers. This, in turn, makes a gap between knowledge and application part. This project was proposed to select the appropriate OWAs for addition in wet-end, and understand their effect on brightness and whiteness of paper using different fillers at same ash level using different pulp furnish.

3. OBJECTIVES

Scientific

- Study the chemistry of the OWA compounds with papermaking furnish

Technical

- To decide the chemical addition sequence in wet-end to get highest brightness/whiteness of paper
- To target the ISO brightness of 90 and 95% through optimised use of OWA at wet-end

Commercial

- Decreasing dose of OWA for the target brightness level of paper

4. SCOPE

- Bleached mixed hardwood pulp of different initial brightness levels
- Commercially available di-, tetra-, and hexa-sulphonic OWAs from different sources
- Different fillers like GCC, PCC and Talc

5. EXPERIMENTAL

1. Materials

1.1 Pulp

Three different pulps furnish collected from different pulp and paper mills in India have been used in this project. The bleached pulp furnishes were mixed hardwood (MHW), mixed hardwood (MHW), bagasse (BBS), recycled (BRC).

1.2. Wet-end Chemicals

a) Optical whitening agents

OWA	Type of OWA	Cost, Rs/kg (as such)
DS1	Di-sulphonated	75
DS2	Di-sulphonated	255
TS1	Tetra-sulphonated	75
TS2	Tetra-sulphonated	55
TS3	Tetra-sulphonated	185
HS1	Hexa-sulphonated	70

b) Dye i.e. iragalite violet.

c) Alkyl ketene dimer (AKD) having 21% solids content (w/v) was used at a fixed dose of 6 kg/t as an alkaline sizing agent to provide hydrophobicity to paper.

d) DSA of 0.02-0.025 degree of substitution was used at a fixed dose of 5 kg/t of pulp.

e) Low molecular weight cationic polyamine fixing agent (CFA) was used at fixed dose of 200 g/t to provide some cationicity to the pulp stock.

f) A medium to high molecular weight cationic polyacrylamide flocculant (CPAM) was used as retention aid at a fixed dose of 200 g/t of pulp.

g) Fillers: Talc (hydrated magnesium silicate), GCC (ground calcium carbonate), PCC (precipitated calcium carbonate).

2. Methods

2.1. Refining of Pulp

The bleached mixed hard wood pulp (MHW) was refined in PFI Mill to get 30^0SR (manufactured by HAMJERN MASKIN) as per TAPPI Test Method T 248 sp-00. The freeness of pulp was measured using Schopper Riegler tester (^{0}SR) Tester.

2.2. Characterisation of Pulp

a) Moisture content of pulp was determined as per TAPPI test method (T 210 cm-86).
b) Ionic behavior and charge demand: The charge (streaming potential) was measured on Mutek PCD-03pH (Particle Charge Detector) and the sample was titrated with cationic polymer to neutralize the charge. The cationic polymer used was PolyDADMAC (0.001N) and the anionic polymer used was Pes-Na (0.001N).
c) Zeta potential: The zeta potential was measured with Mutek SZP-06 (System Zeta Potential). The SZP-06 detects the surface charge of materials. The viscosity of the pulp was determined using the Capillary Viscometer Method as per TAPPI test method (T 230 om-99).
d) Buchner sheets were made for reflectance test as per TAPPI test method (T 218 sp-02).

2.3. Preparation and Characterization of Wet-End Chemicals

a) Optical Whitening Agents: The solids content and E-Value of the different OWAs were determined.

E-Value: It is the absorption of a 1% solution of unit path length. The absorbance is directly depending on the nature of the solution, concentration and the path length of the solution.

Principle: The absorbance of UV light in a solution at a characteristic wavelength is used for the quantitative determination of OWA in solution. OWA reacts as a light transformer. Only the absorption bands from 340-370 nm have the ability to transform into and emit visible light of 440-450 nm. The E-value of a product is thus the absorbance of a hypothetical 1% solution by 10 mm path length at a defined wavelength.

Procedure: Absorbance of 1% (w/v) solution of OWA was measured at 350±1 nm using 10 mm standard quartz cuvette on a UV-VIS Spectrophotometer using distilled water as blank with absorbance zero. 2-3 mL of 5% Na_2CO_3 solution was added to powder OWAs before their dilution using distilled water.

The ionic behavior and charge demand of the OWAs of 0.1% concentration was also determined using the Mutek PCD-03.

Preparation of Di-sulphonated OWA (Powder): The required amount of OBA was weighed on solid basis and was dissolved in hot water at a temperature of 60-65°C as its solubility in water is less.

Preparation of Tetra-sulphonated OWA (Powder): The required amount of OBA was weighed on solid basis and was dissolved in hot water at a temperature of 40-45°C.

b) AKD: 1% (w/v) solution of AKD emulsion was prepared in distilled water on the basis of 20.8% solids in original AKD Emulsion. Particle size analyzer (Horiba, USA) was used for measuring particle size distribution of AKD emulsion. pH of the 1% AKD solution was determined using the pH meter. The ionic behavior and charge demand of the 1% AKD solution was also determined using PCD 03 pH (Particle Charge Detector).

c) DSA of 0.02-0.025 degree of substitution: DSA powder was dispersed in distilled water to make 1% (w/v) slurry. The dispersed slurry was taken into a beaker and placed into water bath. The temperature was raised to gelatinize the slurry. Continuous mild stirring was given to the slurry. The slurry was cooked at 90°C for about 30 minutes. It was then cooled at ambient temperature and used in wet-end as a strength aid. The pH, solids, ionic behavior and charge demand of the DSA were determined.

d) Low molecular weight cationic polyamine fixing agent (CFA): 0.1% (w/v) solution was prepared in distilled water. 1 g of the liquid CFA was weighed and the volume was made up to 1 L using distilled water. The ionic behavior and charge demand of the CFA of 0.1% concentration was determined using the Mutek PCD 03 pH.

e) Medium to high molecular weight cationic polyacrylamide flocculant (CPAM): 0.1% (w/v) solution of the granular flocculant was prepared in distilled water by gradual addition of the granules in lukewarm water (40-45°C). Continuous mild stirring of about 400 rpm was given to the solution for 30 min. The ionic behavior and charge demand of the CPAM of 1gpl concentration was determined using the Mutek PCD 03 pH.

2.4 Stock Preparation

Different components (chemicals and additives) were added to the pulp slurry in the following order with continuous stirring:

Pulp (1% consistency), OWA solution, Dye, CFA: 200 g/t of pulp, DSA: 5 kg/t of pulp, AKD: 6 kg/t of pulp on solid basis, Filler (as required for 21% ash level), CPAM: 200g/t of pulp

2.5 Making of handsheets on sheet former

Handsheets of 70 g/m^2 were made on sheet former as per TAPPI test method (T 272 sp-97).

Sheets pressing and drying was done according to TAPPI test method (T 218 sp-02).

Buchner sheets were made for reflectance test following TAPPI test method (T 218 sp-02).

The handsheets were conditioned at 27±2°C and 65±5% relative humidity for at least 24 hours as per IS/ISO: 187. The ash content of the handsheet was determined as per IS 1060 Part I at 525°C. The ash content was calculated using the following formula:

$$\text{Ash content in paper, \%} = \frac{\text{o. d. weight of ash in paper (g)}}{\text{o. d. weight of handsheet (g)}} \text{ x } 100$$

The first pass ash retention (FPAR) was calculated using the following formula:

$$\text{FPAR, \%} = \frac{\text{Ash in paper (\%)}}{\text{Filler added based on pulp and filler (\%)}} \text{ x } 100$$

2.6 Optical Properties of Handsheets

The following optical properties of paper handsheets were measured with the brightness tester (L&W Elrepho):

- B. brightness (R457 420), ISO brightness (R457 C), CIE whiteness (CIE W D65 D65/10), Yellowness (D65 D65/10), L*, a*, b*, ISO Opacity, Light scattering coefficient, Fluorescence (R457 Flour D65), the fluorescence using C source i.e. R457. Flour C was also calculated using the following formula: R457 C–R457 420 i.e. brightness - B. brightness.

6. RESULTS & DISCUSSION

CHAPTER – 1

Bleached Mixed Hardwood (MHW) Pulp

1. Characteristics of wet-end chemicals

Various physico-chemical characteristics of different wet-end chemicals are given in Table 1. GCC-60 and PCC fillers were slightly anionic and having about 4.7 µeq/g and 6.9 µeq/g of cationic charge demand respectively while talc filler was cationic in nature and it anionic charge demand was 172 µeq/g. AKD was also cationic in nature and it anionic charge demand was 111 µeq/g. The CFA and DSA were having anionic charge demand of 3050 and 1655 µeq/g. The E-value and charge demand of various OWAs are given in Table 2. The E-value determined on the basis of dry solids was the highest for DS1 (562) followed by TS1 (496), DS2 (493), HS1 (374), TS2 (327) and TS3 (265).

2. Characterization of Pulp

As shown in Table 3, the initial ISO brightness of pulp was 85.3%. The cationic charge demand of the pulp was 12.2 µeq/l. It was increased to 16.8 µeq/l after beating the pulp. After addition of all wet-end chemicals but without filler, the cationic charge demand was reduced to 11.7 µeq/l as shown in Table 4.

As shown in Table 5, the optical properties were degraded on beating of pulp. The brightness, whiteness and opacity of handsheets were reduced from 84.8%, 74.4 and 81.7% to 82.8%, 72.1 and 75.7%, respectively on beating of pulp. Brightness and whiteness of the handsheets were further reduced on addition of wet-end chemicals in pulp. After addition of filler, all optical properties were improved. On addition of about 21% GCC-60 in paper sheets, the brightness was improved from 77.6 to 82.3%, whiteness was improved from 65.3 to 74.3 and opacity was improved from 78.9 to 88.7%.

3. Effect of OWA addition on optical properties of paper

3.1. With DS2 OWA

The DS2 was now added in pulp along with other wet-end chemicals. The dosage of DS2 was increased from 0.5 to 16 kg/t. The ash content in this case also was about 22%. The brightness of paper sheets was increased to the maximum level of 97.6% using 14 kg/t dosage of DS2. The corresponding whiteness index value was 144.3. Further increasing the dosage to 16 kg/t did not have any impact on brightness but slightly decreased the whiteness of paper sheets as shown in Table 6

3.2. With TS1 OWA

In order to understand the effect of sulphonic groups in OWA, TS1, a tetra-sulphonated OWA, was added in pulp along with other wet-end chemicals. The dosage of TS1 ranged from 2 to 8 kg/t. The ash content in this case was about 20%. The brightness of paper sheets was increased to 97.4% using 8 kg/t dosage of TS1. The corresponding whiteness

value was 145.2. As compared with previous case with DS2, the improvement in brightness and whiteness was more with TS1. However, in this case too, the greening effect observed through a* value was at 6 kg/t dosage, similar to the case with DS2 as shown in Table 7.

4. *Effect of sequential addition of OWA on optical properties of paper*

4.1. With DS2 OWA

DS2 was added at different addition points to understand the role of its addition point on optical properties of paper. The dosage of DS2 was kept constant at 4 kg/t. The dosage of other wet-end chemicals was also kept constant. It was observed that the addition point of DS2 had no much impact on optical properties of paper sheets. The brightness and whiteness values were marginally increased when DS2 was added after CFA and DSA. The increase in brightness and whiteness was about 0.3 and 0.5 points, respectively as shown in Table 8

4.2. With TS1 OWA

Similar to DS2, TS1 was also added at different addition points to understand the role of addition point of a tetra-sulphonated OWA on optical properties of paper. The dosage of TS1 was also kept constant at 4 kg/t along with other wet-end chemicals. The addition point of TS1 had slight impact on optical properties of paper sheets. The brightness and whiteness values were marginally increased by 0.6 and 2.5 points, respectively when TS1 was added after the addition of CFA and DSA. In this case the cationic charge demand of the final pulp stock was the lowest showing the less anionicity of pulp stock as shown in Table 9.

5. *Effect of cationic additives on efficiency of OWA*

The different cationic wet-end additives were eliminated one by one from the wet-end process and their impact of optical properties of paper was analysed. In first case when all the previously selected wet-end additives were added to pulp the zeta potential of pulp stock was -21.5 mV which, as expected, was increased to more anionic on eliminating the cationic additives. The similar effect on cationic charge demand was observed wherein the cationic demand of pulp stock was increased from 12.2 µeq/L to 16.5, 18.5 and 21.6 µeq/L on eliminating CFA, DSA and both CFA and DSA, respectively. Ash content in paper sheets was slightly reduced due to imbalance of system's charge. However, no change in brightness of paper sheets was observed. Other optical properties of paper were also more or less comparable as shown in Table 10.

6. Effect of intrinsic brightness of filler on optical properties of paper and cost of OWA

As shown in Table 11, GCC and talc fillers were compared at same ash level of about 20-21% for getting about 90% brightness in paper sheets. It was observed that the B. brightness of paper sheets was different with both the fillers due to their different intrinsic brightness. The less B. brightness with talc filler was mainly responsible for getting the lower brightness in paper sheets as compared with GCC filler. To compensate the lower brightness in case of talc filler, the dosage of OWA was increased so that at same level of brightness, the whiteness was more with talc filler but cost of OWA was also very high as compared that with GCC. From the results of different OWAs, it was observed that the papermakers need to compromise on at least one optical property, either brightness or whiteness, if compared at same dosage/ cost of OWA. It was observed that to get the brightness level of about 90%, the dosage/ cost of DS1, DS2 and TS1 OWAs was almost comparable for both the fillers separately.

Similarly at 95% brightness level, the cost of OWA was almost double for talc filler as compared with GCC (Table 12). In this case, however for same filler also, the difference in cost of OWA was little more than that observed at 90% brightness level. In this case the performance of DS2 and TS1 was comparable followed by DS1, TS2 and TS3.

7. *Effect of different OWAs in wet-end and in surface sizing application (at 21% ash level using different fillers)*

One OWA after dose optimization at wet-end was fixed for wet-end addition while other OWAs were added in surface sizing at different doses followed by selection of best combination of that particular OWA at wet-end with other OWAs at surface sizing on the basis of cost reduction without compromising the optical properties of paper.

7.1 With GCC filler

7.1.1 Optimization of different OWAs at wet-end

DS2 was added in wet-end at different doses. At minimum dose of 3 kg/t of DS2 the brightness was 93.0%, CIE whiteness and fluorescence was 136.4 and 21.0 respectively. The optimum dose was 6 kg/t at which brightness was 94.4%, CIE whiteness and fluorescence was 138.3 and 22.3 respectively. On further increasing the dose beyond 6 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 13 kg/t of DS2 the brightness was 93.2%, CIE whiteness and fluorescence was 136.1 and 24.4 respectively. TS3 was added in wet-end at different doses. At minimum dose of 6 kg/t

of TS3, the brightness was 91.8%, CIE whiteness and fluorescence was 133.3 and 19.7 respectively. The optimum dose was 11 kg/t at which brightness was 93.7%, CIE whiteness and fluorescence was 141.4 and 22.9 respectively. On further increasing the dose beyond 11 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 17 kg/t of TS3 the brightness was 92.9%, CIE whiteness and fluorescence was 139.3 and 23.2 respectively. DS1 was added in wet-end at different doses. At minimum dose of 5 kg/t of DS1, the brightness was 92.5%, CIE whiteness and fluorescence was 142.3 and 22.9 respectively. The optimum dose was 8 kg/t at which brightness was 93.7%, CIE whiteness and fluorescence was 142.6 and 24.2 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 13 kg/t of TS3 the brightness was 93.3%, CIE whiteness and fluorescence was 141.1 and 24.8 respectively as shown in Table 13.

7.1.2 Split addition of OWAs in wet-end and surface sizing

7.1.2.1 Effect of different OWA in surface sizing with DS2 addition of 6 kg/t at wet-end

First of all, TS3 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of DS2 the brightness was 94.3%, CIE whiteness and fluorescence was 139.8 and 23.4 respectively. The optimum dose of TS3 in surface sizing was 1 kg/t at which brightness was 94.8%, CIE whiteness and fluorescence was 141.1 and 23.9 respectively. On further increasing the dose of TS3 to 2 kg/t, the brightness was 94.6%, CIE whiteness and fluorescence was 140.6 and 23.6 respectively. DS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of DS2 the brightness was 94.1%, CIE whiteness and fluorescence was 140.4 and 23.1 respectively. The optimum dose of DS2 in surface sizing was 1 kg/t at which brightness was 94.3%, CIE whiteness and fluorescence was 141.2 and 23.3 respectively. On further increasing the dose of DS2 to 2 kg/t, the reduction in optical properties was observed. The brightness was 93.9%, CIE whiteness and fluorescence was 140.3 and 23.2 respectively. TS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of TS1 the brightness was 94.6%, CIE whiteness and fluorescence was 141.3 and 23.2 respectively. The optimum dose of TS1 in surface sizing was 0.4 kg/t. On further increasing the dose of TS1 to 2 kg/t, the reduction in optical properties was observed. The brightness was 94.1 %, CIE whiteness and fluorescence was 140.3 and 23.1 respectively. TS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of TS1 the brightness was 94.2%, CIE whiteness and fluorescence was 140.2 and 23.9 respectively. The optimum dose of TS1 in surface sizing was 1 kg/t on which the brightness was 94.6 % and CIE whiteness was 141.0 and fluorescence was 23.5. On further increasing the dose of TS2 to 2 kg/t, the reduction in optical properties was observed. The brightness was

94.4%, CIE whiteness and fluorescence was 140.3 and 23.5 respectively. DS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of DS1 the brightness was 94.4%, CIE whiteness and fluorescence was 141.6 and 23.2 respectively. The optimum dose of DS1 in surface sizing was 1 kg/t on which the brightness was 94.8% and CIE whiteness was 142.0 and fluorescence was 23.4. On further increasing the dose of DS1 to 2 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of HS1 the brightness was 94.1%, CIE whiteness and fluorescence was 139.9 and 23.3 respectively. The optimum dose of HS1 in surface sizing was 1 kg/t on which the brightness was 94.4% and CIE whiteness was 141.0 and fluorescence was 23.4. On further increasing the dose of HS1 to 2 kg/t, the reduction in optical properties was observed as shown in Table 14.

7.1.2.2 Effect of different OWA in surface sizing with DS2 addition of 4 kg/t at wet-end

TS3 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of TS3 the brightness was 95.0%, CIE whiteness and fluorescence was 141.8 and 22.9 respectively. The optimum dose of TS3 in surface sizing was 1 kg/t on which the brightness was 95.2% and CIE whiteness was 143.2 and fluorescence was 23.7. On further increasing the dose of TS3 to 3 kg/t, the reduction in optical properties was observed. DS2 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of DS2 the brightness was 95.1%, CIE whiteness and fluorescence was 141.1 and 23.1 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 1 kg/t, no improvement in optical properties was observed. TS1 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of TS1, the brightness was 95.2%, CIE whiteness and fluorescence was 141.8 and 22.0 respectively. This was the optimum dose of TS1 in surface sizing. On further increasing the dose of TS1 to 1 kg/t, no improvement in optical properties was observed. TS2 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of TS2, the brightness was 95.1%, CIE whiteness and fluorescence was 141.2 and 22.2 respectively. The optimum dose of TS2 in surface sizing was 1 kg/t. The brightness was 95.6%, CIE whiteness and fluorescence was 141.8 and 22.6 respectively at this dose. On further increasing the dose of TS2 to 2 kg/t, no improvement in optical properties was observed. DS1 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of DS1, the brightness was 95.0%, CIE whiteness and fluorescence was 140.9 and 22.6 respectively. The optimum dose of DS1 in surface sizing was 1 kg/t. The brightness was 95.4%, CIE whiteness and fluorescence was 142.5 and 22.4 respectively at this dose. On further increasing the dose of DS1 to 2 kg/t, no improvement in optical properties was observed. HS1 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum

dose of 0.5 kg/t of HS1, the brightness was 95.2%, CIE whiteness and fluorescence was 142.2 and 23.1 respectively. The optimum dose of HS1 in surface sizing was 1 kg/t. The brightness was 95.4%, CIE whiteness and fluorescence was 142.5 and 23.1 respectively at this dose. On further increasing the dose of HS1 to 2 kg/t, no improvement in optical properties was observed as shown in Table 15.

7.1.2.3 Effect of different OWA in surface sizing with DS2 addition of 3 kg/t at wet-end

TS3 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of TS3 the brightness was 94.2%, CIE whiteness and fluorescence was 141.8 and 22.5 respectively. The optimum dose of TS3 in surface sizing was 1 kg/t on which the brightness was 94.7% and CIE whiteness was 142.1 and fluorescence was 23.6. On further increasing the dose of TS3 to 3 kg/t, the reduction in optical properties was observed. DS2 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of DS2 the brightness was 94.4%, CIE whiteness and fluorescence was 140.7 and 21.4 respectively. The optimum dose of DS2 in surface sizing was 1 kg/t on which the brightness was 94.8% and CIE whiteness was 141.8 and fluorescence was 21.8. On further increasing the dose of DS2 to 1 kg/t, no improvement in optical properties was observed. TS1 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of TS1, the brightness was 94.3%, CIE whiteness and fluorescence was 139.6 and 21.9 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 94.6 %and CIE whiteness was 141.8 and fluorescence was 22.2.This was the optimum dose of TS1 in surface sizing. On further increasing the dose of TS1 to 4 kg/t, no improvement in optical properties was observed. TS2 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of TS2, the brightness was 94.2%, CIE whiteness and fluorescence was 139.0 and 20.9 respectively. The optimum dose of TS2 in surface sizing was 1 kg/t. The brightness was 94.5%, CIE whiteness and fluorescence was 140.1 and 21.6 respectively at this dose. On further increasing the dose of TS2 to 3 kg/t, no improvement in optical properties was observed. DS1 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of DS1, the brightness was 94.5%, CIE whiteness and fluorescence was 141.1 and 21.9 respectively. The optimum dose of DS1 in surface sizing was 2 kg/t. The brightness was 95.2%, CIE whiteness and fluorescence was 143.1 and 22.5 respectively at this dose. On further increasing the dose of DS1 to 3 kg/t, no improvement in optical properties was observed. HS1 was added in surface sizing along with 3 kg/t of DS2 at wet-end. At minimum dose of 0.5 kg/t of HS1, the brightness was 94.0%, CIE whiteness and fluorescence was 138.1 and 20.9 respectively. The optimum dose of HS1 in surface sizing was 1 kg/t. The brightness was 94.3%, CIE whiteness and fluorescence was 138.9 and 21.4 respectively at this dose. On further

increasing the dose of HS1 to 3 kg/t, no improvement in optical properties was observed as shown in Table 16.

7.1.2.4 Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 0.4 kg/t of TS3 the brightness was 94.1 %, CIE whiteness and fluorescence was 142.3 and 22.6 respectively. The optimum dose of TS3 in surface sizing was 1 kg/t at which brightness was 94.4%, CIE whiteness and fluorescence was 142.3 and 23.2 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness was 94.5%, CIE whiteness and fluorescence was 139.2 and 23.4 respectively. DS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 0.4 kg/t of DS2 the brightness was 94.1%, CIE whiteness and fluorescence was 142.4 and 22.4 respectively. The optimum dose of DS2 in surface sizing was 2 kg/t at which brightness was 94.6%, CIE whiteness and fluorescence was 142.9 and 23.6 respectively. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 94.3%, CIE whiteness and fluorescence was 139.3 and 23.7 respectively. TS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 0.4 kg/t of TS1 the brightness was 94.0%, CIE whiteness and fluorescence was 143.1 and 22.8 respectively. The optimum dose of TS1 in surface sizing was 1 kg/t. The brightness was 94.1%, CIE whiteness and fluorescence was 143.1 and 23.1 respectively at this dose. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was 94.0%, CIE whiteness and fluorescence was 138.3 and 23.0 respectively. TS2 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 0.4 kg/t of TS1 the brightness was 94.0%, CIE whiteness and fluorescence was 142.8 and 22.4 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 94.5% and CIE whiteness was 142.2 and fluorescence was 23.1. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 94.4%, CIE whiteness and fluorescence was 140.4 and 23.2 respectively. DS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 0.4 kg/t of DS1 the brightness was 94.3%, CIE whiteness and fluorescence was 143.3 and 22.5 respectively which was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 0.4 kg/t of HS1 the brightness was 94.1%, CIE whiteness and fluorescence was 143.6 and 22.4 respectively. The optimum dose of HS1 in surface sizing was 1 kg/t on which the brightness was 94.0% and CIE whiteness was 142.6 and fluorescence was 22.5. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 17 & 18.

7.1.2.5 Effect of different OWA in surface sizing with DS1 addition of 5 kg/t at wet-end

TS3 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 92.9 %, CIE whiteness and fluorescence was 144.0 and 23.8 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 93.8%, CIE whiteness and fluorescence was 144.4 and 24.1 respectively. On further increasing the dose of TS3 to 4 kg/t, the reduction in optical properties was observed, the brightness was 93.3%, CIE whiteness and fluorescence was 140.3 and 23.2 respectively. DS2 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS2 the brightness was 93.2%, CIE whiteness and fluorescence was 143.7 and 23.7 respectively. The optimum dose of DS1 in surface sizing was 2 kg/t at which brightness was 93.8%, CIE whiteness and fluorescence was 144.2 and 23.8 respectively. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was 93.0%, CIE whiteness and fluorescence was 138.6 and 22.6 respectively. TS1 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 92.8%, CIE whiteness and fluorescence was 143.5 and 23.8 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. The brightness was 93.5 %, CIE whiteness and fluorescence was 143.1 and 23.8 respectively at this dose. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness reduced to 92.8 %, CIE whiteness and fluorescence was 139.5 and 22.9 respectively. TS2 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 92.8%, CIE whiteness and fluorescence was 142.7 and 23.1 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 93.5% and CIE whiteness was 142.3 and fluorescence was 23.2. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 92.9%, CIE whiteness and fluorescence was 135.5 and 22.3 respectively. DS1 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS1, the brightness was 93.1%, CIE whiteness and fluorescence was 142.9 and 23.5 respectively. The optimum dose of DS1 in surface sizing was 2 kg/t on which the brightness w0as 93.9%, CIE whiteness and fluorescence was 142.6 and 23.5 respectively. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 5 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of HS1 the brightness was 92.5%, CIE whiteness and fluorescence was 142.5 and 23.2 respectively. The optimum dose of HS1 in surface sizing was 2 kg/t on which the brightness was 93.3% and CIE whiteness was 142.5 and fluorescence was 23.8. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 19.

7.1.3 Best Combinations of different OWAs at wet and size press

7.1.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 6 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 94.4% and CIE whiteness and fluorescence were 138.3 and 22.3 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 3 kg/t of DS2 at wet-end with 2 kg/t of DS2 in surface sizing, 3 kg/t of DS2 at wet-end with 2 kg/t of TS1 in surface sizing, 4 kg/t of DS2 at wet-end with 2 kg/t of DS1 in surface sizing, 4 kg/t of DS2 at wet-end with 2 kg/t of TS3 in surface sizing, 4 kg/t of DS2 at wet-end with 2 kg/t of TS2 in surface sizing, 4 kg/t of DS2 at wet-end with 2 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 3 kg/t of DS2 at wet-end and 2 kg/t of TS1 in surface sizing along with 3.5 unit gain in whiteness and 0.4 unit gain in brightness. The reduction is cost at this combination was 615 Rs/t of paper as shown in Table 20.

7.1.3.2 TS3 at wet-end with different OWAs at size press

Adding TS3 at a dose of 11 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 93.7% and CIE whiteness and fluorescence were 141.4 and 22.9 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 6 kg/t of TS3 at wet-end with 2 kg/t of DS2 in surface sizing, 6 kg/t of DS2 at wet-end with 0.4 kg/t of DS1 in surface sizing, 6 kg/t of TS3 at wet-end with 1 kg/t of TS1 in surface sizing, 6 kg/t of DS2 at wet-end with 1 kg/t of TS3 in surface sizing, 6 kg/t of DS2 at wet-end with 2 kg/t of TS2 in surface sizing, 6 kg/t of TS3 at wet-end with 1 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 6 kg/t of TS3 at wet-end and 0.4 kg/t of DS1 in surface sizing along with 1.9 unit gain in whiteness and 0.6 unit gain in brightness. The reduction is cost at this combination was 890 Rs/t of paper as shown in Table 21.

7.1.3.3 DS1 at wet-end with different OWAs at size press

Adding DS1 at a dose of 8 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 93.7% and CIE whiteness and fluorescence were 142.6 and 24.2 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations were 5 kg/t of DS1 at wet-end with 2 kg/t of DS2 in surface sizing, 5 kg/t of DS1 at wet-end with 2 kg/t of DS1 in surface sizing, 5 kg/t of DS1 at wet-end with 2 kg/t of TS1 in surface sizing, 5 kg/t of DS1 at wet-end with 2 kg/t of TS3 in

surface sizing, 5 kg/t of DS1 at wet-end with 2 kg/t of TS2 in surface sizing, 5 kg/t of DS1 at wet-end with 2 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 5 kg/t of DS1 at wet-end and 2 kg/t of DS1 in surface sizing along with comparable optical properties. The reduction is cost at this combination was 843 Rs/t of paper as shown in Table 22.

7.2 With Talc filler

7.2.1 Optimization of different OWAs at wet-end

DS2 was added in wet-end at different doses. At minimum dose of 2 kg/t of DS2 the brightness was 88.3%, CIE whiteness and fluorescence was 129.3 and 19.2 respectively. The optimum dose was 8 kg/t at which brightness was 91.9%, CIE whiteness and fluorescence was 139.3 and 25.2 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 12 kg/t of DS2 the brightness was 90.1%, CIE whiteness and fluorescence was 132.3 and 22.6 respectively. TS3 was added in wet-end at different doses. At minimum dose of 8 kg/t of TS3 the brightness was 90.0%, CIE whiteness and fluorescence was 136.9 and 23.3 respectively. The optimum dose was 16 kg/t at which brightness was 91.9%, CIE whiteness and fluorescence was 142.5 and 26.1 respectively. On further increasing the dose beyond 16 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 18 kg/t of TS3 the brightness was 91.3%, CIE whiteness and fluorescence was 141.2 and 25.9 respectively. DS1 was added in wet-end at different doses. At minimum dose of 6 kg/t of DS1 the brightness was 90.6%, CIE whiteness and fluorescence was 137.7 and 24.4 respectively. The optimum dose was 12 kg/t at which brightness was 91.6%, CIE whiteness and fluorescence was 136.6 and 25.7 respectively. On further increasing the dose beyond 12 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At maximum dose of 14 kg/t of DS1 the brightness was 91.4%, CIE whiteness and fluorescence was 134.1 and 25.6 respectively as shown in Table 23.

7.2.2 Split addition of OWAs in wet-end surface sizing

7.2.2.1 Effect of different OWA in surface sizing with DS2 addition of 4 kg/t at wet-end

TS3 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 90.1%, CIE whiteness and fluorescence was 132.4 and 21.6 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 90.4%, CIE whiteness and fluorescence was 131.5 and 21.6 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 89.7%, CIE whiteness and

fluorescence was 128.6 and 20.5 respectively. DS2 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 89.5%, CIE whiteness and fluorescence was 131.8 and 20.5 respectively. This was the optimum dose of DS2 in surface sizing.. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 88.4%, CIE whiteness and fluorescence was 126.7 and 18.3 respectively. TS1 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 90.0%, CIE whiteness and fluorescence was 131.8 and 11.8 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was 89.4%, CIE whiteness and fluorescence was 129.4 and 11.1 respectively. TS2 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 90.4 %, CIE whiteness and fluorescence was 133.1 and 12.0 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 90.9% and CIE whiteness was 133.5 and fluorescence was 12.7. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 90.6%, CIE whiteness and fluorescence was 131.5 and 12.1 respectively. DS1 was added in surface sizing along with 4 kg/t of DS2 at wet-end. At minimum dose of 1.0 kg/t of DS1 the brightness was 89.9%, CIE whiteness and fluorescence was 131.6 and 11.5 respectively. Same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 24.

7.2.2.2 Effect of different OWA in surface sizing with DS2 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 92.2%, CIE whiteness and fluorescence was 140.1 and 13.5 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 92.4%, CIE whiteness and fluorescence was 140.6 and 13.9 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 91.6%, CIE whiteness and fluorescence was 137.2 and 12.7 respectively. DS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 90.7%, CIE whiteness and fluorescence was 138.8 and 22.5 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.6%, CIE whiteness and fluorescence was 133.8 and 20.2 respectively. TS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 90.7%, CIE whiteness and fluorescence was 138.8 and 22.5 respectively. The same was optimum dose of TS1 in surface sizing. On further increasing the dose of TS1 to 4 kg/t,

the reduction in optical properties was observed. The brightness was reduced to 89.6%, CIE whiteness and fluorescence was 133.8 and 20.2 respectively. TS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 91.7%, CIE whiteness and fluorescence was 140.3 and 13.4 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 92.2% and CIE whiteness was 141.0 and fluorescence was 14.1. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.6%, CIE whiteness and fluorescence was 138.3 and 13.3 respectively. DS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1.0 kg/t of DS1 the brightness was 91.0%, CIE whiteness and fluorescence was 138.8 and 12.5 respectively. Same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 25.

7.2.2.3 Effect of different OWA in surface sizing with DS2 addition of 8 kg/t at wet-end

TS3 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 91.6%, CIE whiteness and fluorescence was 141.7 and 24.9 respectively. The same was the optimum dose of TS3 in surface sizing. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 91.3%, CIE whiteness and fluorescence was 138.1 and 23.8 respectively. DS2 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 91.6%, CIE whiteness and fluorescence was 141.7 and 24.9 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.3%, CIE whiteness and fluorescence was 138.1 and 23.8 respectively. TS1 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.4%, CIE whiteness and fluorescence was 142.0 and 12.8 respectively. The same was optimum dose of TS1 in surface sizing. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 90.6 %, CIE whiteness and fluorescence was 138.5 and 12.4 respectively. TS2 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 92.1%, CIE whiteness and fluorescence was 142.8 and 13.8 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 92.5% and CIE whiteness was 143.7 and fluorescence was 14.1. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.7%, CIE whiteness and fluorescence was 140.5 and 13.3 respectively. DS1 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1.0 kg/t of DS1 the brightness was 91.4%, CIE whiteness and fluorescence was 141.3 and 13.0 respectively.

Same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table .26.

7.2.2.4 Effect of different OWA in surface sizing with TS3 addition of 8 kg/t at wet-end

TS3 was added in surface sizing along with 8 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 90.9%, CIE whiteness and fluorescence was 141.9 and 24.3 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 91.2%, CIE whiteness and fluorescence was 141.5 and 24.6 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 90.5%, CIE whiteness and fluorescence was 135.4 and 24.1 respectively. TS3 was added in surface sizing along with 8 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 90.5%, CIE whiteness and fluorescence was 141.8 and 23.5 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.1%, CIE whiteness and fluorescence was 128.4 and 21.1 respectively. TS1 was added in surface sizing along with 8 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 90.6%, CIE whiteness and fluorescence was 140.0 and 23.9 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 90.6%, CIE whiteness and fluorescence was 135.4 and 24.0 respectively. TS2 was added in surface sizing along with 8 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 90.9 %, CIE whiteness and fluorescence was 140.3 and 24.5 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 91.3% and CIE whiteness was 140.9 and fluorescence was 24.7. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 90.8%, CIE whiteness and fluorescence was 139.6 and 24.3 respectively. HS1 was added in surface sizing along with 8 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 90.6%, CIE whiteness and fluorescence was 141.2 and 24.4 respectively. Same was the optimum dose of HS1 in surface sizing. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 27.

7.2.2.5 Effect of different OWA in surface sizing with TS3 addition of 10 kg/t at wet-end

TS3 was added in surface sizing along with 10 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 91.6%, CIE whiteness and fluorescence was 145.2 and 25.3 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 91.9%, CIE whiteness and fluorescence was 144.8 and 25.7 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 91.3%, CIE whiteness and

fluorescence was 138.9 and 25.1 respectively. TS3 was added in surface sizing along with 10 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 91.2 %, CIE whiteness and fluorescence was 145.0 and 24.5 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.8%, CIE whiteness and fluorescence was 132.1 and 22.1 respectively. TS1 was added in surface sizing along with 10 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.2%, CIE whiteness and fluorescence was 145.0 and 24.5 respectively. The optimum dose of TS1 in surface sizing was 1 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.8 %, CIE whiteness and fluorescence was 132.1 and 22.1 respectively. TS2 was added in surface sizing along with 10 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 91.7%, CIE whiteness and fluorescence was 144.1 and 25.7 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 92.0% and CIE whiteness was 144.3 and fluorescence was 25.8. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.4%, CIE whiteness and fluorescence was 142.2 and 25.3 respectively. DS1 was added in surface sizing along with 10 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 91.4%, CIE whiteness and fluorescence was 145.5 and 24.7 respectively. The same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.8%, CIE whiteness and fluorescence was 132.0 and 22.1 respectively. HS1 was added in surface sizing along with 10 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 91.4%, CIE whiteness and fluorescence was 144.6 and 25.6 respectively. Same was the optimum dose of HS1 in surface sizing. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 28.

7.2.2.6 Effect of different OWA in surface sizing with DS1 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 91.3%, CIE whiteness and fluorescence was 143.8 and 24.9 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 91.6%, CIE whiteness and fluorescence was 143.4 and 25.2 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 90.9%, CIE whiteness and fluorescence was 137.4 and 24.6 respectively. DS2 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 90.6%, CIE whiteness and fluorescence was 141.9 and 23.9 respectively. This was the

optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.5%, CIE whiteness and fluorescence was 130.6 and 21.7 respectively. TS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.0%, CIE whiteness and fluorescence was 142.0 and 24.6 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.0 %, CIE whiteness and fluorescence was 137.5 and 24.7 respectively. TS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.0%, CIE whiteness and fluorescence was 142.0 and 24.6 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t on which the brightness was 91.3% and CIE whiteness was 141.2 and fluorescence was 24.9. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 91.0%, CIE whiteness and fluorescence was 137.5 and 24.7 respectively. TS2 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 91.4%, CIE whiteness and fluorescence was 142.4 and 25.2 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 91.7% and CIE whiteness was 142.8 and fluorescence was 25.3. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.1%, CIE whiteness and fluorescence was 141.1 and 24.9 respectively. DS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 91.1%, CIE whiteness and fluorescence was 144.2 and 24.3 respectively. The same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.5%, CIE whiteness and fluorescence was 130.5 and 21.7 respectively. HS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 91.1%, CIE whiteness and fluorescence was 143.1 and 25.1 respectively. Same was the optimum dose of HS1 in surface sizing. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 29.

7.2.2.7 Effect of different OWA in surface sizing with DS1 addition of 9 kg/t at wet-end

TS3 was added in surface sizing along with 9 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 91.8%, CIE whiteness and fluorescence was 146.1 and 25.7 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 92.1%, CIE whiteness and fluorescence was 145.7 and 26.0 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 91.5%, CIE whiteness and fluorescence was 139.9 and 25.4 respectively. DS2 was added in surface sizing along with 9

kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 91.4%, CIE whiteness and fluorescence was 145.5 and 24.8 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.9%, CIE whiteness and fluorescence was 132.9 and 22.3 respectively. TS1 was added in surface sizing along with 9 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.6%, CIE whiteness and fluorescence was 144.5 and 25.6 respectively. The optimum dose of TS1 in surface sizing was 1 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.6%, CIE whiteness and fluorescence was 140.4 and 25.6 respectively. TS2 was added in surface sizing along with 9 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 92.0%, CIE whiteness and fluorescence was 145.3 and 26.1 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 92.2% and CIE whiteness was 145.4 and fluorescence was 26.1. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 91.5%, CIE whiteness and fluorescence was 142.9 and 25.6 respectively. DS1 was added in surface sizing along with 9 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 91.6%, CIE whiteness and fluorescence was 146.1 and 25.0 respectively. The same was the optimum dose of DS1 in surface sizing. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 90.0%, CIE whiteness and fluorescence was 132.9 and 22.4 respectively. HS1 was added in surface sizing along with 9 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 91.7%, CIE whiteness and fluorescence was 145.8 and 26.0 respectively. Same was the optimum dose of HS1 in surface sizing. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 30.

7.2.3 Best Combinations of different OWAs at wet and size press

7.2.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 8 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.9% and CIE whiteness and fluorescence were 139.3 and 12.9 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 6 kg/t of DS2 at wet-end with 2 kg/t of TS3 in surface sizing, 6 kg/t of DS2 at wet-end with 2 kg/t of TS2 in surface sizing, 8 kg/t of DS2 at wet-end with 1 kg/t of DS1 in surface sizing, 8 kg/t of DS2 at wet-end with 1 kg/t of TS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 6 kg/t of DS2 at wet-end and 2

kg/t of TS2 in surface sizing along with comparable optical properties. The reduction is cost at this combination was 398 Rs/t of paper as shown in Table 31.

7.2.3.2 TS3 at wet-end with different OWAs at size press

Adding TS3 at a dose of 16 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.9% and CIE whiteness and fluorescence were 142.5 and 26.1 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 10 kg/t of TS3 at wet-end with 1 kg/t of TS1 in surface sizing, 10 kg/t of DS2 at wet-end with 2 kg/t of TS2 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 10 kg/t of TS3 at wet-end and 1 kg/t of TS1 in surface sizing along with comparable optical properties. The reduction is cost at this combination was 1030 Rs/t of paper as shown in Table 32.

7.2.3.3 DS1 at wet-end with different OWAs at size press

Adding DS1 at a dose of 12 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.6% and CIE whiteness and fluorescence were 136.6 and 25.7 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations among all was 9 kg/t of DS1 at wet-end with 1 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The reduction in cost at this combination was 924 Rs/t of paper as shown in Table 33.

7.3 With PCC filler

7.3.1 Split addition of OWAs in wet-end surface sizing

7.3.1.1 Effect of different OWA in surface sizing with DS2 addition of 2, 3, 4, 5 & 6 kg/t at wet-end

Dose of TS3 was varied in surface sizing by keeping the fixed doses of DS2 i.e. 2,3,4,5 and 6 kg/t of DS2 at wet-end. With 2 kg/t of DS2 the dose of TS3 in surface sizing was 4 kg/t, With 3 kg/t of DS2 the dose of TS3 in surface sizing was 3 kg/t, With 4 kg/t of DS2 the dose of TS3 in surface sizing was 3 kg/t, With 5 kg/t of DS2 the dose of TS3 in surface sizing was 3 kg/t and with 6 kg/t of DS2 the dose of TS3 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of TS1 was varied in surface sizing by keeping the fixed doses of DS2 i.e. 2,3,4,5 and 6 kg/t of DS2 at wet-end. With 2 kg/t of DS2 the dose of TS1 in surface sizing was 4 kg/t, With 3 kg/t of DS2

the dose of TS1 in surface sizing was 3 kg/t, With 4 kg/t of DS2 the dose of TS1 in surface sizing was 3 kg/t, With 5 kg/t of DS2 the dose of TS1 in surface sizing was 3 kg/t and with 6 kg/t of DS2 the dose of TS1 in surface sizing was 2 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of TS2 was varied in surface sizing by keeping the fixed doses of DS2 i.e. 2,3,4,5 and 6 kg/t of DS2 at wet-end. With 2 kg/t of DS2 the dose of TS2 in surface sizing was 3 kg/t, With 3 kg/t of DS2 the dose of TS2 in surface sizing was 3 kg/t, With 4 kg/t of DS2 the dose of TS2 in surface sizing was 3 kg/t, With 5 kg/t of DS2 the dose of TS2 in surface sizing was 3 kg/t and with 6 kg/t of DS2 the dose of TS2 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of DS1 was varied in surface sizing by keeping the fixed doses of DS2 i.e. 2,3,4,5 and 6 kg/t of DS2 at wet-end. With 2 kg/t of DS2 the dose of DS1 in surface sizing was 2 kg/t, With 3 kg/t of DS2 the dose of DS1 in surface sizing was 1 kg/t, With 4 kg/t of DS2 the dose of DS1 in surface sizing was 2 kg/t, With 5 kg/t of DS2 the dose of DS1 in surface sizing was 2 kg/t and with 6 kg/t of DS2 the dose of DS1 in surface sizing was 2 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of DS1 in surface sizing the slight reduction in optical properties was observed as shown in Table 34 - 38

7.3.1.2 Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

Dose of TS3 was varied in surface sizing by keeping the fixed doses of TS3 i.e. 6 kg/t of at wet-end. With 6 kg/t of TS3 the dose of TS3 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of TS1 was varied in surface sizing by keeping the fixed doses of DS2 i.e. 6 kg/t of at wet-end. With 6 kg/t of TS3 the dose of TS1 in surface sizing was 4 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of TS2 was varied in surface sizing by keeping the fixed doses of TS3 i.e. 6 kg/t of at wet-end. With 6 kg/t of TS3 the dose of TS2 in surface sizing was 4 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of DS1 was varied in surface sizing by keeping the fixed doses of TS3 i.e. 6 kg/t of at wet-end. With 6 kg/t of TS3 the dose of DS1 in surface sizing was 1 kg/t on which the maximum values of optical properties were observed. On further increasing the dose of DS1 in surface sizing the slight reduction in optical properties was observed as shown in Table 39

7.3.1.3 Effect of different OWA in surface sizing with DS1 addition of 6 kg/t at wet-end

Dose of TS3 was varied in surface sizing by keeping the fixed doses of DS1 i.e. 6 kg/t of at wet-end. With 6 kg/t of DS1 the dose of TS3 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. Brightness was 96.4, whiteness was 142.4 and fluorescence was 22.8 at this dose. On further increasing the dose of TS3 in surface sizing the slight reduction in optical properties was observed. Dose of DS2 was varied in surface sizing by keeping the fixed doses of DS1 i.e. 6 kg/t of at wet-end. With 6 kg/t of DS1 at wet-end, the dose of DS2 in surface sizing was 2 kg/t on which the maximum values of optical properties were observed. Brightness was 95.9, whiteness was 142.4 and fluorescence was 22.6 at this dose. On further increasing the dose of DS2 to 4 kg/t in surface sizing the slight reduction in optical properties was observed. Dose of TS1 was varied in surface sizing by keeping the fixed doses of DS1 i.e. 6 kg/t of at wet-end. With 6 kg/t of DS1 in wet-end, the dose of TS1 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. Brightness was 96.0, whiteness was 142.7 and fluorescence was 22.9 at this dose. On further increasing the dose of TS1 in surface sizing the slight reduction in optical properties was observed. Dose of DS1 was varied in surface sizing by keeping the fixed doses of DS1 i.e. 6 kg/t of at wet-end. With 6 kg/t of DS1 at wet-end, the dose of DS1 in surface sizing was 1 kg/t on which the maximum values of optical properties were observed. Brightness was 95.5, whiteness was 141.4 and fluorescence was 22.6 at this dose. On further increasing the dose of DS1 in surface sizing the slight reduction in optical properties was observed. Dose of HS1 was varied in surface sizing by keeping the fixed doses of DS1 i.e. 6 kg/t of at wet-end. With 6 kg/t of DS1 at wet-end, the dose of HS1 in surface sizing was 3 kg/t on which the maximum values of optical properties were observed. Brightness was 96.1, whiteness was 142.0 and fluorescence was 22.6 at this dose. On further increasing the dose of DS1 in surface sizing the slight reduction in optical properties was observed as shown in Table 40.

7.3.2 Best combinations of different OWAs at wet and size press

7.3.2.1 DS2 at wet-end with different OWAs at size press

Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations among all was 4 kg/t of DS2 at wet-end with 3 kg/t of TS2 in surface sizing and 4 kg/t of DS2 in surface sizing with 3 kg/t of TS1 at size press with slight improvement in optical properties along with significant reduction in cost. The costs at these combinations were 1181 and 1238 Rs/t of paper respectively as shown in Table 41.

7.3.2.2 TS3 at wet-end with different OWAs at size press

Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations among all was 6 kg/t of TS3 at wet-end with 4 kg/t of TS2 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The cost at this combination was 1324 Rs/t of paper as shown in Table 42.

7.3.2.3 DS1 at wet-end with different OWAs at size press

Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. At 8 kg/t of DS1 the brightness was 96.3, whiteness was 140.7 and fluorescence was 23.6. The best combinations among all was 6 kg/t of DS1 at wet-end with 2 kg/t of TS2 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The cost reduction at this combination was 551 Rs/t of paper as shown in Table 43.

7.4 Addition of broke (5 to 30%) in the papermaking furnish and its effect on the efficiency of OWAs

7.4.1 Effect of broke addition in wet-end with GCC at 21% ash level

Broke was added in pulp stock in different proportions viz. 5%, 15% and 30% and the effect of broke addition on optical properties of paper was analyzed. At DS2 dose of 3 kg/t the brightness was 93.0, whiteness was 136.4 and fluorescence was 21.0. On adding the 5% broke, slight increase in whiteness and fluorescence was observed while brightness was almost comparable. On further increasing the proportion of broke to 30%, the optical properties were found comparable. So there was no adverse effect of broke addition on performance of OWA at wet-end as shown in Table 44.

7.4.2 Effect of broke addition during the split addition of OWAs in wet-end and surface sizing with GCC at 21% ash level at wet-end

DS2 was added at wet-end at a dose of 3 kg/t and TS1 was added in surface sizing at a dose of 2 kg/t. The brightness was 94.6, whiteness was 141.8 and fluorescence was 22.2. On adding the 5% broke, slight reduction in optical properties was observed. On further increasing the proportion of broke to 30%, the slight reduction optical properties were observed as shown in Table 45.

7.4.3 Effect of broke addition in wet-end with talc at 21% ash level

Broke was added in pulp stock in different proportions viz. 5%, 15% and 30% and the effect of broke addition on optical properties of paper was analyzed. At DS2 dose of 6 kg/t the brightness was 90.6, whiteness was 137.4 and fluorescence was 24.3. On adding the 5%

broke, improvement in whiteness and brightness was observed while fluorescence was almost comparable. On further increasing the proportion of broke to 30%, further increase in optical properties was found. This may be due to the presence of some amount of OWA in broke. So there was no adverse effect of broke addition on performance of OWA at wet-end along with talc filler as shown in Table 46.

7.4.4 Effect of broke addition during the split addition of OWAs in wet-end and surface sizing with talc at 21% ash level at wet-end

DS2 was added at wet-end at a dose of 6 kg/t and TS2 was added in surface sizing at a dose of 2 kg/t. The brightness was 92.2, whiteness was 141.0 and fluorescence was 14.1. On adding the 5% broke, comparable optical properties were observed. On further increasing the proportion of broke to 30%, no change in optical properties was observed as shown in Table 47.

7.5 Identification of impurities and interfering metals in OWA and their effect on optical properties of paper (using EDTA as chelating agent for the treatment of water)

The total hardness of process water was 164 ppm as $CaCO_3$. The water was treated with EDTA as chelating agent in order to remove water hardness completely. The treated water was then used in process for making the hand sheets. DS2 at a dose of 3 kg/t was added in wet-end. In case of without treatment of process water, the brightness was 92.4, whiteness was 136.2 and fluorescence was 21.0. In case of using treated water at wet-end not any significant change in optical properties was observed. So it was observed that there was no negative effect of Ca^{2+} and Mg^{2+} ions on performance of OWA at wet-end as shown in Table 48.

Table 1: Characterization of wet-end chemicals

Parameters	Talc	GCC	PCC	CFA	AKD	DSA
ISO Brightness, %	89.7	93.4	95.8	-	-	-
Solids (as such), %	94.6	69.7	58.9	-	16.1	89.6
pH (Conc., %)	10.3 (10)	8.6 (10)	9.7 (10)	7.4 (0.1)	3.1 (1)	6.4 (1)
Zeta potential, mV	+103	-97.7	-129	-	-	-
Charge demand, µeq/g	172 (Anionic)	4.7 (Cationic)	6.9 (Cationic)	3050 (Anionic)	111 (Anionic)	1655 (Anionic)

Table 2: Characterization of different OWAs

Name of OWA (% solids)	Type of OWA	E-value (1%/1 cm)
DS2 (99.9)	Di- sulphonated	493
DS1 (22.4)	Di- sulphonated	562
TS1 (25.7)	Tetra-sulphonated	496
TS3 (99.4)	Tetra-sulphonated	265
TS2 (22.6)	Tetra-sulphonated	327
HS1 (20.7)	Hexa-sulphonated	374

Table 3: Characterization of pulp

Parameters	Values
Viscosity, cP	7.1
ISO Brightness, %	85.3
Zeta potential, mV	-21.7
Cationic charge demand, µeq/L	12.2

Table 4: Charge study of unbeaten and beaten pulp

Parameters	Unbeaten	Beaten	Beaten + Chemicals (without filler)
pH	7.9	8.1	8.3
CSF, ml	600	462	470
Zeta potential, mV	-21.7	-22.1	-16.2
Cationic charge demand, µeq/L	12.2	16.8	11.7

Table 5: Effect of beating and wet-end chemicals on optical properties pulp (without OWA)

Properties	Unbeaten	Beaten	Beaten + Chemicals	
GCC, kg/t	-	-	-	310
Ash, %	-	-	-	21.8
ISO Brightness, %	84.8	82.8	77.6	82.3
CIE whiteness	74.4	72.1	65.3	74.3
Yellowness	6.37	6.41	7.53	5.08
L*	95.8	95.0	92.9	94.3
a*	0.02	0.06	0.22	0.22
b*	3.35	3.37	3.80	2.55
Fluorescence	0.37	0.25	1.2	1.0
Opacity, %	81.7	75.7	78.9	88.7
S. Coeff.,m^2/kg	39.8	29.4	29.2	53.5

Table 6: Effect of DS2 on optical properties of paper

DS2, kg/t	0.5	0.75	1	2	4	6	8	10	12	14	16
Ash, %	21.8	21.4	21.5	21.8	22.0	21.8	21.8	22.1	22.0	20.8	20.5
ISO Brightness, %	89.5	90.9	91.8	93.7	95.3	96.4	96.8	97.0	97.4	97.6	97.5
B. brightness, %	84.3	84.5	84.6	84.6	84.4	84.5	84.6	84.6	84.4	84.2	83.9
CIE whiteness	110.8	117.1	122.6	131.8	139.8	142.3	143.1	143.8	144.1	144.3	143.5
Yellowness	-7.95	-10.5	-12.6	-16.3	-19.8	-20.8	-21.3	-21.7	-21.8	-22.0	-21.8
Fluorescence C	5.23	6.43	7.25	9.09	10.9	11.9	12.3	12.4	13.0	13.5	13.6
Fluorescence D65	10.9	13.4	15.0	18.5	22.2	23.8	24.5	25.3	25.8	26.6	26.7
L*	95.6	95.9	95.9	96.2	96.4	96.6	96.7	96.7	96.9	97.0	97.0
a*	2.05	3.07	3.07	3.08	3.30	3.10	2.90	2.75	2.53	2.30	2.04
b*	-4.85	-6.24	-7.34	-9.32	-11.0	-11.5	-11.6	-11.8	-11.8	-11.8	-11.6
Opacity, %	88.5	88.0	88.9	88.7	88.6	88.7	88.9	89.0	89.2	88.0	87.7
S. Coeff.,m^2/kg	55.7	55.8	56.0	55.2	55.8	55.3	57.0	56.6	56.5	55.1	55.4

Sequence: Pulp (1% consistency) + OWA + CFA, 0.2 kg/t + DSA, 5 kg/t + AKD, 6 kg/t + GCC-60, 310 kg/t → Dilution to 0.33% consistency + CPAM, 0.2 kg/t

Table 7: Effect of TS1 on optical properties of paper

TS1, kg/t	**2**	**4**	**6**	**8**
Zeta potential, mV	-18.0	-20.5	-22.0	-23.2
Cationic charge demand, µeq/L	7.1	13.2	17.0	23.4
Ash, %	20.0	19.5	19.2	19.2
ISO Brightness, %	94.2	95.9	97.0	97.4
B. brightness	84.6	84.6	84.5	84.4
CIE whiteness	132.8	140.3	144.1	145.2
Yellowness	-16.7	-19.9	-21.6	-22.1
Fluorescence C	9.6	11.4	12.5	12.9
Fluorescence D65	18.8	22.1	24.0	24.8
L*	96.2	96.4	96.4	96.6
a*	3.19	3.44	3.40	3.28
b*	-9.56	-11.1	-11.9	-12.1
Opacity, %	87.9	87.8	87.5	86.4
S. Coeff.,m^2/kg	54.3	54.0	53.8	51.6

Sequence: Pulp (1% consistency) + OWA + CFA, 0.2 kg/t + DSA, 5 kg/t + AKD, 6 kg/t + GCC-60, 310 kg/t → Dilution to 0.33% consistency + CPAM, 0.2 kg/t

Table 8: Effect of addition point of DS2 (4 kg/t) in wet-end on optical properties of paper

Particulars	Pulp + **DS2** + CFA + DSA + AKD + GCC-60 + CPAM	Pulp + CFA + **DS2**+ DSA + AKD + GCC-60 + CPAM	Pulp + CFA + DSA + **DS2** + AKD + GCC-60 + CPAM	Pulp + CFA + DSA + AKD + **DS2** + GCC-60 + CPAM	Pulp + CFA + DSA + AKD + GCC-60 + **DS2** + CPAM
Zeta potential, mV	-16.5	-16.4	-15.0	-15.9	-16.6
Cationic charge demand, µeq/l	10.0	10.0	8.4	6.9	7.2
Ash, %	21.8	21.4	21.3	22.0	21.5
ISO Brightness, %	95.9	95.9	96.2	95.9	96.1
B. brightness, %	84.6	84.6	84.7	84.6	84.6
CIE whiteness	140.5	140.3	141.0	140.4	140.5
Yellowness	-20.0	-19.9	-20.0	-20.0	-7.95
Fluorescence C	11.4	11.4	11.4	11.4	11.5
Fluorescence D65	22.5	22.4	22.5	22.4	22.7
L*	95.6	95.6	95.6	95.6	95.6
a*	3.30	3.30	3.28	3.29	3.30
b*	-11.2	-11.1	-11.2	-11.1	-11.2
Opacity, %	88.0	87.8	88.2	87.5	87.9
S. Coeff.,m^2/kg	54.3	55.0	54.8	55.2	55.3

Table 9: Effect of addition point of TS1 (4 kg/t) in wet-end on optical properties of paper

Particulars	Pulp + **TS1** + CFA + DSA + AKD + GCC-60 + CPAM	Pulp + CFA + **TS1** + DSA + AKD + GCC-60 + CPAM	Pulp + CFA + DSA + **TS1** + AKD + GCC-60 + CPAM	Pulp + CFA + DSA + AKD + **TS1** + GCC-60 + CPAM	Pulp + CFA + DSA + AKD + GCC-60 + **TS1** + CPAM
Zeta potential, mV	-22.0	-21.9	-21.5	-21.2	-20.9
Cationic charge demand, µeq/L	19.2	18.0	16.1	17.0	17.3
ISO Brightness, %	95.7	96.1	96.3	96.4	96.1
B. brightness, %	84.1	84.2	84.2	84.4	84.2
CIE whiteness	141.0	142.4	143.5	143.4	142.2
Yellowness	-20.1	-20.9	-21.3	-21.3	-20.8
Fluorescence C	11.6	11.9	12.1	12.0	11.9
Fluorescence D65	22.6	23.2	23.5	23.4	23.1
L*	96.3	96.4	96.4	96.4	96.4
a*	3.45	3.50	3.58	3.57	3.48
b*	-11.3	-11.6	-11.9	-11.9	-11.6

Table 10: Effect of cationic additives on efficiency of OWA (DS2)

Particulars	Pulp + **DS2** + CFA + DSA + AKD + GCC-60 + CPAM	Pulp + **DS2** + DSA + AKD + GCC-60 + CPAM	Pulp + **DS2** + CFA + AKD + GCC-60 + CPAM	Pulp + **DS2** + AKD + GCC-60 + CPAM
Zeta potential, mV	-21.5	-23.7	-25.9	-26.8
Cationic charge demand, µeq/L	12.2	16.5	18.5	21.6
Ash, %	20.1	19.5	19.1	19.3
ISO Brightness, %	97.8	98.0	98.0	98.0
B. brightness	84.1	84.0	84.2	84.0
CIE whiteness	145.0	145.0	145.4	145.8
Yellowness	-22.3	-22.3	-22.4	-22.7
Fluorescence C	13.7	14.0	13.8	14.0
Fluorescence D65	26.3	26.9	26.5	26.8
L*	96.8	96.9	96.9	96.8
a*	2.50	2.30	2.59	2.50
b*	-12.0	-11.9	-12.1	-12.2

Table 11: Effect of filler on the cost of OWA at 20-21% ash level and 90%brightness

OWA	DS1		DS2		TS1		TS2		TS3	
Filler	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**
ISO Brightness, %	89.9	90.5	90.2	90.0	90.3	90.3	90.5	90.2	90.5	90.4
B. brightness, %	88.1	86.7	88.1	86.6	88.4	86.6	88.5	86.9	88.3	86.8
CIE whiteness	92.1	103.4	93.8	101.1	93.8	101.9	94.0	100.3	95.5	102.4
Fluorescence C	1.9	3.8	2.0	3.5	2.0	3.6	1.9	3.2	2.3	3.5
Fluorescence D65	3.71	7.7	4.1	7.1	4.0	7.3	4.0	6.4	4.5	7.2
Dose, kg/t	0.05	0.17	0.06	0.2	0.06	0.2	0.1	0.27	0.15	0.45

Table 12: Effect of filler on the cost of OWA at 20-21% ash level and 95%brightness

OWA	DS1		DS2		TS1		TS2		TS3	
Filler	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**	**GCC**	**Talc**
ISO Brightness, %	95.2	95.4	94.8	95.2	95.1	95.2	95.3	95.1	95.4	95.3
B. brightness, %	88.1	86.5	88.2	86.7	88.6	86.8	88.7	86.8	88.5	86.9
CIE whiteness	123.0	129.6	120.2	129.2	120.6	128.2	121.0	127.5	122.5	128.9
Fluorescence C	7.1	8.9	6.6	8.5	6.6	8.4	6.6	8.5	7.0	8.5
Fluorescence D65	14.2	17.3	13.0	16.9	13.0	16.4	13.1	16.3	13.7	16.5
Dose, kg/t	0.5	1	0.6	1.15	0.6	1.15	1	1.7	1.3	2

Effect of different OWAs in wet-end and in surface sizing application (at 21% ash level using different fillers)

With GCC filler

Table 13: Optimization of different OWAs at wet-end

OWA	DS1				DS2						TS3					
Dose, kg/t	**5**	**8**	**10**	**13**	**3**	**4**	**6**	**8**	**10**	**13**	**6**	**10**	**11**	**13**	**15**	**17**
ISO Brightness, %	92.5	**93.7**	93.6	93.3	93.0	93.2	**94.4**	93.5	93.2	93.2	91.8	93.2	**93.7**	93.4	93.3	92.9
B. brightness, %	81.4	**81.2**	81.1	80.6	83.4	83.9	**81.8**	81.2	80.9	81.3	81.7	81.8	**81.4**	81.4	81.2	81.2
CIE Whiteness	142.3	**142.6**	142.1	141.1	136.4	137.2	**138.3**	137.6	137.3	136.1	133.3	140.1	**141.4**	140.2	140.3	139.3
Fluorescence	22.9	**24.2**	24.4	24.8	21.0	22.7	**22.3**	23.8	23.9	24.4	19.7	22.7	**22.9**	23.7	24.1	23.2
Fluorescence, C	11.8	**12.5**	12.5	12.7	10.6	11.4	**11.2**	12.3	12.3	12.3	10.1	11.4	**12.3**	12.0	12.1	11.7
Yellowness	-21.6	**-21.4**	-21.0	-21.2	-20.4	-20.4	**-20.3**	-20.0	-20.4	-19.7	-18.0	-21.5	**-21.3**	-20.0	-21.2	-20.6
L*	95.1	**95.5**	95.6	95.7	95.6	95.1	**95.3**	95.5	95.4	95.6	95.0	95.3	**95.7**	95.4	95.3	95.3
a*	3.37	**3.18**	2.48	1.93	3.46	3.11	**3.12**	2.93	2.72	2.22	3.50	3.51	**3.61**	3.43	3.30	3.01
b*	-11.8	**-10.9**	-10.8	-10.3	-11.0	-10.5	**-10.9**	-10.9	-10.9	-10.5	-10.2	-11.8	**-11.4**	-11.6	-11.6	-11.4
Opacity, %	87.9	**87.6**	87.3	87.8	86.7	87.1	**87.2**	83.2	83.9	84.9	85.7	84.2	**83.7**	83.4	83.9	83.5
S. Coeff., m^2/kg	46.5	**45.5**	46.1	46.7	47.8	46.6	**46.8**	44.1	44.9	45.2	45.5	42.8	**43.8**	43.9	44.1	43.2

Split addition of different OWAs in wet-end and surface sizing

Table 14: Effect of different OWAs in surface sizing with DS2 at a dose of 6 kg/t at wet-end

DS2 at wet-end, kg/t		6																		
OWA in surface sizing, kg/t	Type	0	Only starch	DS1			DS2			TS1			TS2			TS3			HS1		
	Dose, kg/t			0.4	1	2	0.4	1	2	0.4	1	2	0.4	1	2	0.4	1	2	0.4	1	2
ISO Brightness, %		94.4	94.0	94.4	**94.8**	94.5	94.1	**94.3**	93.9	**94.6**	94.4	94.1	94.2	**94.6**	94.4	94.3	**94.8**	94.6	94.1	**94.4**	93.6
B. brightness, %		81.8	82.4	82.5	**82.7**	82.4	82.6	**82.3**	82.3	**82.3**	82.5	82.3	82.3	**82.5**	82.1	82.5	**82.3**	82.4	82.4	**82.7**	82.4
CIE Whiteness		138.3	139.5	141.6	**142.0**	141.3	140.4	**141.2**	140.3	**141.3**	141.1	140.3	140.2	**141.0**	140.3	139.8	**141.1**	140.6	139.9	**141.0**	140.6
Fluorescence		22.3	22.9	23.2	**23.4**	23.3	23.1	**23.3**	23.2	**23.2**	23.2	23.1	22.9	**23.5**	23.5	23.4	**23.9**	23.6	23.3	**23.4**	23.3
Fluorescence, C		11.2	11.6	11.9	**12.1**	12.1	11.5	**12.0**	11.6	**12.3**	11.9	11.8	11.9	**12.1**	12.3	11.8	**12.5**	12.2	11.7	**11.7**	11.2
Yellowness		-20.3	-20.4	-20.6	**-21.1**	-21.0	-20.8	**-21.0**	-20.8	**-20.7**	-20.7	-20.5	-20.6	**-21.3**	-21.1	-20.7	**-21.1**	-21.2	-20.3	**-20.7**	-20.7
L*		95.3	95.6	95.8	**95.2**	95.6	95.7	**95.5**	95.7	**95.6**	95.9	95.6	95.6	**95.8**	95.4	95.5	**95.7**	95.7	95.1	**95.3**	95.9
a*		3.12	3.31	3.42	**3.40**	3.35	3.37	**3.42**	3.20	**3.41**	3.42	3.34	3.33	**3.40**	3.27	3.34	**3.48**	3.40	3.35	**3.30**	3.21
b*		-10.9	-11.2	-11.3	**-11.4**	-11.2	-11.5	**-11.7**	-11.8	**-11.4**	-11.4	-11.4	-11.2	**-11.4**	-11.4	-11.4	**-11.6**	-11.5	-11.3	**-11.4**	-11.5
Opacity, %		87.2	87.7	87.3	**87.1**	87.5	87.3	**87.2**	86.8	**87.2**	86.8	87.2	87.2	**87.6**	87.4	87.2	**87.5**	87.3	86.9	**87.6**	87.3
S. Coeff., m^2/kg		46.8	47.4	47.8	**46.9**	47.2	46.9	**46.1**	46.7	**46.9**	46.5	47.4	47.5	**47.1**	47.8	47.0	**47.2**	47.5	47.6	**47.1**	46.9

Table *15: Effect of different OWAs in surface sizing with DS2 at a dose of 4 kg/t at wet-end*

DS2 at wet-end, kg/t		4																	
OWA in surface sizing, kg/t	Type	0	Only starch	TS3				DS2		TS1			TS2		DS1			HS1		
	Dose, kg/t			0.4	1	2	3	0.5	1	0.5	1	0.5	1	2	0.5	1	2	0.5	1	2
ISO Brightness, %		93.2	94.1	95.0	**95.2**	95.2	95.0	**95.1**	95.0	**95.2**	94.7	95.1	**95.6**	95.2	95.0	**95.4**	95.1	95.2	**95.4**	94.8
B. brightness, %		83.9	83.6	83.4	**83.2**	83.2	83.0	**83.4**	83.2	**83.1**	83.1	83.1	**83.3**	83.0	83.2	**83.1**	83.2	82.9	**83.2**	83.1
CIE Whiteness		137.2	138.2	141.8	**143.2**	141.4	139.8	**141.1**	141.2	**141.8**	140.4	141.2	**141.8**	141.1	140.9	**142.5**	142.1	142.2	**142.5**	140.9
Fluorescence		22.7	21.5	22.9	**23.7**	23.8	23.6	**23.1**	22.8	**22.0**	22.2	22.2	**22.6**	22.6	22.6	**22.4**	22.2	23.1	**23.1**	22.9
Fluorescence, C		11.4	10.9	11.6	**12.0**	12.0	12.0	**11.7**	11.8	**12.1**	11.6	12.0	**12.3**	12.2	11.8	**12.3**	11.9	12.3	**12.2**	11.7
Yellowness		-20.3	-20.5	-21.5	**-21.2**	-21.1	-19.8	**-20.1**	-20.0	**-21.2**	-20.9	-21.9	**-22.1**	-21.9	-21.7	**-21.3**	-21.1	-21.1	**-20.6**	-20.4
L*		95.1	95.7	95.5	**95.8**	96.0	96.1	**95.7**	95.8	**95.4**	95.3	95.2	**95.8**	96.0	95.9	**95.3**	95.7	95.8	**95.5**	95.7
a*		3.11	3.49	3.34	**3.36**	2.59	1.62	**3.44**	2.71	**3.41**	3.38	3.51	**3.58**	3.42	3.49	**3.51**	3.46	3.53	**3.49**	3.33
b*		-10.5	-11.4	-11.6	**-12.1**	-11.3	-10.4	**-11.9**	-11.6	**-11.8**	-11.1	-11.6	**-11.7**	-11.7	-11.8	**-11.4**	-11.1	-11.6	**-11.3**	-11.3
Opacity, %		87.1	87.1	85.8	**86.6**	86.9	86.8	**86.7**	86.1	**86.8**	86.6	87.3	**87.8**	87.1	87.3	**86.3**	87.6	86.3	**86.7**	87.2
S. Coeff., m^2/kg		46.6	47.2	46.2	**46.9**	47.4	46.7	**48.1**	47.8	**47.9**	48.1	47.9	**48.1**	47.3	49.0	**47.9**	48.5	46.9	**47.4**	48.1

Table 16: Effect of different OWAs in surface sizing with DS2 at a dose of 3 kg/t at wet-end

DS2 at wet-end, kg/t			**3**																							
OWA in surface sizing, kg/t	**Type**	0	**TS3**				**DS2**				**TS1**				**TS2**				**DS1**				**HS1**			
	Dose, kg/t		0.5	1	2	3	0.5	1	2	3	0.5	**2**	3	4	0.5	**1**	2	3	0.5	1	**2**	3	0.5	**1**	2	3
ISO Brightness, %		93.0	94.2	**94.7**	94.6	94.5	94.4	**94.8**	94.2	93.7	94.3	**94.6**	94.1	93.2	94.2	**94.5**	94.4	93.5	94.5	94.9	**95.2**	94.4	94.0	**94.3**	93.9	93.5
B. brightness, %		83.4	82.6	**82.8**	82.5	82.6	82.9	**83.1**	82.5	82.6	82.9	**82.6**	82.8	82.7	82.7	**82.9**	82.8	82.6	82.7	82.8	**83.1**	82.5	82.4	**82.3**	82.3	82.2
CIE Whiteness		136.4	141.8	**142.1**	139.6	137.3	140.7	**141.8**	140.9	139.7	139.6	**141.8**	141.3	138.7	139.0	**140.1**	139.7	138.9	141.1	142.9	**143.1**	139.9	138.1	**138.9**	138.2	137.5
Fluorescence		21.0	22.5	**23.6**	23.6	23.1	21.4	**21.8**	21.1	20.8	21.9	**22.2**	22.0	21.4	20.9	**21.6**	21.3	20.9	21.9	22.3	**22.5**	21.6	20.9	**21.4**	20.9	20.4
Fluorescence, C		10.6	11.6	**11.9**	12.1	11.9	11.5	**11.7**	11.7	11.1	11.4	**12.0**	11.3	10.5	11.5	**11.6**	11.6	10.9	11.8	12.1	**12.1**	11.9	11.6	**12.0**	11.6	11.3
Yellowness		-20.4	-21.7	**-21.6**	-20.9	-20.1	-21.0	**-21.3**	-20.8	-20.4	-21.2	**-21.3**	-21.2	-20.8	-20.8	**-20.9**	-21.1	-20.8	-21.1	-21.6	**-21.8**	-21.4	-20.3	**-20.5**	-20.3	-20.9
L*		95.6	95.5	**95.7**	95.8	96.1	95.2	**95.8**	95.9	95.3	95.8	**95.6**	95.7	95.3	95.6	**95.4**	95.3	96.0	95.2	95.7	**95.6**	95.9	95.5	**95.2**	95.6	95.1
a*		3.46	3.58	**3.11**	2.53	1.77	3.51	**3.48**	3.17	2.69	3.49	**3.45**	3.09	2.69	3.28	**3.31**	3.21	2.93	3.51	3.52	**3.41**	3.24	3.48	**3.44**	3.24	2.39
b*		-11.0	-11.9	**-11.7**	-11.2	-10.6	-11.8	**-12.1**	-11.7	-11.5	-11.7	**-12.2**	-11.9	-11.2	-11.8	**-11.3**	-11.7	-11.1	-11.4	-12.1	**-11.9**	-11.4	-11.6	**-11.8**	-11.3	-11.2
Opacity, %		86.7	86.5	**85.8**	86.8	86.3	87.2	**86.2**	86.8	86.4	85.9	**86.1**	86.9	86.3	86.9	**86.2**	87.1	86.4	86.1	86.7	**87.3**	86.4	87.1	**86.8**	86.2	86.4
S. Coeff., m^2/kg		47.8	46.4	**46.5**	47.1	46.3	47.9	**46.1**	46.9	47.2	46.4	**47.3**	46.7	47.1	47.5	**47.1**	47.2	46.7	46.9	46.8	**47.3**	47.1	47.2	**46.4**	46.1	46.9

Table 17: Effect of different OWAs in surface sizing with TS3 at a dose of 6 kg/t at wet-end

TS3 at wet-end, kg/t		**6**																				
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**					**DS2**					**TS1**					**TS2**				
	Dose, kg/t			0.4	1	**2**	3	4	0.4	1	**2**	3	4	0.4	1	**2**	3	4	0.4	1	**2**	3	4
ISO Brightness, %		91.8	93.8	94.1	94.4	**94.7**	94.7	94.5	94.1	94.3	**94.6**	94.6	94.3	94.0	94.1	**94.3**	94.2	94.0	94.0	94.1	**94.5**	94.4	94.4
B. brightness, %		81.7	82.8	82.7	82.4	**82.8**	82.4	82.5	82.6	82.7	**82.7**	82.6	82.4	82.8	82.8	**82.7**	82.6	82.6	82.8	82.8	**82.5**	82.6	82.6
CIE Whiteness		133.3	142.1	142.3	142.3	**141.9**	140.9	139.2	142.4	142.4	**142.9**	140.9	139.3	143.1	143.1	**142.3**	140.7	138.3	142.8	142.5	**142.2**	141.1	140.4
Fluorescence		19.7	22.1	22.6	23.2	**23.8**	23.6	23.4	22.4	23.0	**23.6**	23.9	23.7	22.8	23.1	**23.4**	23.4	23.0	22.4	22.6	**23.1**	23.1	23.2
Fluorescence, C		10.1	11.0	11.4	12.0	**11.9**	12.3	12.0	11.5	11.6	**11.9**	12.0	11.9	11.2	11.3	**11.5**	11.7	11.8	11.2	11.3	**12.0**	11.7	11.8
Yellowness		-18.0	-21.2	-21.3	-21.3	**-21.3**	-21.2	-20.9	-21.3	-21.4	**-21.3**	-21.2	-21.1	-21.5	-21.8	**-21.9**	-21.4	-20.5	-21.5	-21.6	**-22.1**	-21.7	-21.6
L*		95.0	95.1	95.3	95.1	**95.3**	95.8	95.7	95.6	95.5	**95.4**	95.7	95.4	95.1	95.1	**95.0**	95.5	95.7	95.6	95.4	**95.5**	95.4	95.7
a*		3.50	4.18	3.83	3.37	**2.80**	2.47	2.38	3.72	3.56	**3.24**	2.86	2.42	3.43	3.44	**3.39**	3.26	3.04	3.44	3.46	**3.22**	3.07	2.63
b*		-10.2	-11.1	-11.9	-11.8	**-11.5**	-11.3	-11.1	-11.7	-11.7	**-11.7**	-11.6	-11.4	-12.1	-12.1	**-12.0**	-11.7	-11.1	-11.8	-11.9	**-11.6**	-11.9	-11.8
Opacity, %		85.7	85.9	86.4	86.0	**86.4**	86.2	85.9	86.7	85.9	**86.2**	85.7	86.0	86.7	85.9	**86.2**	86.4	86.1	86.2	86.0	**86.1**	86.1	86.0
S. Coeff., m^2/kg		45.5	46.0	46.1	46.3	**46.8**	46.1	46.0	46.4	46.0	**46.7**	46.2	46.4	46.3	46.0	**46.1**	47.0	46.7	46.1	46.3	**46.4**	46.3	46.5

Table 18: Effect of different OWAs in surface sizing with TS3 at a dose of 6 kg/t at wet-end

TS3 at wet-end, kg/t		6										
OWA in surface sizing, kg/t	Type	0	Only starch	DS1					HS1				
	Dose,			0.4	1	2	3	4	0.4	1	2	3	4
ISO Brightness, %		91.8	93.8	94.3	94.4	**94.5**	94.4	94.2	**94.1**	94.0	94.0	94.0	94.0
B. brightness, %		81.7	82.8	82.6	82.5	**82.3**	82.3	82.6	**82.7**	82.5	82.4	82.3	82.1
CIE Whiteness		133.3	142.1	143.3	142.7	**141.4**	139.5	137.2	**143.6**	142.6	141.7	140.8	140.0
Fluorescence		19.7	22.1	22.5	22.7	**23.0**	23.1	23.1	**22.4**	22.5	22.6	22.7	22.8
Fluorescence, C		10.1	11.0	11.7	11.9	**12.2**	12.1	11.6	**11.4**	11.5	11.6	11.7	11.9
Yellowness		-18.0	-21.2	-21.6	-21.6	**-21.5**	-21.2	-20.6	**-21.2**	-21.3	-21.4	-21.4	-21.4
L*		95.0	95.1	95.4	95.1	**95.5**	95.7	95.2	**95.2**	95.9	95.1	95.4	95.7
a*		3.50	4.18	3.40	3.37	**3.20**	2.90	2.45	**3.34**	3.28	3.12	2.86	2.50
b*		-10.0	-11.1	-12.0	-11.9	**-11.7**	-11.4	-10.9	**-11.9**	-11.9	-11.9	-11.7	-11.4
Opacity, %		85.7	85.9	85.9	86.2	**86.7**	86.1	86.2	**86.1**	86.0	86.2	86.7	85.9
S. Coeff., m^2/kg		45.5	46.0	46.0	46.2	**46.4**	45.9	46.1	**46.3**	45.8	46.1	46.3	46.0

Table 19: Effect of different OWAs in surface sizing with DS1 at a dose of 5 kg/t at wet-end

DS1 at wet-end, kg/t			5																							
OWA in surface sizing, kg/t	Type	0	TS3				DS2				TS1				TS2				DS1				HS1			
	Dose, kg/t		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ISO Brightness, %		92.5	92.9	93.8	**94.0**	93.3	93.2	**93.8**	93.8	93.0	92.8	**93.5**	93.4	92.8	92.8	**93.5**	93.5	92.9	93.1	**93.9**	93.8	93.0	92.5	93.3	**93.4**	92.7
B. brightness, %		81.4	81.6	81.5	**81.4**	81.6	81.8	**81.5**	81.4	81.6	81.2	**81.1**	81.5	81.4	81.4	**81.3**	81.1	81.6	81.5	**81.6**	81.4	81.4	81.4	81.5	**81.5**	81.7
CIE Whiteness		142.3	144.0	144.4	**143.2**	140.3	143.7	**144.2**	142.5	138.6	143.5	**143.1**	141.7	139.5	142.7	**142.3**	140.0	135.5	142.9	**142.6**	140.6	136.9	142.5	142.5	**140.6**	137.0
Fluorescence		22.9	23.8	24.1	**23.9**	23.2	23.7	**23.8**	23.5	22.6	23.8	**23.8**	23.5	22.9	23.1	**23.2**	22.9	22.3	23.5	**23.5**	22.9	21.8	23.2	23.8	**23.7**	22.8
Fluorescence, C		11.8	11.3	12.3	**12.6**	11.7	11.4	**12.3**	12.4	11.4	11.6	**12.4**	11.9	11.4	11.4	**12.2**	12.4	11.3	11.6	**12.3**	12.4	11.6	11.1	11.8	**11.9**	11.0
Yellowness		-21.6	-21.8	-21.7	**-21.4**	-20.8	-21.7	**-21.1**	-19.4	-16.8	-21.6	**-21.6**	-21.9	-21.1	-20.4	**-21.1**	-21.2	-20.6	-21.7	**-21.9**	-21.6	-20.6	-21.5	-21.5	**-21.1**	-20.3
L*		95.1	95.6	95.1	**95.5**	95.7	95.7	**95.1**	95.8	95.6	95.6	**95.8**	95.8	95.2	95.1	**95.5**	95.1	95.7	95.3	**95.5**	95.1	95.7	95.7	95.6	**95.7**	95.8
a*		3.37	3.47	3.44	**3.32**	3.10	3.38	**3.39**	3.25	2.98	3.62	**3.64**	3.38	2.84	3.63	**3.69**	3.47	2.98	3.81	**3.88**	3.64	3.09	3.64	3.76	**3.54**	2.98
b*		-11.8	-12.0	-11.9	**-11.5**	-10.8	-12.3	**-12.1**	-11.8	-11.0	-11.4	**-12.0**	-11.7	-10.9	-11.8	**-11.9**	-11.0	-10.6	-12.0	**-12.1**	-11.5	-10.4	-11.7	-11.7	**-11.4**	-10.8
Opacity, %		87.9	87.2	86.9	**87.9**	86.5	86.8	**87.8**	86.7	85.8	87.1	**86.7**	87.6	86.2	86.1	**87.1**	86.4	85.8	87.7	**87.3**	86.5	86.8	86.9	87.3	**87.1**	86.1
S. Coeff., m^2/kg		45.9	46.2	47.1	**47.6**	46.3	47.3	**46.8**	47.6	47.1	47.3	**46.8**	47.6	47.1	46.5	**45.9**	46.9	47.1	47.2	**47.6**	45.8	46.9	45.9	46.1	**46.0**	46.2

Best Combinations of different OWAs at wet and size press

Table 20: Best combinations of OWAs with talc (DS2 at wet-end and other OWAs at size press)

DS2 at wet-end, kg/t		**6**	**3**	**4**	**3**	**4**	**4**	**4**
At size press	**OWA**	**--**	**DS2**	**DS1**	**TS1**	**TS3**	**TS2**	**HS1**
	Dose, kg/t	**--**	**2**	**2**	**2**	**2**	**2**	**2**
ISO Brightness, %		94.4	94.8	95.4	**94.6**	95.2	95.6	95.1
B. brightness, %		81.8	83.1	83.1	**82.6**	83.2	83.3	83.2
CIE Whiteness		138.3	141.8	142.5	**141.8**	143.2	141.8	142.5
Fluorescence		22.3	21.8	22.4	**22.2**	23.7	22.6	23.1
Fluorescence, C		11.2	11.7	12.3	**12.0**	12.0	12.3	11.9
Yellowness		-20.32	-21.3	-21.3	**-21.3**	-21.2	-22.1	-20.6
L*		95.3	95.8	95.3	**95.6**	95.8	95.8	95.5
a*		3.12	3.48	3.51	**3.45**	3.36	3.58	3.49
b*		-10.95	-12.1	-11.4	**-12.2**	-12.1	-11.7	-11.3
Opacity, %		87.2	86.2	86.3	**86.1**	86.6	87.8	86.7

Table 21: Best combinations of OWAs with talc (TS3 at wet-end and other OWAs at size press)

TS3 wet-end, kg/t		**11**	**6**	**6**	**6**	**6**	**6**	**6**
At size press	**OWA**	--	**DS2**	**DS1**	**TS1**	**TS3**	**TS2**	**HS1**
	Dose, kg/t	--	2	**0.4**	**1**	**1**	**2**	**1**
ISO Brightness, %		93.7	94.6	**94.3**	94.1	94.7	94.5	94.0
B. brightness, %		81.4	82.7	**82.6**	82.8	82.4	82.5	82.5
CIE Whiteness		141.4	142.9	**143.3**	143.1	142.3	142.2	142.6
Fluorescence		22.9	23.6	**22.5**	23.1	23.2	23.1	22.63
Fluorescence, C		12.3	11.9	**11.7**	11.3	12.0	12.0	11.5
Yellowness		-21.3	-21.3	**-21.6**	-21.8	-21.3	-22.1	-22.5
L*		95.7	95.4	**95.4**	95.1	95.1	95.5	95.5
a*		3.61	3.24	**3.40**	3.44	3.37	3.22	3.35
b*		-11.4	-11.7	**-12.0**	-12.2	-11.8	-11.6	-11.9
Opacity, %		83.7	86.2	**85.9**	85.9	86.0	86.1	86.7

Table 22: ***Best combinations of OWAs with talc (DS1 at wet-end and other OWAs at size press)***

DS1 at wet-end, kg/t		**8**	**5**	**5**	**5**	**5**	**5**	**5**
At size press	**OWA**	**--**	**DS2**	**DS1**	**TS1**	**TS3**	**TS2**	**HS1**
	Dose, kg/t	**--**	**2**	**2**	**2**	**2**	**2**	**2**
ISO Brightness, %		93.7	93.8	**93.9**	93.5	93.8	93.4	93.3
B. brightness, %		81.2	81.5	**81.6**	81.1	81.5	81.4	81.5
CIE Whiteness		142.6	144.2	**142.6**	143.1	144.4	142.5	142.5
Fluorescence		24.2	23.8	**23.5**	23.8	24.1	22.8	23.8
Fluorescence, C		12.5	12.3	**12.3**	12.4	12.3	12.0	11.8
Yellowness		-21.4	-21.1	**-21.9**	-21.6	-21.7	-20.7	-21.5
L*		95.5	95.1	**95.5**	95.8	95.1	95.7	95.6
a*		3.18	3.39	**3.88**	3.64	3.44	3.79	3.76
b*		-10.9	-12.2	**-12.1**	-12.0	-11.9	-11.9	-11.7
Opacity, %		87.6	87.8	**87.3**	86.7	86.9	86.9	87.3

With Talc filler

Table 23: Optimization of different OWAs at wet-end

OWA	DS2							TS3						DS1			
Dose, kg/t	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**8**	**10**	**12**	**14**	**16**	**18**	**6**	**9**	**12**	**14**
ISO Brightness, %	80.5	88.3	89.5	90.6	**91.9**	90.5	90.1	90.0	90.5	90.9	91.4	**91.9**	91.3	90.6	91.5	**91.6**	91.4
B. brightness, %	78.7	79.0	78.6	79.1	**79.0**	78.9	78.6	78.3	78.3	78.5	78.6	**78.6**	78.4	78.2	78.5	**78.5**	78.3
CIE Whiteness	73.3	129.3	131.1	137.5	**139.3**	134.7	132.3	136.9	138.4	140.4	141.4	**142.5**	141.2	137.7	138.1	**136.6**	134.1
Fluorescence	1.82	19.2	21.9	24.3	**25.2**	22.8	22.6	23.3	23.9	24.9	25.3	**26.1**	25.9	24.4	25.4	**25.7**	25.6
Fluorescence, C	2.8	9.3	10.9	11.5	**12.9**	11.6	11.5	11.7	12.2	12.4	12.8	**13.3**	12.9	12.4	13.0	**13.1**	13.1
Yellowness	4.9	-17.4	-19.2	-20.5	**-20.6**	-17.1	-15.9	-20.4	-21.1	-22.0	-22.5	**-22.9**	-22.5	-21.1	-21.3	**-20.8**	-19.8
L*	93.7	93.9	94.1	94.2	**94.3**	94.0	94.2	94.3	94.31	94.4	94.5	**94.6**	94.5	94.4	94.7	**94.9**	94.9
a*	2.03	3.01	3.20	3.23	**3.29**	2.48	1.92	3.73	3.68	3.69	3.61	**3.48**	3.32	3.14	2.66	**2.20**	1.64
b*	0.19	-9.77	-10.2	-10.8	**-11.4**	-10.9	-10.4	-11.3	-11.6	-12.0	-12.2	**-12.4**	-12.1	-11.4	-11.4	**-11.0**	-10.4
Opacity, %	83.8	84.2	84.5	83.9	**84.7**	84.3	84.0	79.6	80.5	80.9	82.0	**80.3**	81.5	82.0	80.3	**81.5**	80.6
S. Coeff.,m^2/kg	35.7	36.1	36.4	35.9	**36.3**	36.1	35.8	32.2	32.4	33.08	34.2	**33.6**	33.9	34.2	33.6	**33.9**	33.9

Split addition of OWAs in wet-end and surface sizing

Table 24: Effect of different OWAs in surface sizing with DS2 at a dose of 4 kg/t at wet-end

DS2 at wet-end, kg/t		4																			
OWA in surface sizing, kg/t	Type	Only starch	TS3				DS2				TS1				TS2				DS1			
	Dose, kg/t		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ISO Brightness, %		89.5	90.1	**90.4**	90.2	89.7	**89.5**	89.4	89.0	88.4	90.0	**90.1**	89.9	89.4	90.4	**90.9**	91.0	90.6	**89.9**	89.8	89.3	88.3
B. brightness, %		78.3	78.7	**78.4**	78.5	78.1	**78.2**	78.0	78.1	78.0	78.2	**78.3**	78.2	78.3	78.4	**78.2**	78.4	78.5	**78.4**	78.5	78.1	78.6
CIE Whiteness		131.1	132.4	**131.5**	130.2	128.6	**131.8**	130.7	129.0	126.7	131.8	**132.5**	130.8	129.4	133.1	**133.5**	132.0	131.5	**131.6**	130.6	128.9	126.4
Fluorescence		21.9	21.6	**21.3**	20.9	20.5	**20.5**	19.5	18.7	18.3	11.8	**11.8**	11.7	11.1	12.0	**12.7**	12.6	12.1	**11.5**	11.3	11.2	9.7
Fluorescence, C		11.2	11.4	**12.0**	11.7	11.6	**11.3**	11.4	10.9	10.4	21.5	**21.2**	20.9	20.5	21.9	**21.9**	21.7	21.2	**20.7**	19.5	18.5	17.8
Yellowness		-19.2	-19.5	**-19.5**	-19.2	-18.5	**-18.1**	-16.8	-16.0	-15.7	-19.5	**-19.5**	-19.2	-18.7	-19.8	**-20.1**	-20.1	-19.7	**-18.5**	-17.1	-16.1	-15.4
L*		94.1	94.1	**94.2**	94.2	94.2	**94.3**	94.3	94.2	94.2	93.8	**94.0**	94.1	94.3	93.8	**94.0**	94.1	94.2	**94.2**	94.2	94.1	94.1
a*		3.20	3.04	**2.79**	2.43	1.97	**2.80**	2.50	2.16	1.77	3.05	**2.66**	2.33	2.05	3.08	**2.98**	2.75	2.38	**3.08**	2.90	2.55	2.04
b*		-10.2	-10.7	**-10.4**	-10.0	-9.57	**-10.4**	-10.0	-9.6	-9.1	-11.2	**-11.2**	-10.7	-10.0	-11.3	**-11.4**	-10.9	-10.5	**-10.2**	-9.9	-9.5	-9.0
Opacity, %		83.5	83.0	**84.1**	83.8	83.7	**83.7**	83.5	83.1	83.7	83.7	**83.9**	83.0	83.4	83.6	**83.1**	83.9	83.1	**83.6**	83.7	83.2	83.5
S. Coeff., m^2/kg		35.2	34.2	**36.1**	35.8	35.1	**35.8**	35.1	35.0	35.8	35.1	**35.8**	35.4	35.2	35.9	**35.3**	35.8	35.2	**35.7**	35.1	35.3	35.0

Table 25: Effect of different OWAs in surface sizing with DS2 at a dose of 6 kg/t at wet-end

DS2 at wet-end, kg/t		6																			
OWA in surface sizing, kg/t	Type	Only starch	TS3				DS2				TS1				TS2				DS1			
	Dose, kg/t		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ISO Brightness, %		91.7	92.2	**92.4**	92.1	91.6	**90.7**	90.6	90.2	89.6	**90.7**	90.6	90.2	89.6	91.7	**92.2**	92.1	91.6	**91.0**	91.0	90.5	89.6
B. brightness, %		78.6	78.7	**78.5**	78.2	78.9	**78.1**	78.3	78.5	78.4	**78.1**	78.3	78.5	78.4	78.3	**78.1**	78.2	78.3	**78.5**	78.6	78.2	78.1
CIE Whiteness		139.4	140.1	**140.6**	138.4	137.2	**138.8**	137.7	136.1	133.8	**138.8**	137.7	136.1	133.8	140.3	**141.0**	138.9	138.3	**138.8**	137.9	136.3	133.9
Fluorescence		13.1	13.5	**13.9**	13.9	12.7	**22.5**	21.4	20.7	20.2	**22.5**	21.4	20.7	20.2	13.4	**14.1**	13.9	13.3	**12.5**	12.4	12.3	11.5
Fluorescence, C		24.2	24.4	**24.4**	24.2	23.7	**12.6**	12.3	11.7	11.2	**12.6**	12.3	11.7	11.2	24.4	**24.3**	24.1	23.6	**22.7**	21.5	20.7	20.1
Yellowness		-21.1	-21.5	**-21.7**	-21.6	-21.3	**-18.7**	-17.5	-16.8	-16.6	**-18.7**	-17.5	-16.8	-16.6	-21.4	**-21.7**	-21.6	-21.2	**-19.1**	-17.9	-17.1	-16.6
L*		93.9	94.0	**94.1**	94.2	94.3	**94.3**	94.3	94.3	94.2	**94.3**	94.3	94.3	94.2	94.0	**94.1**	94.2	94.3	**94.2**	94.2	94.1	94.1
a*		3.26	3.32	**3.20**	2.88	2.37	**2.90**	2.61	2.28	1.91	**2.90**	2.61	2.28	1.91	3.17	**3.10**	2.89	2.55	**3.21**	3.03	2.69	2.18
b*		-12.1	-12.2	**-12.1**	-11.4	-11.3	**-11.3**	-10.9	-10.4	-9.8	**11.8**	-10.8	-10.4	-9.8	-12.7	**-12.2**	-11.2	-11.5	**-11.2**	-10.8	-10.4	-9.1
Opacity, %		83.7	83.2	**83.1**	83.9	83.5	**83.9**	83.1	83.5	83.7	**84.1**	83.8	83.7	83.5	83.6	**83.1**	83.9	83.1	**83.1**	83.5	83.1	83.7
S. Coeff., m^2/kg		35.7	35.0	**34.8**	35.7	35.9	**35.8**	35.2	36.0	35.1	**36.1**	35.8	35.8	35.1	35.9	**35.3**	35.8	35.2	**35.2**	35.1	35.0	35.8

Table 26: Effect of different OWAs in surface sizing with DS2 at a dose of 8 kg/t at wet-end

DS2 at wet-end, kg/t		8																			
OWA in surface sizing, kg/t	Type	Only starch	TS3				DS2				TS1				TS2				DS1			
	Dose, kg/t		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ISO Brightness, %		90.9	**91.6**	91.8	91.7	91.3	**91.6**	91.8	91.7	91.3	**91.4**	91.5	91.2	90.6	92.1	**92.5**	92.4	91.7	**91.4**	91.4	90.9	90.1
B. brightness, %		78.5	**78.3**	78.3	78.7	78.4	**78.3**	78.3	78.7	78.4	**78.6**	78.2	78.3	78.2	78.3	**78.4**	78.2	78.4	**78.4**	78.4	78.5	78.1
CIE Whiteness		139.3	**141.7**	140.9	139.7	138.1	**141.7**	140.9	139.7	138.1	**142.0**	141.2	140.0	138.5	142.8	**143.7**	141.2	140.5	**141.3**	140.5	139.1	136.8
Fluorescence		25.2	**24.9**	24.6	24.2	23.8	**24.9**	24.6	24.2	23.8	**12.8**	13.3	12.9	12.4	13.8	**14.1**	14.2	13.3	**13.0**	13.0	12.4	12.0
Fluorescence, C		12.4	**13.3**	13.5	13.0	12.9	**13.3**	13.5	13.0	12.9	**24.9**	24.5	24.1	23.6	25.2	**25.1**	24.9	24.4	**23.5**	22.5	21.7	21.1
Yellowness		-20.6	**-20.9**	-21.0	-20.7	-20.0	**-20.9**	-21.0	-20.7	-20.0	**-21.0**	-20.9	-20.6	-20.0	-21.6	**-21.8**	-21.7	-21.3	**-19.0**	-18.0	-17.4	-17.1
L*		94.3	**94.3**	94.3	94.3	94.3	**94.3**	94.3	94.3	94.3	**94.2**	94.3	94.4	94.4	94.1	**94.2**	94.2	94.3	**94.2**	94.2	94.1	94.1
a*		3.12	**3.00**	2.78	2.45	2.03	**3.00**	2.78	2.45	2.03	**2.96**	2.66	2.42	2.25	2.98	**2.94**	2.76	2.43	**3.10**	2.92	2.58	2.08
b*		-11.3	**-11.8**	-11.5	-11.1	-10.7	**-11.8**	-11.5	-11.1	-10.7	**-12.2**	-12.0	-11.7	-11.2	-12.2	**-12.3**	-11.8	-11.3	**-11.6**	-11.2	-10.7	-10.1
Opacity, %		83.4	**83.6**	83.2	83.6	83.1	**83.6**	83.2	83.6	83.1	**84.1**	83.8	84.2	83.7	83.9	**83.0**	83.4	84.2	**83.9**	83.1	84.1	83.8
S. Coeff.,m^2/kg		35.5	**35.8**	35.0	35.9	35.3	**35.8**	35.0	35.9	35.3	**36.1**	35.8	36.1	35.8	35.8	**35.4**	35.2	36.1	**35.8**	35.2	36.1	35.8

Table 27: Effect of different OWAs in surface sizing with TS3 at a dose of 8 kg/t at wet-end

TS3 at wet-end, kg/t		8																			
OWA in surface sizing, kg/t	Type	Only starch	TS3				DS2				TS1				TS2				HS1			
	Dose, kg/t		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ISO Brightness, %		90.2	90.9	**91.2**	91.0	90.5	**90.5**	90.5	90.0	89.1	90.6	**90.9**	90.9	90.6	90.9	**91.3**	91.2	90.8	**90.6**	90.5	90.3	90.1
B. brightness, %		77.9	78.6	**78.2**	78.2	77.9	**78.2**	78.4	77.9	78.4	77.9	**78.2**	78.4	78.2	78.3	**78.2**	78.0	77.9	**78.1**	78.4	78.2	78.1
CIE Whiteness		140.7	141.9	**141.5**	139.3	135.4	**141.8**	140.4	135.9	128.4	140.0	**139.2**	137.6	135.4	140.3	**140.9**	140.7	139.6	**141.2**	140.2	139.2	138.3
Fluorescence		23.5	24.3	**24.6**	24.6	24.1	**23.5**	23.2	22.4	21.1	23.9	**24.2**	24.3	24.0	24.5	**24.7**	24.6	24.3	**24.4**	24.3	24.1	23.9
Fluorescence, C		12.3	12.3	**13.0**	12.8	12.6	**12.3**	12.1	12.1	10.7	12.7	**12.7**	12.5	12.4	12.6	**13.1**	13.2	12.9	**12.5**	12.1	12.1	12.0
Yellowness		-22.3	-23.9	**-24.4**	-23.9	-22.3	**-22.4**	-21.7	-20.0	-17.4	-23.1	**-23.5**	-23.2	-22.2	-23.5	**-24.2**	-24.3	-23.6	**-22.8**	-22.4	-21.9	-21.6
L*		94.3	93.7	**94.2**	94.4	94.1	**94.2**	94.1	94.1	94.1	94.5	**94.2**	94.1	94.1	94.1	**93.9**	94.2	94.2	**93.6**	93.6	94.2	94.2
a*		3.73	3.88	**3.71**	3.24	2.45	**3.79**	3.74	3.16	2.05	3.86	**3.69**	3.34	2.80	3.71	**3.68**	3.55	3.30	**3.53**	3.47	3.41	3.34
b*		-12.3	-12.8	**-12.6**	-12.3	-12.1	**-12.4**	-12.0	-10.9	-9.3	-12.2	**-12.1**	-11.8	-11.2	-12.1	**-12.3**	-12.3	-11.9	**-12.3**	-12.1	-11.9	-11.7
Opacity, %		83.7	83.2	**83.5**	83.0	84.1	**83.0**	84.1	83.8	83.7	83.7	**83.9**	83.0	83.4	83.6	**83.1**	83.9	83.1	**83.7**	83.9	83.0	83.4
S. Coeff., m^2/kg		35.1	35.3	**35.0**	34.2	36.1	**34.2**	36.1	35.8	35.1	35.1	**35.8**	35.4	35.2	35.9	**35.3**	35.8	35.2	**35.1**	35.8	35.4	35.2

Table 28: Effect of different OWAs in surface sizing with TS3 at a dose of 10 kg/t at wet-end

TS3 at wet-end, kg/t		**10**																						
OWA in surface sizing, kg/t	**Type**	**Only starch**	**TS3**				**DS2**				**TS1**				**TS2**				**DS1**				**HS1**			
	Dose, kg/t		**1**	**2**	3	4	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	4
ISO Brightness, %		90.9	91.6	**91.9**	91.7	91.3	**91.2**	91.1	90.7	89.8	**91.2**	91.1	90.7	89.8	91.7	**92.0**	91.9	91.4	**91.4**	91.3	90.8	89.8	**91.4**	91.2	91.0	90.7
B. brightness, %		77.9	78.2	**78.2**	78.0	78.2	**78.4**	77.9	78.4	78.3	**78.4**	77.9	78.4	78.3	78.4	**78.3**	78.2	78	**78.2**	78.0	78.3	78.3	**77.9**	78.1	78.1	77.9
CIE Whiteness		143.9	145.2	**144.8**	142.7	138.9	**145.0**	143.8	139.5	132.1	**145.0**	143.8	139.5	132.1	144.1	**144.3**	143.7	142.2	**145.5**	144.4	139.9	132.0	**144.6**	143.3	142.0	140.6
Fluorescence		24.6	25.3	**25.7**	25.6	25.1	**24.5**	24.2	23.4	22.1	**24.5**	24.2	23.4	22.1	25.7	**25.8**	25.7	25.3	**24.7**	24.4	23.6	22.1	**25.6**	25.4	25.2	24.9
Fluorescence, C		13.0	13.4	**13.7**	13.7	13.1	**12.8**	13.2	12.3	11.5	**12.8**	13.2	12.3	11.5	13.3	**13.7**	13.7	13.4	**13.2**	13.3	12.5	11.5	**13.5**	13.1	12.9	12.8
Yellowness		-23.7	-25.3	**-25.9**	-25.4	-23.8	**-23.7**	-23.7	-21.4	-18.8	**-23.7**	-23.7	-21.4	-18.8	-25.2	**-25.8**	-25.7	-24.8	**-23.8**	-23.2	-21.5	-18.8	**-24.2**	-23.7	-23.2	-22.6
L*		94.1	94.4	**94.4**	93.7	94.4	**94.1**	93.7	94.1	93.9	**94.1**	93.7	94.1	93.9	94.3	**94.1**	94.3	94.3	**94.0**	94.2	93.8	93.8	**94.4**	93.5	94.4	94.1
a*		3.90	4.08	**3.95**	3.51	2.75	**4.03**	4.02	3.48	2.41	**4.03**	4.02	3.48	2.41	3.87	**3.81**	3.64	3.35	**4.07**	4.03	3.49	2.47	**3.69**	3.57	3.45	3.32
b*		-12.9	-12.9	**-12.9**	-12.9	-12.9	**-13.0**	-12.4	-11.7	-10.1	**-13.0**	-12.7	-11.7	-10.1	-12.9	**-13.0**	-12.9	-12.5	**-13.0**	-12.7	-11.7	-10.0	**-13.0**	-12.7	-12.0	-12.3
Opacity, %		83.7	83.2	**83.5**	83.0	84.1	**83.0**	84.1	83.8	83.7	**83.7**	83.9	83.0	83.4	83.6	**83.1**	83.9	83.1	**83.6**	83.7	83.2	83.5	**83.7**	83.9	83.0	83.4
S. Coeff., m^2/kg		35.1	35.3	**35.0**	34.2	36.1	**34.2**	36.1	35.8	35.1	**35.1**	35.8	35.4	35.2	35.9	**35.3**	35.8	35.2	**36.5**	35.5	35.2	35.1	**35.1**	35.8	35.4	35.2

Table 29: Effect of different OWAs in surface sizing with DS1 at a dose of 7kg/t at wet-end

DS1 at wet-end, kg/t		**7**																							
OWA in surface sizing, kg/t	**Type**	**0**	**TS3**				**DS2**				**TS1**				**TS2**				**DS1**				**HS1**			
	Dose, kg/t		**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	4
ISO Brightness, %		90.6	91.3	**91.6**	91.4	90.9	**90.9**	90.8	90.4	89.5	91.0	**91.3**	91.3	91.0	91.4	**91.7**	91.6	91.1	**91.1**	91.0	90.5	89.5	**91.1**	90.9	90.7	90.4
B. brightness, %		78.2	78.2	**77.9**	78.2	78.2	**78.0**	78.4	78.4	77.9	78.2	**78.4**	78.2	78.5	78.0	**78.2**	78.4	78.3	**78.3**	78.2	78.2	78.1	**78.1**	78	77.9	78.1
CIE Whiteness		142.5	143.8	**143.4**	141.2	137.4	**143.7**	142.4	138.0	130.6	142.0	**141.2**	139.7	137.5	142.4	**142.8**	142.4	141.1	**144.2**	143.1	138.5	130.5	**143.1**	141.9	140.8	139.6
Fluorescence		24.1	24.9	**25.2**	25.1	24.6	**24.1**	23.7	23.0	21.7	24.6	**24.9**	24.9	24.7	25.2	**25.3**	25.2	24.9	**24.3**	24.0	23.1	21.7	**25.1**	24.9	24.7	24.5
Fluorescence, C		12.4	13.1	**13.7**	13.2	12.7	**12.9**	12.4	12.0	11.6	12.8	**12.9**	13.1	12.5	13.4	**13.5**	13.2	12.8	**12.8**	12.8	12.3	11.4	**13.0**	12.9	12.8	12.3
Yellowness		-23.1	-24.8	**-25.3**	-24.8	-23.2	**-23.2**	-22.5	-20.9	-18.2	-24.1	**-24.5**	-24.2	-23.2	-24.4	**-25.1**	-25.1	-24.4	**-23.3**	-22.6	-21.0	-18.2	**-23.6**	-23.1	-22.7	-22.2
L*		94.4	94.8	**94.1**	94.4	94.4	**93.9**	94.1	94.1	93.7	94.1	**93.9**	94.2	93.8	94.2	**94.3**	93.6	94.3	**94.2**	94.1	94.0	94.2	**93.6**	94.2	94.2	93.6
a*		3.84	4.00	**3.85**	3.39	2.62	**3.94**	3.91	3.35	2.26	3.94	**3.79**	3.47	2.96	3.80	**3.76**	3.61	3.34	**3.97**	3.90	3.34	2.29	**3.62**	3.53	3.44	3.34
b*		-12.7	-12.7	**-12.6**	-12.6	-12.6	**-12.7**	-12.4	-11.4	-9.79	-12.6	**-12.5**	-12.2	-11.7	-12.5	**-12.6**	-12.6	-12.3	**-12.8**	-12.4	-11.4	-9.70	**-12.7**	-12.4	-12.2	-12.0
Opacity, %		83.7	83.2	**83.5**	83.0	84.1	**83.0**	84.1	83.8	83.7	83.7	**83.9**	83.0	83.4	83.6	**83.1**	83.9	83.1	**83.6**	83.7	83.2	83.5	**83.7**	83.9	83.0	83.4
S. Coeff., m^2/kg		35.1	35.3	**35.0**	34.2	36.1	**34.2**	36.1	35.8	35.1	35.1	**35.8**	35.4	35.2	35.9	**35.3**	35.8	35.2	**35.7**	35.1	35.3	35.0	**35.1**	35.8	35.4	35.2

Table 30: Effect of different OWAs in surface sizing with DS1 at a dose of 9 kg/t at wet-end

DS1 at wet-end, kg/t		**9**																							
OWA in surface sizing, kg/t	**Type**	**0**	**TS3**				**DS2**				**TS1**				**TS2**				**DS1**				**HS1**			
	Dose, kg/t		**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	4
ISO Brightness, %		91.1	91.8	**92.1**	92.0	91.5	**91.4**	91.3	90.8	89.9	**91.6**	91.9	91.9	91.6	92.0	**92.2**	92.0	91.5	**91.6**	91.5	91.0	90.0	**91.7**	91.5	91.2	90.8
B. brightness, %		78	78.2	**78.6**	77.9	78.6	**77.9**	78.1	78.2	78.4	**78.5**	78.2	78.2	78.0	77.9	**77.9**	78	78.2	**78.3**	78.2	78.2	78.1	**78.4**	78.2	78.1	78.4
CIE Whiteness		144.7	146.1	**145.7**	143.7	139.9	**145.5**	144.4	140.2	132.9	**144.5**	143.8	142.4	140.4	145.3	**145.4**	144.6	142.9	**146.1**	145.1	140.7	132.9	**145.8**	144.3	142.8	141.3
Fluorescence		24.9	25.7	**26.0**	25.9	25.4	**24.8**	24.4	23.6	22.3	**25.6**	25.8	25.8	25.6	26.1	**26.1**	26.0	25.6	**25.0**	24.7	23.8	22.4	**26.0**	25.8	25.5	25.2
Fluorescence, C		13.1	13.6	**13.5**	14.1	12.9	**13.5**	13.2	12.6	11.5	**13.1**	13.7	13.7	13.6	14.1	**14.3**	14.0	13.3	**13.3**	13.3	12.8	11.9	**13.3**	13.3	13.1	12.4
Yellowness		-24.1	-25.8	**-26.3**	-25.8	-24.2	**-24.0**	-23.4	-21.8	-19.8	**-25.3**	-25.7	-25.4	-24.4	-25.7	**-26.3**	-26.1	-25.2	**-24.1**	-23.5	-21.9	-19.2	**-24.7**	-24.1	-23.5	-22.2
L*		93.7	94.4	**94.3**	94.3	93.7	**94.1**	93.8	94.2	94.1	**94.1**	94.1	94.5	94.2	94.3	**94.3**	93.8	94.3	**120.0**	121.0	122.0	123.0	**94.4**	93.5	94.4	94.1
a*		3.91	4.11	**3.99**	3.57	2.83	**4.07**	4.08	3.56	2.51	**3.97**	3.88	3.61	3.16	3.91	**3.83**	3.64	3.33	**4.12**	4.10	3.59	2.60	**3.75**	3.60	3.44	3.28
b*		-13.2	-13.1	**-13.1**	-13.1	-13.1	**-13.9**	-12.8	-11.2	-10.1	**-13.2**	-13.4	-12.8	-12.4	-13.2	**-13.2**	-13.0	-12.9	**-13.2**	-12.9	-11.9	-10.2	**-13.3**	-13.0	-12.7	-12.6
Opacity, %		83.7	83.2	**83.5**	83.0	84.1	**83.2**	83.5	83.0	84.1	**83.7**	83.9	83.0	83.4	83.6	**83.1**	83.9	83.1	**83.6**	83.7	83.2	83.5	**83.7**	83.9	83.0	83.4
S. Coeff.,m^2/kg		35.1	35.3	**35.0**	34.2	36.1	**35.3**	35.0	34.2	36.1	**35.1**	35.8	35.4	35.2	35.9	**35.3**	35.8	35.2	**35.7**	35.1	35.3	35.0	**35.1**	35.8	35.4	35.2

Best Combinations of different OWAs at wet and size press

Table 31: Best combinations of OWAs with talc (DS2 at wet-end and other OWAs at size press)

DS2 at wet-end, kg/t		**8**	**6**	**8**	**6**	**8**	**8**
At size press	**OWA**	**--**	**TS3**	**DS2**	**TS2**	**DS1**	**TS1**
	Dose, kg/t	**--**	**2**	**1**	**2**	**1**	**1**
ISO Brightness, %		91.9	92.4	91.1	92.2	91.4	91.4
B. brightness, %		79.0	78.5	78.2	78.1	78.4	78.6
CIE Whiteness		139.3	140.6	141.3	141.0	141.3	142.0
Fluorescence, C		25.2	13.9	23.4	14.1	13.0	12.8
Fluorescence		12.9	24.4	12.9	24.3	23.5	24.9
Yellowness		-20.6	-21.7	-18.8	-21.7	-19.0	-21.0
L*		94.3	94.1	94.4	94.1	94.2	94.2
a*		3.29	3.20	2.79	3.10	3.10	2.96
b*		-11.4	-12.0	-11.5	-12.0	-11.8	-12.1

Table 32: Best combinations of OWAs with talc (TS3 at wet-end and other OWAs at size press)

TS3 wet-end, kg/t		**16**	**10**					
At size press	**OWA**	**Nil**	**TS3**	**DS2**	**TS1**	**TS2**	**DS1**	**HS1**
	Dose, kg/t		**2**	**1**	**1**	**2**	**1**	**1**
ISO Brightness, %		91.9	91.9	91.2	**91.2**	**92.0**	91.4	91.4
B. brightness, %		78.6	78.2	78.4	**78.4**	**78.3**	78.2	77.9
CIE Whiteness		142.5	144.8	145.0	**145.0**	**144.3**	145.5	144.6
Fluorescence		26.1	25.7	24.5	**24.5**	**25.8**	24.7	25.6
Fluorescence, C		13.3	13.7	12.8	**12.8**	**13.7**	13.2	13.5
Yellowness		-22.9	-25.9	-23.7	**-23.7**	**-25.8**	-23.8	-24.2
L*		94.6	94.4	94.1	**94.1**	**94.1**	94.0	94.4
a*		3.48	3.95	4.03	**4.03**	**3.81**	4.07	3.69
b*		-12.4	-12.9	-13.1	**-13.1**	**-13.0**	-13.1	-13.1

Table 33: Best combinations of OWAs with talc (DS1 at wet-end and other OWAs at size press)

DS1 at wet-end, kg/t		12	9					
At size press	OWA	--	TS3	DS2	TS1	TS2	DS1	HS1
	Dose, kg/t	--	2	1	1	2	1	1
ISO Brightness, %		91.6	92.1	91.4	91.6	92.2	91.6	**91.7**
B. brightness, %		78.5	78.6	77.9	78.5	77.9	78.3	**78.4**
CIE Whiteness		136.6	145.7	145.5	144.5	145.4	146.1	**145.8**
Fluorescence		25.7	26.0	24.8	25.6	26.1	25.0	**26.0**
Fluorescence, C		13.1	13.5	13.5	13.1	14.3	13.3	**13.3**
Yellowness		-20.7	-26.3	-24.0	-25.3	-26.3	-24.1	**-24.7**
L*		94.9	94.3	94.1	94.1	94.3	120.0	**94.4**
a*		2.20	3.99	4.07	3.97	3.83	4.12	**3.75**
b*		-11.0	-13.2	-13.2	-13.2	-13.2	-13.2	**-13.3**

With PCC filler

Split addition of OWAs in wet-end and surface sizing

Table 34: Effect of different OWAs in surface sizing with DS2 at a dose of 2 kg/t at wet-end

DS2 at wet-end, kg/t		2																		
OWA in surface sizing, kg/t	Type	0	TS3					TS1					TS2					DS1			
	Dose, kg/t		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4
ISO Brightness, %		91.1	91.2	91.7	92.1	**92.4**	92.6	91.3	91.8	92.0	**92.1**	91.8	91.5	92.0	**92.3**	92.3	92.2	91.1	**91.3**	91.3	91.0
B. brightness, %		84.1	83.8	83.9	83.8	**84.3**	84.3	83.4	84.2	84.0	**83.6**	84.1	83.4	83.9	**84.1**	84.3	83.8	83.6	**83.0**	84.0	84.2
CIE Whiteness		130.2	134.3	136.0	136.9	**136.8**	135.9	134.1	136.3	137.4	**137.4**	136.4	136.8	137.8	**138.4**	138.6	138.3	132.7	**132.7**	132.2	131.3
Fluorescence		18.9	20.2	21.4	22.2	**22.8**	23.0	20.0	21.0	21.7	**22.0**	22.0	20.7	21.0	**21.3**	21.4	21.4	19.4	**19.6**	19.7	19.7
Fluorescence, C		7.0	7.4	7.8	8.3	**8.1**	8.3	7.9	7.6	8.0	**8.5**	7.7	8.1	8.1	**8.2**	8.0	8.4	7.5	**8.3**	7.3	6.8
Yellowness		-16.5	-17.6	-18.4	-18.8	**-18.9**	-18.5	-17.6	-18.9	-19.8	**-20.0**	-19.7	-18.3	-18.8	**-18.9**	-18.7	-18.1	-16.7	**-16.8**	-16.8	-16.6
L*		95.8	96.0	96.7	96.4	**96.2**	96.8	96.5	96.6	96.4	**96.2**	96.5	96.1	96.2	**96.4**	96.5	95.2	96.4	**96.4**	96.5	96.2
a*		3.38	3.22	2.98	2.69	**2.35**	1.97	3.28	3.21	3.08	**2.89**	2.63	3.48	3.34	**3.28**	3.28	3.36	3.24	**2.89**	2.39	1.75
b*		-8.96	-9.70	-9.90	-9.90	**-9.70**	-9.30	-9.60	-10.1	-10.4	**-10.5**	-10.4	-10.3	-10.5	**-10.5**	-10.3	-9.90	-9.50	**-9.60**	-9.70	-9.80
Opacity, %		90.1	91.2	91.5	91.7	**90.5**	91.9	91.0	92.1	91.5	**91.2**	91.5	90.8	91.3	**92.0**	90.7	91.4	90.8	**91.3**	92.0	91.8
S. Coeff., m^2/kg		62.1	65.1	66	65.8	**65.2**	66.1	65.0	66.1	64.2	**65.1**	66.0	64.9	65.2	**66.0**	64.8	65.8	64.9	**65.2**	66.0	65.3

Table 35: Effect of different OWAs in surface sizing with DS2 at a dose of 3 kg/t at wet-end

DS2 at wet-end, kg/t		3																		
OWA in surface sizing, kg/t	**Type**	**Only starch**	**TS3**					**TS1**				**TS2**					**DS1**			
	Dose, kg/t		**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**0.5**	**1**	**2**	**3**	**4**
ISO Brightness, %		93.2	93.8	94.2	**94.6**	94.8	93.8	94.3	**94.6**	94.6	94.3	93.7	94.1	**94.4**	94.4	94.2	93.4	**93.8**	93.7	93.4	92.9
B. brightness, %		84.1	83.5	83.8	**83.9**	83.8	83.6	83.4	**84.2**	84.0	83.6	83.7	83.4	**83.9**	84.1	84.3	83.5	**83.6**	83.0	84.0	84.2
CIE Whiteness		134.7	137.0	138.5	**139.0**	138.7	137.5	139.4	**140.3**	140.0	138.7	138.4	139.5	**140.1**	140.2	140.0	134.9	**135.3**	135.0	134.1	132.7
Fluorescence		20.1	21.4	22.4	**23.1**	23.5	21.4	22.3	**22.8**	22.9	22.7	21.6	22.0	**22.3**	22.4	22.4	20.4	**20.7**	20.9	21.0	21.0
Fluorescence, C		9.1	10.3	10.4	**10.7**	11.0	10.2	10.9	**10.4**	10.6	10.7	10.0	10.7	**10.5**	10.3	9.9	9.9	**10.2**	10.7	9.4	8.7
Yellowness		-17.6	-18.7	-19.4	**-19.7**	-19.6	-19.0	-20.4	**-21.2**	-21.4	-21.1	-19.4	-19.9	**-20.1**	-19.9	-19.4	-17.7	**-18.0**	-18.0	-17.8	-17..5
L*		96.3	96.0	96.0	**96.7**	96.4	96.3	96.5	**96.6**	96.4	96.2	96.2	96.1	**96.2**	96.4	96.5	96.5	**96.2**	96.3	96.0	96.3
a*		3.38	3.20	2.97	**2.70**	2.38	3.42	3.36	**3.24**	3.06	2.82	3.65	3.54	**3.49**	3.52	3.61	3.38	**3.07**	2.68	2.16	1.49
b*		-9.70	-10.0	-10.1	**-10.0**	-9.70	-10.1	-10.5	**-10.7**	-10.7	-10.5	-10.9	-11.1	**-11.1**	-10.9	-10.5	-9.85	**-10.0**	-10.1	-10.2	-10.3
Opacity, %		91.8	90.8	91.2	**91.5**	91.7	90.7	91.8	**91.0**	92.1	91.5	90.5	91.9	**92.2**	90.8	91.3	91.4	**90.8**	91.3	92.0	91.8
S. Coeff., m^2/kg		93.2	64.6	65.1	**66.0**	65.8	64.8	65.9	**65.0**	66.1	64.2	65.2	65.6	**65.2**	65.3	66.1	65.8	**64.9**	65.2	66.0	65.3

Table 36: Effect of different OWAs in surface sizing with DS2 at a dose of 4 kg/t at wet-end

DS2 at wet-end, kg/t		Only starch	`4																
OWA in surface sizing, kg/t	Type		TS1					TS2					DS1				TS3			
	Dose, kg/t		1	2	3	4	5	1	2	3	4	5	1	2	3	4	2	3	4	5
ISO Brightness, %		94.5	95.2	95.7	**95.9**	95.9	95.7	95.0	95.4	**95.6**	95.6	95.4	95.0	**95.1**	95.1	94.8	95.6	**95.9**	96.1	96.2
B. brightness, %		83.4	84.0	84.1	**84.1**	83.6	83.4	84.2	84.1	**83.5**	83.7	83.4	84.0	**83.8**	83.9	84.0	84.0	**83.9**	83.5	83.8
CIE Whiteness		136.8	139.5	141.1	**141.7**	141.1	139.5	139.4	140.4	**141.0**	141.2	140.9	137.1	**137.3**	137.1	136.3	140.2	**140.5**	139.9	138.4
Fluorescence		21.4	22.5	23.2	**23.5**	23.5	23.1	22.3	22.7	**22.9**	23.1	23.1	21.4	**21.7**	21.9	22.1	23.3	**23.8**	24.0	24.0
Fluorescence, C		11.1	11.2	11.6	**11.9**	12.3	12.3	10.8	11.3	**12.1**	11.9	12.0	11.0	**11.3**	11.2	10.8	11.6	**12.0**	12.6	12.4
Yellowness		-18.2	-20.1	-21.4	**-22.2**	-22.5	-22.1	-19.9	-20.4	**-20.7**	-20.6	-20.2	-18.8	**-18.9**	-18.9	-18.8	-20.1	**-20.3**	-20.0	-19.4
L*		96.2	96.4	96.1	**96.3**	96.3	96.5	96.5	96.4	**96.0**	96.2	96.1	96.4	**96.4**	96.5	96.2	96.2	**96.3**	96.0	96.0
a*		3.40	3.41	3.37	**3.26**	3.08	2.85	3.54	3.45	**3.42**	3.47	3.59	3.29	**3.16**	2.88	2.47	2.95	**2.69**	2.39	2.04
b*		-9.70	-10.2	-10.5	**-10.6**	-10.5	-10.2	-11.3	-11.5	**-11.5**	-11.3	-10.9	-10.1	**-10.2**	-10.3	-10.1	-10.10	**-9.90**	-9.50	-8.90
Opacity, %		91.9	92.2	91.3	**92.0**	91.8	90.7	91.2	91.4	**90.5**	91.9	91.7	91.4	**90.5**	91.9	91.4	91.4	**91.8**	90.8	91.2
S. Coeff., m^2/kg		66.1	66.5	65.2	**66.0**	65.3	64.8	65.1	65.8	**65.2**	66.1	65.8	65.8	**65.2**	66.1	66.3	65.8	**65.8**	64.6	65.1

Table 37: Effect of different OWAs in surface sizing with DS2 at a dose of 5 kg/t at wet-end

DS2 at wet-end, kg/t		5																		
OWA in surface sizing, kg/t	Type	Only starch	TS3					TS1					TS2					DS1			
	Dose, kg/t		1	2	5	5	7	1	2	3	4	5	1	2	3	4	5	1	2	3	4
ISO Brightness, %		95.1	95.5	95.8	**96.1**	96.2	96.0	95.4	95.9	**96.2**	96.2	95.9	95.3	95.6	**95.8**	95.8	95.5	95.3	**95.5**	95.4	95.1
B. brightness, %		84.3	84.2	83.5	**83.5**	84.0	83.4	84.1	83.6	**84.1**	83.7	83.4	83.8	84.2	**84.3**	84.0	83.9	83.8	**83.6**	83.8	83.5
CIE Whiteness		138.6	140.3	141.2	**141.2**	138.5	132.3	140.1	141.4	**141.7**	140.9	139.0	139.5	140.6	**141.2**	141.4	141.2	138.4	**138.8**	138.6	138.0
Fluorescence		22.1	23.2	23.9	**24.3**	24.1	22.8	23.2	23.7	**23.9**	23.7	23.1	22.5	23.0	**23.2**	23.4	23.5	22.2	**22.5**	22.8	23.0
Fluorescence, C		10.8	11.3	12.3	**12.6**	12.2	12.6	11.3	12.3	**12.1**	12.5	12.5	11.5	11.4	**11.5**	11.8	11.6	11.5	**11.9**	11.6	11.6
Yellowness		-19.3	-20.2	-20.6	**-20.6**	-19.4	-16.7	-20.8	-22.2	**-23.0**	-23.2	-22.9	-19.8	-20.4	**-20.8**	-20.7	-20.4	-19.4	**-19.6**	-19.6	-19.4
L*		96.2	96.8	95.8	**95.8**	96.2	96.2	96.5	95.9	**96.1**	96.5	96.2	95.2	96.5	**96.2**	96.4	96.2	96.3	**96.3**	96.4	96.4
a*		3.24	3.09	2.90	**2.66**	2.05	1.25	3.26	3.22	**3.12**	2.96	2.73	3.14	3.07	**3.07**	3.14	3.27	3.18	**3.16**	2.99	2.68
b*		-9.90	-10.0	-9.90	**-9.60**	-8.40	-6.40	-9.90	-10.1	**-10.1**	-9.90	-9.50	-11.5	-11.7	**-11.7**	-11.5	-11.1	-10.1	**-10.2**	-10.3	-10.4
Opacity, %		90.5	91.9	91.7	**92.2**	91.4	90.8	91.5	91.2	**91.5**	91.7	90.5	90.8	91.3	**92.0**	90.7	91.4	90.7	**91.4**	90.8	90.7
S. Coeff., m^2/kg		65.2	66.1	66.0	**66.5**	65.8	65.8	64.2	65.1	**66.0**	65.8	65.2	64.9	65.2	**66.0**	64.8	65.8	64.8	**65.8**	65.8	65.9

Table 38: Effect of different OWAs in surface sizing with DS2 at a dose of 6 kg/t at wet-end

DS2 at wet-end, kg/t		6																		
OWA in surface sizing, kg/t	Type	Only starch	TS3					TS1					TS2					DS1			
	Dose, kg/t		1	3	5	7	9	1	2	3	4	5	1	2	3	4	5	1	2	3	4
ISO Brightness, %		94.3	94.7	**95.1**	95.2	94.8	94.0	94.5	95.0	**95.2**	95.2	95.0	94.6	95.0	**95.1**	95.0	94.8	94.6	**94.8**	94.7	94.4
B. brightness, %		84.0	83.9	**83.5**	83.8	83.9	83.8	83.6	84.1	**83.7**	83.4	84.0	83.4	83.9	**84.1**	84.3	83.8	83.6	**83.0**	84.0	84.2
CIE Whiteness		139.4	140.9	**141.2**	138.0	131.2	120.8	139.3	140.3	**140.3**	139.2	137.0	139.0	140.0	**140.7**	140.9	140.6	139.2	**139.6**	139.6	139.0
Fluorescence		22.9	23.7	**24.5**	24.1	22.4	19.5	23.5	23.9	**23.9**	23.5	22.8	22.5	22.9	**23.2**	23.4	23.4	22.7	**23.1**	23.4	23.7
Fluorescence, C		10.3	10.8	**11.6**	11.4	10.9	10.2	10.9	10.9	**11.5**	11.8	11.0	11.2	11.1	**11.0**	10.7	11.0	11.0	**11.8**	10.7	10.2
Yellowness		-19.9	-20.6	**-20.8**	-19.6	-16.5	-11.8	-21.2	-22.6	**-23.3**	-23.6	-23.3	-19.2	-19.9	**-20.3**	-20.3	-20.0	-19.8	**-19.9**	-20.0	-19.8
L*		96.2	96.3	**96.0**	96.0	96.7	96.4	95.9	96.1	**96.5**	96.2	96.4	96.1	96.2	**96.4**	96.5	95.2	96.2	**96.3**	96.3	96.4
a*		3.14	3.01	**2.61**	2.02	1.26	0.32	2.95	2.92	**2.84**	2.68	2.47	2.46	2.41	**2.43**	2.52	2.68	2.98	**3.06**	3.01	2.81
b*		-9.70	-9.70	**-9.10**	-7.70	-5.50	-2.50	-9.20	-9.30	**-9.20**	-8.90	-8.40	-11.5	-11.7	**-11.7**	-11.5	-11.1	-9.90	**-10.0**	-10.1	-10.2
Opacity, %		91.4	91.8	**90.8**	91.2	91.5	91.7	91.8	90.7	**92.2**	91.3	92.0	90.5	91.9	**91.7**	90.5	91.9	90.8	**91.3**	92.0	91.8
S. Coeff., m^2/kg		65.8	65.8	**64.6**	65.1	66.0	65.8	65.3	64.8	**66.5**	65.2	66.0	65.2	66.1	**65.8**	65.2	66.1	64.9	**65.2**	66.0	65.3

Table 39: Effect of different OWAs in surface sizing with TS3 at a dose of 6 kg/t at wet-end

TS3 at wet-end, kg/t		**6**																		
OWA in surface sizing, kg/t	**Type**	**Only starch**	**TS3**					**TS1**				**TS2**					**DS1**			
	Dose, kg/t		**1**	**2**	**3**	**4**	**5**	**1**	**3**	**4**	**5**	**1**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**
ISO Brightness, %		94.0	94.8	95.4	**95.6**	95.6	95.3	94.6	94.9	**95.2**	95.2	94.2	94.9	**95.1**	95.1	95.0	**94.6**	94.8	94.7	94.3
B. brightness, %		84.0	83.8	83.9	**83.8**	83.8	83.6	83.7	83.8	**83.8**	83.7	83.9	83.9	**83.5**	83.8	83.7	**84.1**	83.9	83.9	83.8
CIE Whiteness		135.7	138.4	140.0	**140.5**	139.7	137.8	138.4	140.0	**140.1**	138.5	137.3	140.4	**140.9**	140.7	139.9	**137.4**	137.3	136.3	134.3
Fluorescence		20.1	21.6	22.7	**23.3**	23.6	23.4	21.5	22.4	**23.0**	22.8	21.3	22.3	**22.7**	23.0	23.2	**21.3**	21.7	21.7	21.5
Fluorescence, C		10.0	11.0	11.5	**11.8**	11.9	11.7	10.9	11.1	**11.4**	11.5	10.4	11.0	**11.6**	11.3	11.2	**10.5**	10.9	10.7	10.5
Yellowness		-18.2	-19.3	-20.1	**-20.3**	-20.1	-19.5	-19.1	-19.8	**-20.1**	-19.6	-18.6	-19.9	**-20.3**	-20.4	-20.3	**-19.2**	-19.2	-18.9	-18.2
L*		96.1	96.2	96.0	**95.7**	96.5	97.1	95.8	95.1	**96.3**	96.1	96.9	95.9	**96.3**	96.0	96.2	**96.1**	96.1	96.1	96.2
a*		3.31	3.18	2.99	**2.73**	2.42	2.05	3.50	3.47	**3.07**	2.72	3.52	3.54	**3.52**	3.47	3.40	**3.35**	3.22	2.99	2.66
b*		-12.0	-12.4	-12.6	**-12.6**	-12.4	-12.0	-10.2	-10.6	**-10.8**	-10.6	-11.3	-11.5	**-11.3**	-10.9	-10.0	**-10.60**	-10.4	-10.0	-9.40
Opacity, %		91.4	91.8	90.8	**91.2**	91.5	91.7	91.8	90.7	**92.2**	91.3	90.5	91.9	**91.7**	90.5	91.9	**90.8**	91.3	92.0	91.8
S. Coeff., m^2/kg		65.8	65.8	64.6	**65.1**	66.0	65.8	65.3	64.8	**66.5**	65.2	65.2	66.1	**65.8**	65.2	66.1	**64.9**	65.2	66.0	65.3

Split addition of OWAs in wet-end surface sizing

Table 40: Effect of different OWAs in surface sizing

DS1 at wet-end, kg/t		6																			
OWA in surface sizing, kg/t	**Type**	**Only starch**	**TS3**				**DS2**				**TS1**				**DS1**				**HS1**			
	Dose, kg/t		**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**1**	**2**	**3**	**4**
ISO Brightness, %		95.0	95.2	95.8	**96.4**	96.1	95.4	**95.9**	95.7	95.1	95.4	95.2	95.7	**96.0**	95.2	**95.5**	95.4	95.1	95.7	96.0	**96.1**	95.8
B. brightness, %		84.1	84.0	84.3	**84.2**	84.0	84.3	**83.9**	84.1	84.2	84.3	83.8	84.0	**83.9**	84.2	**84.4**	84.1	84.0	83.8	84.0	**84.1**	83.9
CIE Whiteness		140.3	141.0	141.9	**142.4**	141.7	141.3	**142.4**	139.8	138.5	141.3	141.1	141.5	**142.7**	139.8	**141.4**	139.5	138.5	141.9	142.7	**142.0**	138.2
Fluorescence		22.1	22.4	22.6	**22.8**	22.5	22.4	**22.6**	22.3	22.0	22.4	22.2	22.5	**22.9**	22.1	**22.6**	22.4	22.0	22.4	22.8	**22.6**	22.2
Fluorescence, C		10.9	11.2	11.5	**12.2**	12.1	11.1	**12.0**	11.6	10.9	11.1	11.4	11.7	**12.1**	11.0	**11.1**	11.3	11.1	11.9	12	**12**	11.9
Yellowness		-18.7	-18.9	-19.0	**-19.3**	-19.1	-18.9	**-19.3**	-19.2	-19.1	-18.9	-18.9	-19.1	**-19.3**	-18.7	**-18.8**	-18.7	-18.1	-19.2	-19.3	**-19.2**	-18.9
L*		96.4	96.2	96.2	**96.4**	96.3	96.3	**96.1**	96.5	96.1	96.3	96.3	96.1	**96.1**	96.3	**96.0**	96.4	96.3	96.1	96.5	**96.2**	96.1
a*		3.24	3.29	3.39	**3.48**	3.11	3.33	**3.41**	3.27	2.99	3.33	3.30	3.46	**3.51**	3.20	**3.35**	3.20	2.87	3.32	3.46	**3.39**	3.33
b*		-11.1	-11.3	-11.4	**-11.9**	-11.3	-11.1	**-11.7**	-11.0	-10.5	-11.1	-11.2	-11.4	**-12.3**	-10.9	**-11.3**	-11.0	-10.2	-11.4	-12.7	**-12.1**	-10.6
Opacity, %		92.2	91.3	92.0	**91.8**	91.5	91.3	**91.1**	91.3	92.0	91.3	91.4	90.9	**91.1**	91.4	**92.2**	91.8	91.7	91.2	91.4	**91.0**	91.0
S. Coeff., m^2/kg		66.5	65.2	66.0	**65.3**	65.0	65.2	**64.9**	65.2	66.0	65.2	66.3	64.9	**65.0**	66.4	**66.5**	65.4	65.9	65.1	65.8	**65.2**	65.0

Best Combinations of different OWAs at wet and size press

Table 41: Best combinations of OWAs with PCC (DS2 at wet-end and other OWAs at size press)

DS2 at wet-end, kg/t		**4**	**5**	**4**	**5**	**4**	**5**
OWA in surface sizing, kg/t	**Type**	**TS3**	**TS3**	**TS1**	**DS1**	**TS2**	**TS2**
	Dose, kg/t	**3**	**5**	**3**	**3**	**3**	**3**
ISO Brightness, %		95.9	96.2	**95.9**	95.4	**95.6**	95.8
B. brightness, %		83.9	84.0	**84.1**	83.8	**83.5**	84.3
CIE Whiteness		140.5	138.5	**141.7**	138.6	**141.0**	141.2
Fluorescence		23.8	24.1	**23.5**	22.8	**22.9**	23.2
Fluorescence, C		12.0	12.2	**11.9**	11.6	**12.1**	11.5
Yellowness		-20.3	-19.5	**-22.2**	-19.6	**-20.7**	-20.8
L*		96.3	96.2	**96.3**	96.4	**96.0**	96.2
a*		2.69	2.05	**3.26**	2.99	**3.42**	3.07
b*		-9.90	-8.40	**-10.6**	-10.3	**-11.5**	-11.7
Opacity, %		91.8	91.4	**92.0**	90.8	**90.5**	92.0

Table 42: Best combinations of OWAs with PCC (TS3 at wet-end and other OWAs at size press)

TS3 at wet-end, kg/t		**5**	**6**		
OWA in surface sizing, kg/t	**Type**	**TS3**	**TS1**	**DS1**	**TS2**
	Dose, kg/t	**3**	**4**	**2**	**4**
ISO Brightness, %		95.2	95.2	94.8	**95.1**
B. brightness, %		83.6	83.8	83.9	**83.5**
CIE Whiteness		138.9	140.1	137.3	**140.9**
Fluorescence		22.8	23.0	21.7	**22.7**
Fluorescence, C		11.6	11.4	10.9	**11.6**
Yellowness		-19.6	-20.1	-19.2	**-20.3**
L*		95.8	96.3	96.1	**96.3**
a*		2.82	3.07	3.22	**3.52**
b*		-11.3	-10.8	-10.4	**-11.9**
Opacity, %		92.2	92.2	91.3	**91.7**

Table 43: ***Best combinations of OWAs with PCC (DS1 at wet-end and other OWAs at size press)***

DS1 in wet-end, kg/t		**8**	**6**					
OWA in surface sizing, kg/t	**Type**	**0**	**DS2**	**TS3**	**DS1**	**TS2**	**TS1**	**HS1**
	Dose, kg/t		2	3	1	**2**	**3**	**3**
ISO Brightness, %		96.3	95.9	96.4	95.5	**96.4**	**96.0**	**96.1**
B. brightness, %		84.2	83.9	84.2	84.4	**84.1**	**83.9**	**84.1**
CIE Whiteness		140.7	142.4	142.4	141.4	**142.8**	**142.7**	**142.0**
Fluorescence		23.6	22.6	22.8	22.6	**22.9**	**22.9**	**22.6**
Fluorescence, C		12.1	12.0	12.2	11.1	**11.5**	**12.1**	**12.0**
Yellowness		-20.3	-19.4	-19.3	-18.9	**-19.2**	**-19.3**	**-19.3**
L*		96.3	96.1	96.4	96.0	**96.0**	**96.1**	**96.2**
a*		3.37	3.41	3.48	3.35	**3.42**	**3.51**	**3.39**
b*		-11.1	-11.7	-11.9	-11.3	**-12.0**	**-12.4**	**-12.1**

Addition of broke (5 to 30%) in the papermaking furnish and its effect on the efficiency of OWAs

Table 44: Effect of broke addition in wet-end with GCC at 21% ash level

DS2, kg/t	**3**	**0**	**0**	**0**	**3**	**3**
Broke addition, %	**0**	**5**	**15**	**30**	**5**	**30**
ISO Brightness, %	93.0	84.1	86.3	87.0	93.1	92.9
B. brightness, %	83.4	81.2	82.3	82.0	82.2	81.7
CIE Whiteness	136.4	91.1	99.9	106.7	138.3	140.1
Fluorescence	21.0	2.92	4.03	4.98	21.69	22.27
Yellowness	-20.4	-1.27	-4.29	-7.40	-19.9	-21.1
L*	95.6	94.3	94.8	94.5	95.33	95.0
a*	3.46	1.21	1.62	1.89	3.67	3.78
b*	-11.0	-1.14	-2.83	-4.5	-11.2	-11.7
Opacity, %	86.7	87.1	86.5	86.2	86.1	85.3
S. Coeff., m^2/kg	47.8	47.1	45.9	46.2	46.9	47.1

Table 45: Effect of broke addition during the split addition of OWAs in wet-end and surface sizing

DS2 at wet-end, kg/t	**3**	**3**	**3**	**3**	**3**
TS1 in surface sizing, kg/t	**2**	**0**	**2**	**0**	**2**
Broke addition, %	**0**	**5**	**5**	**30**	**30**
ISO Brightness, %	94.6	93.1	93.6	92.9	93.5
B. brightness, %	82.6	82.2	82.3	81.7	82.1
CIE Whiteness	141.8	138.3	140.1	140.1	141.2
Fluorescence	22.2	21.7	21.8	22.3	22.0
Yellowness	-21.3	-20.0	-20.4	-21.1	-21.3
L*	95.6	95.32	95.6	94.9	95.1
a*	3.45	3.67	3.75	3.78	3.81
b*	-12.2	-11.2	-11.3	-11.7	-11.8
Opacity, %	86.1	86.1	85.2	85.3	85.1
S. Coeff., m^2/kg	46.1	46.9	47.2	47.1	46.8

Table 46: Effect of Broke addition in wet-end with Talc at 21% ash level

DS2, kg/t	6	0	0	0	6	6
Broke addition, %	**0**	**5**	**15**	**30**	**5**	**30**
ISO Brightness, %	90.6	81.4	83.7	84.9	91.5	91.7
B. brightness, %	79.1	79.3	79.9	79.7	79.3	79.7
CIE Whiteness	137.5	81.6	94.2	104.2	140.1	140.8
Fluorescence	24.3	2.11	3.21	10.6	23.9	23.7
Yellowness	-20.5	-1.75	-2.86	-6.88	-21.9	-22.3
L*	94.2	93.6	93.9	93.8	94.4	94.7
a*	3.23	0.70	1.39	2.01	3.65	3.60
b*	-10.8	-0.60	-2.07	-4.24	-11.9	-12.2
Opacity, %	83.9	83.2	83.1	84.0	83.2	84.1
S. Coeff., m^2/kg	35.9	39.8	40.1	40.2	40.2	40.1

Table 47: Effect of broke addition during the split addition of OWAs in wet-end and surface sizing *with talc at 21% ash level at wet-end*

DS2, kg/t	6	6	6	6	6
TS2, kg/t	**2**	**0**	**2**	**0**	**2**
Broke addition, %	**0**	**5**	**5**	**30**	**30**
ISO Brightness, %	92.2	91.5	92.0	91.7	92.2
B. brightness, %	78.1	79.3	79.5	79.7	80.0
CIE Whiteness	141.0	140.1	141.2	140.8	142.0
Fluorescence	24.3	23.9	24.1	23.7	24.0
Yellowness	-21.7	-21.8	-21.9	-22.3	-23.0
L*	94.1	94.4	94.7	94.4	94.6
a*	3.10	3.65	3.85	3.60	3.87
b*	-12.0	-12.0	-12.3	-12.2	-12.5
Opacity, %	83.1	83.2	83.5	84.1	84.3
S. Coeff., m^2/kg	35.3	40.2	39.4	40.1	39.9

Table 48: Identification of impurities and interfering metals in OWA and their effect on optical properties of paper (using EDTA as chelating agent for the treatment of water)

DS2, kg/t	**3**	**3**
Total hardness as $CaCO_3$, ppm	**164**	**Zero**
ISO Brightness, %	92.4	92.0
B. brightness, %	82.3	81.3
CIE Whiteness	136.2	137.7
Fluorescence	21.0	21.9
Yellowness	-19.1	-19.7
L*	95.4	95.2
a*	3.70	3.86
b*	-10.8	-11.1
Opacity, %	86.2	85.1
S. Coeff., m^2/kg	46.9	47.1
Ash, %	17.9	10.2
FPAR, %	77.8	44.3

CHAPTER – 2

Bleached Bagasse (BBS) Pulp

RESULTS & DISCUSSION

2 Effect of different OWAs in wet-end and in surface sizing application (at 21% ash level using different fillers)

Study was done using bleached bagasse pulp and each OWA after dose optimization at wet-end was fixed for wet-end addition while other OWAs were added in surface sizing at different doses followed by selection of best combination of that particular OWA at wet-end with other OWAs at surface sizing on the basis of cost reduction without compromising the optical properties of paper.

2.1 With GCC filler

2.1.1 Optimization of DS2 at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 87.0, whiteness was 80.0 and fluorescence was 0.80. At minimum dose of 4 kg/t of DS2 the brightness was 98.7%, CIE whiteness and fluorescence was 144.3 and 21.9 respectively. The optimum dose was 10 kg/t at which brightness was 102.3%, CIE whiteness and fluorescence was 155.3 and 28.1 respectively. On further increasing the dose beyond 12 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 4 kg/t of TS3 the brightness was 96.8%, CIE whiteness and fluorescence was 138.4 and 19.3 respectively. The optimum dose was 14 kg/t at which brightness was 101.4%, CIE whiteness and fluorescence was 154.3 and 26.8 respectively. On further increasing the dose beyond 14 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. At maximum dose of 16 kg/t of TS3 the brightness was reduced to 99.2%, CIE whiteness and fluorescence was 154.3 and 26.8 respectively. DS1 was added in wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 99.0%, CIE whiteness and fluorescence was 147.1 and 23.4 respectively. The optimum dose was 10 kg/t at which brightness was 101.1%, CIE whiteness and fluorescence was 154.2 and 28.5 respectively. On further increasing the dose beyond 12 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At this dose, the brightness was reduced to 99.2%, CIE whiteness and fluorescence was 150.3 and 27.0 respectively as shown in Table 49.

2.1.2 Split addition of OWAs in wet-end and surface sizing

2.1.2.1 Effect of different OWA in surface sizing with DS2 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 99.1%, CIE whiteness and fluorescence was 151.3 and 25.64 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 100.1%, CIE whiteness and fluorescence was 150.4 and 25.95 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness was 98.1%, CIE whiteness and fluorescence was 148.3 and 24.87 respectively. DS2 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 the brightness was 99.1%, CIE whiteness and fluorescence was 151.3 and 25.64 respectively. The optimum dose of DS2 in surface sizing was 2 kg/t at which brightness was 101.9%, CIE whiteness and fluorescence was 154.9 and 27.72 respectively. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. The brightness reduced to 98.1%, CIE whiteness and fluorescence was 148.3 and 24.87 respectively. TS1 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 101.9%, CIE whiteness and fluorescence was 155.2 and 27.90 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 97.2%, CIE whiteness and fluorescence was 149.2 and 24.82 respectively. TS2 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 99.3%, CIE whiteness and fluorescence was 153.1 and 25.14 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 103.1% and CIE whiteness was 158.6 and fluorescence was 28.12. On further increasing the dose of TS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was 100.0%, CIE whiteness and fluorescence was 148.7 and 25.36 respectively. DS1 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 98.9%, CIE whiteness and fluorescence was 151.6 and 25.23 respectively. The optimum dose of DS1 in surface sizing was 2 kg/t on which the brightness was 100.8% and CIE whiteness was 153.8 and fluorescence was 26.01. On further increasing the dose of DS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 50.

2.1.2.2 Effect of different OWA in surface sizing with TS3 addition of 9 kg/t at wet-end

TS3 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 99.2%, CIE whiteness and fluorescence was 152.4 and 25.7 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was

100.4%, CIE whiteness and fluorescence was 155.2 and 26.8 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 99.4%, CIE whiteness and fluorescence was 154.7 and 26.5 respectively. DS2 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 98.6 %, CIE whiteness and fluorescence was 150.9 and 25.1 respectively. On further increasing the dose of DS2 to 2 kg/t, the reduction in optical properties was observed. The brightness was reduced to 97.6%, CIE whiteness and fluorescence was 147.9 and 24.5 respectively. TS1 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 98.7%, CIE whiteness and fluorescence was 151.2 and 26.7 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 98.5%, CIE whiteness and fluorescence was 153.2 and 26.7 respectively. TS2 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 99.1%, CIE whiteness and fluorescence was 151.2 and 25.3 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 99.5% and CIE whiteness was 153.7 and fluorescence was 25.8. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 97.8%, CIE whiteness and fluorescence was 147.6 and 24.3 respectively. HS1 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 99.4%, CIE whiteness and fluorescence was 150.5 and 25.3 respectively. The optimum dose of HS1 in surface sizing was 3 kg/t, on which brightness was 100.6, whiteness and fluorescence was 155.2 and 26.2 respectively. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 51.

2.1.2.3 Effect of different OWA in surface sizing with DS1 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 99.1%, CIE whiteness and fluorescence was 153.0 and 27.90 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 99.4%, CIE whiteness and fluorescence was 154.8 and 28.13 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 97.5%, CIE whiteness and fluorescence was 144.8 and 27.17 respectively. DS2 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 97.7%, CIE whiteness and fluorescence was 141.0 and 25.40 respectively. This was the optimum dose of DS2 in surface sizing. On further increasing the dose of DS2 to 2 kg/t, the reduction in optical properties was observed. The brightness was reduced to 95.8%, CIE

whiteness and fluorescence was 130.3 and 22.35 respectively. TS1 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 99.2%, CIE whiteness and fluorescence was 153.0 and 28.01 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 99.9%, CIE whiteness and fluorescence was 155.0 and 28.72 respectively. TS2 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 99.5 %, CIE whiteness and fluorescence was 153.8 and 28.32 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 99.8% and CIE whiteness was 154.8 and fluorescence was 28.70. On further increasing the dose of TS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.4 %, CIE whiteness and fluorescence was 149.2 and 28.21 respectively. HS1 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 99.5%, CIE whiteness and fluorescence was 154.8 and 28.21 respectively. The optimum dose of HS1 in surface sizing was 3 kg/t. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 52

2.1.3 Best Combinations of different OWAs at wet and size press

2.1.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 7 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 102.3% and CIE whiteness and fluorescence were 155.3 and 28.1 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 7 kg/t of DS2 at wet-end with 2 kg/t of DS2 in surface sizing, 7 kg/t of DS2 at wet-end with 3 kg/t of TS3 in surface sizing, 7 kg/t of DS2 in wet-end and 2 kg/t of TS1 in surface sizing, 7 kg/t of DS2 in wet-end along with 2 kg/t of TS2 in surface sizing, 7 kg/t of DS2 at wet-end with 2 kg/t of DS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 7kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties as shown in Table 53.

2.1.3.2 TS3 at wet-end with different OWAs at size press

Adding TS3 at a dose of 9 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 101.1% and CIE whiteness and fluorescence were 154.3 and 26.8 respectively. Various OWAs at different doses were added in surface sizing along with TS3

addition at wet-end. The best combinations were 9 kg/t of TS3 at wet-end with 3 kg/t of TS3 in surface sizing, 9 kg/t of TS3 at wet-end with 3 kg/t of TS1 in surface sizing, 9 kg/t of TS3 in wet-end and 2 kg/t of TS2 in surface sizing, 9 kg/t of TS3 in wet-end along with 3 kg/t of HS1 in surface sizing. The best combination among all these was addition of 9kg/t of TS3 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 54.

2.1.3. 3 DS1 at wet-end with different OWAs at size press

Adding DS1 at a dose of 10 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 101.1% and CIE whiteness and fluorescence were 154.2 and 28.50 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations were 6 kg/t of DS1 at wet-end with 2 kg/t of TS3 in surface sizing, 6 kg/t of DS1 at wet-end with 3 kg/t of TS1 in surface sizing, 6 kg/t of DS1 in wet-end and 2 kg/t of TS2 in surface sizing, 6 kg/t of DS1 in wet-end along with 3 kg/t of HS1 in surface sizing. The best combination among all these was addition of 6kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 55.

2.2 With Talc filler

2.2.1 Optimization of DS2 at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 85.1, whiteness was 79.0 and fluorescence was 1.54. At minimum dose of 4 kg/t of DS2 the brightness was 95.1%, CIE whiteness and fluorescence was 139.6 and 21.86 respectively. The optimum dose was 10 kg/t at which brightness was 99.4%, CIE whiteness and fluorescence was 149.2 and 26.5 respectively. On further increasing the dose beyond 10 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 4 kg/t of TS3 the brightness was 95.1%, CIE whiteness and fluorescence was 140.0 and 21.8 respectively. The optimum dose was 10 kg/t at which brightness was 99.0%, CIE whiteness and fluorescence was 148.9 and 26.4 respectively. On further increasing the dose to 12 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. DS1 was added in wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 96.8%, CIE whiteness and fluorescence was 145.4 and 22.9 respectively. The optimum dose was 12 kg/t at which brightness was 100.0%, CIE whiteness and fluorescence was 152.0 and 27.8

respectively. On further increasing the dose beyond 12 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At this dose, the brightness was reduced to 98.4%, CIE whiteness and fluorescence was 150.1 and 25.7 respectively as shown in Table 56.

2.2.2 Split addition of OWAs in wet-end and surface sizing

2.2.2.1 Effect of different OWA in surface sizing with DS2 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 96.8%, CIE whiteness and fluorescence was 150.2 and 26.8 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 98.5%, CIE whiteness and fluorescence was 152.4 and 28.2 respectively. On further increasing the dose of TS3 to 3 kg/t, the brightness was 97.9%, CIE whiteness and fluorescence was 151.8 and 28.1 respectively. DS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 the brightness was 96.7%, CIE whiteness and fluorescence was 147.6 and 26.4 respectively. The optimum dose of DS2 in surface sizing was 2 kg/t at which brightness was 96.7%, CIE whiteness and fluorescence was 146.0 and 26.4 respectively. On further increasing the dose of DS2 to 3 kg/t, the reduction in optical properties was observed. The brightness reduced to 95.2%, CIE whiteness and fluorescence was 141.4 and 22.8 respectively. TS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 98.2%, CIE whiteness and fluorescence was 154.5 and 27.5 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 2 kg/t, the reduction in optical properties was observed. The brightness was reduced to 98.2%, CIE whiteness and fluorescence was 154.5 and 27.5 respectively. TS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 97.0%, CIE whiteness and fluorescence was 150.4 and 27.1 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 98.7% and CIE whiteness was 154.4 and fluorescence was 27.8. On further increasing the dose of TS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was 98.0%, CIE whiteness and fluorescence was 152.8 and 27.9 respectively. HS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of HS1 the brightness was 96.9%, CIE whiteness and fluorescence was 149.7 and 26.4 respectively. The optimum dose of HS1 in surface sizing was 2 kg/t on which the brightness was 99.1% and CIE whiteness was 155.8 and fluorescence was 27.9. On further increasing the dose of HS1 to 3 kg/t, as shown in Table 57

2.2.2.2 Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 95.9%, CIE whiteness and fluorescence was 147.3 and 25.1 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 97.8%, CIE whiteness and fluorescence was 147.9 and 25.4 respectively. On further increasing the dose of TS3 to 3 kg/t, the brightness reduced to 95.5%, CIE whiteness and fluorescence was 145.3 and 24.2 respectively. DS2 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of DS2 in surface sizing, the brightness was 95.4%, CIE whiteness and fluorescence was 146.2 and 24.8 respectively. On further increasing the dose of DS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was reduced to 94.1%, CIE whiteness and fluorescence was 142.0 and 23.9 respectively. TS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 96.0%, CIE whiteness and fluorescence was 147.2 and 25.2 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 3kg/t, the reduction in optical properties was observed. The brightness was reduced to 96.1%, CIE whiteness and fluorescence was 145.3 and 24.2 respectively. TS2 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 96.1%, CIE whiteness and fluorescence was 147.0 and 25.1 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 97.8% and CIE whiteness was 147.9 and fluorescence was 25.4. On further increasing the dose of TS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was reduced to 95.0%, CIE whiteness and fluorescence was 146.4 and 23.9 respectively. HS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 96.7%, CIE whiteness and fluorescence was 146.8 and 25.2 respectively. The optimum dose of HS1 in surface sizing was 2 kg/t, on which brightness was 98.1, whiteness and fluorescence was 148.8 and 25.9 respectively. On further increasing the dose of HS1 to 3 kg/t, the reduction in optical properties was observed as shown in Table 58.

2.2.2.3 Effect of different OWA in surface sizing with DS1 addition of 8 kg/t at wet-end

TS3 was added in surface sizing along with 8 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 97.3%, CIE whiteness and fluorescence was 149.5 and 25.1 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 97.6%, CIE whiteness and fluorescence was 150.9 and 27.2 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 97.3%, CIE whiteness and

fluorescence was 147.9 and 26.5 respectively. TS1 was added in surface sizing along with 8 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 97.3%, CIE whiteness and fluorescence was 149.4 and 25.2 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 97.2%, CIE whiteness and fluorescence was 143.0 and 25.4 respectively. TS2 was added in surface sizing along with 8 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 97.2%, CIE whiteness and fluorescence was 149.9 and 26.4 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 98.2% and CIE whiteness was 152.7 and fluorescence was 27.5. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 98.0%, CIE whiteness and fluorescence was 151.2 and 27.3 respectively. HS1 was added in surface sizing along with 8 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 97.2%, CIE whiteness and fluorescence was 149.6 and 26.4 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t. On which the brightness was 99.4 and whiteness and fluorescence was 153.4 and 27.6 as shown in Table 59.

2.2.3 Best combinations of different OWAs in wet-end and surface sizing

2.2.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 10 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 99.4% and CIE whiteness and fluorescence were 149.2 and 26.5 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 6 kg/t of DS2 at wet-end with 2 kg/t of TS2 in surface sizing, 6 kg/t of DS2 at wet-end with 2 kg/t of HS1 in surface sizing, 6 kg/t of DS2 in wet-end and 2 kg/t of TS3 in surface sizing, 6 kg/t of DS2 in wet-end along with 2 kg/t of DS2 in surface sizing, 6 kg/t of DS2 at wet-end with 2 kg/t of TS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 6kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties as shown in Table 60.

2.2.3.2 TS3 at wet-end with different OWAs at size press

Adding TS3 at a dose of 10 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 99.0% and CIE whiteness and fluorescence were 148.9 and 26.4 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 6 kg/t of TS3 at wet-end with 2 kg/t of TS3

in surface sizing, 6 kg/t of TS3 at wet-end with 1kg/t of DS2 in surface sizing, 6 kg/t of TS3 in wet-end and 2 kg/t of TS1 in surface sizing, 6 kg/t of TS3 in wet-end along with 2 kg/t of TS2 in surface sizing. The best combination among all these was addition of 6kg/t of TS3 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties as shown in Table 61.

2.2.3.3 DS1 at wet-end with different OWAs at size press

Adding DS1 at a dose of 12 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 100.0% and CIE whiteness and fluorescence were 152.0 and 27.8 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations with 8 kg/t of DS1 at wet-end were 2 kg/t of TS3, 2 kg/t of TS1, 2 kg/t of TS2 and 6 kg/t of DS1 in surface sizing. The best combination among all these was addition of 8kg/t of DS1 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 62.

2.3 With PCC filler

2.3.1 Optimization of DS2 at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 87.5, whiteness was 80.6 and fluorescence was 0.70. At minimum dose of 4 kg/t of DS2 the brightness was 96.8%, CIE whiteness and fluorescence was 145.4 and 22.9 respectively. The optimum dose was 10 kg/t at which brightness was 101.5%, CIE whiteness and fluorescence was 153.4 and 26.3 respectively. On further increasing the dose beyond 10 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 4 kg/t of TS3 the brightness was 96.5%, CIE whiteness and fluorescence was 142.2 and 0.70 respectively. The optimum dose was 13 kg/t at which brightness was 101.0%, CIE whiteness and fluorescence was 149.2 and 23.4 respectively. On further increasing the dose to 15 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. DS1 was added at wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 97.8%, CIE whiteness and fluorescence was 149.2 and 26.3 respectively. The optimum dose was 10 kg/t at which brightness was 101.8%, CIE whiteness and fluorescence was 154.2 and 26.4 respectively. On further increasing the dose beyond 10 kg/t the reduction in values of brightness whiteness, a* and b* was observed as shown in Table 63.

2.3.2 Split addition of OWAs in wet-end and surface sizing

2.3.2.1 Effect of different OWA in surface sizing with DS2 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 101.2%, CIE whiteness and fluorescence was 154.1 and 26.2 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 101.8%, CIE whiteness and fluorescence was 156.1 and 27.2 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness was 102.0%, CIE whiteness and fluorescence was 155.5 and 27.1 respectively. TS1 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 100.9%, CIE whiteness and fluorescence was 153.7 and 25.2 respectively. The optimum dose of TS1 in surface sizing was 4 kg/t. The brightness was 101.7%, CIE whiteness and fluorescence was 154.3 and 27.4 respectively. TS2 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 101.2%, CIE whiteness and fluorescence was 156.7 and 27.4 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 101.9% and CIE whiteness was 157.7 and fluorescence was 27.4. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was 101.5%, CIE whiteness and fluorescence was 156.5 and 28.5 respectively. HS1 was added in surface sizing along with 7 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 100.7%, CIE whiteness and fluorescence was 154.8 and 26.8 respectively. The optimum dose of DS1 in surface sizing was 2 kg/t on which the brightness was 101.0% and CIE whiteness was 156.8 and fluorescence was 28.1. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 64.

2.3.2.2 Effect of different OWA in surface sizing with TS3 addition of 9 kg/t at wet-end

TS3 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 100.8%, CIE whiteness and fluorescence was 152.7 and 25.5 respectively. The optimum dose of TS3 in surface sizing was 4 kg/t at which brightness was 101.7%, CIE whiteness and fluorescence was 156.8 and 28.2 respectively. TS1 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 100.6%, CIE whiteness and fluorescence was 148.5 and 23.1 respectively. The optimum dose of TS1 in surface sizing was 4 kg/t. TS2 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 101.0%, CIE whiteness and fluorescence was 155.2 and 26.9 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 101.7% and CIE

whiteness was 157.6 and fluorescence was 27.8. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 9 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 100.6%, CIE whiteness and fluorescence was 151.7 and 24.5 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t, on which brightness was 101.8%, whiteness and fluorescence was 156.7 and 26.9 respectively as shown in Table 65.

2.3.2.3 Effect of different OWA in surface sizing with DS1 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 101.6%, CIE whiteness and fluorescence was 153.8 and 26.2 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 102.1%, CIE whiteness and fluorescence was 154.8 and 27.3 respectively. On further increasing the dose of TS3 to 4 kg/t, slight reduction in optical properties was observed. TS1 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 101.2%, CIE whiteness and fluorescence was 153.9 and 26.5 respectively. The optimum dose of TS1 in surface sizing was 2 kg/t. On further increasing the dose of TS1 to 2 kg/t, the reduction in optical properties was observed. TS2 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 101.8%, CIE whiteness and fluorescence was 153.9 and 26.1 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 102.5% and CIE whiteness was 156.3 and fluorescence was 27.6. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 6 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 102.6%, CIE whiteness and fluorescence was 154.2 and 26.4 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t. On which the brightness was 102.2 and whiteness and fluorescence was 156.9 and 28.1 as shown in Table 66.

2.3.3 Best Combinations of different OWAs at wet and size press

2.3.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 10 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 101.5% and CIE whiteness and fluorescence were 153.9 and 26.4 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 7 kg/t of DS2 at wet-end with 4 kg/t of TS3 in surface sizing, 7 kg/t of DS2 at wet-end with 3kg/t of TS1 in surface sizing, 7 kg/t of DS2 in wet-end and 2 kg/t of TS2 in surface sizing, 7 kg/t of DS2 in wet-end along with 2 kg/t of HS1

in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 7kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties as shown in Table 67.

2.3.3.2 Best combinations of different OWAs at surface sizing with TS3 at wet-end

Adding TS3 at a dose of 13 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 101.0% and CIE whiteness and fluorescence were 149.2 and 23.4 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 9 kg/t of TS3 at wet-end with 4 kg/t of TS3 in surface sizing, 9 kg/t of TS3 in wet-end and 4 kg/t of TS1 in surface sizing, 9 kg/t of TS3 in wet-end along with 2 kg/t of TS2 in surface sizing. The best combination among all these was addition of 9kg/t of TS3 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties as shown in Table 68.

.*2.3.3.3 Best combinations of different OWAs at surface sizing with DS1 at wet-end*

Adding DS1 at a dose of 10 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 101.8% and CIE whiteness and fluorescence were 154.8 and 27.3 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations with 6 kg/t of DS1 at wet-end were 2 kg/t of TS3, 2 kg/t of TS1, 2 kg/t of TS2 and 4 kg/t of HS1 in surface sizing. The best combination among all these was addition of 6 kg/t of DS1 at wet-end and 2 kg/t of TS1 in surface sizing along with comparable optical properties as shown in Table 69.

Effect of different OWAs in wet-end and in surface sizing application (at 21% ash level using different fillers)

With GCC filler

Table 49: Optimization of different OWAs at wet-end

OWA	DS2					TS3					DS1			
Dose, kg/t	**0**	**4**	**8**	**10**	**12**	**4**	**8**	**12**	**14**	**16**	**4**	**8**	**10**	**12**
ISO Brightness, %	87.0	98.7	100.3	**102.3**	101.2	96.8	98.7	99.8	**101.1**	99.2	99.0	100.8	**101.1**	99.2
B. brightness, %	86.8	87.8	87.4	**87.3**	87.5	87.4	86.7	87.1	**86.8**	87.1	87.5	87.2	**87.1**	86.5
CIE Whiteness	80.0	144.3	151.4	**155.3**	153.2	138.4	148.8	152.6	**154.3**	153.6	147.1	153.0	**154.2**	150.3
Fluorescence	0.80	21.9	25.86	**28.1**	27.24	19.3	24.2	26.0	**26.8**	25.7	23.4	27.0	**28.5**	27.0
Fluorescence, C	0.2	10.9	12.9	**15.0**	13.7	9.4	12.0	12.7	**14.3**	12.1	11.5	13.6	**14.0**	12.7
Yellowness	4.26	-20.50	-23.5	**-25.0**	-24.5	-18.2	-22.8	-24.4	**-25.0**	-24.2	-21.9	-24.6	**-25.2**	-24.8
L*	95.8	97.3	97.6	**97.4**	97.6	96.9	97.1	97.3	**97.2**	97.3	97.3	97.5	**97.6**	97.4
a*	0.24	3.73	3.77	**3.81**	3.54	3.62	4.04	4.08	**4.15**	3.99	3.86	3.68	**3.42**	3.24
b*	2.14	-11.6	-13.0	**-13.9**	-13.7	-10.5	-12.8	-13.6	**-13.7**	-13.6	-12.3	-13.5	**-13.7**	-13.0
Opacity, %	89.9	89.5	90.0	**90.6**	89.1	90.7	91.0	90.4	**91.1**	90.2	89.0	90.4	**91.2**	90.0
S. Coeff., m^2/kg	70.4	70.1	70.7	**71.0**	69.5	71.2	70.6	**71.5**	70.6	71.2	69.2	72.5	**72.3**	69.2

Table 50: Effect of different OWA in surface sizing with DS2 addition of 7 kg/t at wet-end

DS2 at wet-end, kg/t		**10**	**7**																			
OWA in surface sizing, kg/t	**Type**	**0**	**0**	**Only starch**	**TS3**				**DS2**				**TS1**				**TS2**				**DS1**			
	Dose, kg/t				**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**1**	**2**	**3**	**4**
ISO Brightness, %		102.3	99.5	98.4	99.1	**101.9**	100.1	98.1	99.1	**101.9**	100.1	98.1	99.0	**101.9**	99.8	97.2	99.3	**103.1**	100.0	98.9	**100.8**	99.0	97.8
B. brightness, %		87.3	87.6	87.2	87.4	**87.2**	87.3	87.0	87.4	**87.2**	87.3	87.0	87.3	**87.2**	87.3	87.0	87.4	**87.5**	87.0	87.1	**87.4**	87.0	87.4
CIE Whiteness		155.3	149.4	150.7	151.3	**154.9**	150.4	148.3	151.3	**154.9**	150.4	148.3	151.8	**155.2**	152.4	149.2	153.1	**158.6**	148.7	151.6	**153.8**	149.5	145.4
Fluorescence		28.1	25.0	25.1	25.6	**27.7**	25.9	24.8	25.6	**27.7**	25.9	24.8	25.4	**7.9**	26.1	24.8	25.1	**28.1**	25.3	25.2	**26.0**	25.0	24.2
Fluorescence, C		15.0	11.9	11.2	11.7	**14.7**	12.8	11.1	11.7	**14.7**	12.8	11.1	11.7	**14.7**	12.5	10.2	11.9	**15.6**	13.0	11.8	**13.4**	12.0	10.4
Yellowness		-25.0	-22.1	-21.9	-22.7	**-24.8**	-23.7	-21.1	-22.7	**-24.8**	-23.7	-21.1	-22.7	**-24.8**	-23.1	-21.8	-22.6	**-25.1**	-22.1	-23.0	**-24.1**	-22.0	-21.5
L*		97.4	97.3	97.0	97.1	97.2	97.0	97.0	97.1	97.2	97.0	97.0	97.0	97.3	97.0	97.3	97.3	97.0	97.1	97.0	97.1	97.4	97.2
a*		3.81	3.75	3.74	3.76	**3.80**	3.51	3.12	3.76	**3.80**	3.51	3.12	3.75	**3.79**	3.61	3.17	3.69	**3.81**	2.97	3.70	**3.72**	3.29	2.97
b*		-13.8	-12.4	-12.9	-12.9	**-13.5**	-13.0	-12.2	-12.9	**-13.5**	-13.0	-12.2	-12.9	**-13.5**	-13.0	-12.7	-13.0	**-13.8**	-12.3	-13.0	**-13.2**	-12.5	-12.0
Opacity, %		90.6	89.2	89.1	89.2	**90.5**	90.0	89.7	89.2	**90.5**	90.0	89.7	89.5	**89.1**	89.7	90.5	90.2	**90.0**	90.4	89.9	**90.1**	91.1	91.8
S. Coeff., m^2/kg		71.0	71.1	70.2	71.4	**71.6**	**70.7**	70.4	71.4	**71.6**	70.7	70.4	70.9	**71.2**	70.3	**71.6**	71.6	**71.0**	71.4	70.9	**70.5**	71.5	71.9

Table 51: Effect of different OWA in surface sizing with TS3 addition of 9 kg/t at wet-end

TS3 at wet-end, kg/t		**14**	**9**																			
OWA in surface sizing, kg/t	**Type**	**0**	**0**	**Only starch**	**TS3**				**DS2**		**TS1**				**TS2**				**HS1**			
	Dose, kg/t				**1**	**2**	**3**	**4**	**1**	**2**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
ISO Brightness, %		101.1	99.0	98.4	99.2	99.5	**100.4**	99.4	**98.6**	97.6	98.7	99.1	**99.6**	98.5	99.1	**99.5**	99.0	97.8	99.4	99.8	**100.6**	98.5
B. brightness, %		86.8	86.9	86.0	86.4	86.6	**86.4**	86.1	**86.1**	86.0	85.8	86.1	**85.9**	85.9	86.0	**86.4**	86.1	85.8	85.6	86.1	**85.7**	85.8
CIE Whiteness		154.3	149.6	150.5	152.4	154.3	**155.2**	154.7	**150.9**	147.9	151.2	153.9	**154.7**	153.2	151.2	**153.7**	150.2	147.6	151.2	154.9	**155.2**	154.4
Fluorescence		26.8	24.8	25.0	25.7	26.5	**26.8**	26.5	**25.1**	24.5	26.7	27.6	**27.8**	26.7	25.3	**25.8**	25.4	24.3	25.3	25.8	**26.2**	25.9
Fluorescence, C		14.3	12.1	12.4	12.8	12.9	**14.0**	13.3	**12.5**	11.6	12.9	13.0	**13.7**	12.6	13.1	**13.1**	12.9	12.0	13.8	13.7	**14.9**	12.7
Yellowness		-25.0	-22.9	-23.0	-24.8	-25.4	**-25.7**	-25.8	**-23.1**	-23.2	-23.8	-25.6	**-25.7**	-25.2	-23.8	**-25.1**	-25.0	-23.8	-23.4	-25.7	**-25.8**	-24.9
L*		97.2	97.4	97.2	97.1	97.1	**97.0**	96.8	**97.0**	96.7	97.2	97.1	**97.0**	96.8	97.1	**96.9**	97.0	97.1	97.0	96.7	**97.0**	96.9
a*		4.15	4.05	4.11	4.13	4.15	**4.21**	3.98	**4.02**	3.35	4.08	3.65	**3.70**	3.51	4.19	**4.37**	4.30	3.87	4.13	4.20	**4.29**	3.87
b*		-13.6	-12.8	-12.9	-13.3	-14.0	**-14.3**	-14.2	**-12.9**	-12.7	-13.1	-13.9	**-14.0**	-13.9	-13.4	**-13.9**	-13.8	-12.4	-13.4	-14.0	**-14.9**	-13.8
Opacity, %		91.1	91.1	90.7	91.0	90.7	**89.5**	89.9	**91.4**	89.5	91.8	90.4	**90.7**	89.7	91.0	**90.8**	89.8	90.6	89.0	89.6	**90.8**	89.1
S. Coeff., m^2/kg		71.5	71.4	70.8	71.2	70.5	**70.6**	71.8	**70.6**	69.9	69.8	70.5	**69.0**	70.9	71.2	**71.5**	69.4	69.9	70.6	71.9	**71.7**	70.0

Table 52: Effect of different OWA in surface sizing with DS1 addition of 6 kg/t at wet-end

DS1 at wet-end, kg/t		10	6																	
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3				DS2		TS1				TS2			HS1			
	Dose, kg/t				1	2	3	4	1	2	1	2	3	4	1	2	3	1	2	3	4
ISO Brightness, %		101.1	99.4	98.9	99.1	99.4	**99.8**	97.5	**97.7**	95.8	99.2	99.4	**99.9**	99.3	99.3	**99.8**	89.4	99.5	99.8	**100.8**	99.5
B. brightness, %		87.1	86.0	85.7	85.4	85.9	**85.4**	85.8	**85.9**	85.4	85.4	86.0	**85.7**	85.4	85.4	**85.8**	85.6	85.1	85.5	**85.3**	85.6
CIE Whiteness		154.2	151.8	152.7	153.0	154.8	**155.9**	144.8	**141.0**	130.3	153.0	153.8	**155.0**	151.0	151.0	**154.8**	149.2	153.4	154.8	**156.0**	153.4
Fluorescence		28.5	27.2	27.8	27.9	28.1	**28.4**	27.2	**25.4**	22.3	28.0	28.6	**28.7**	28.0	28.0	**28.7**	28.2	28.2	28.7	**28.9**	27.9
Fluorescence, C		14.0	13.4	13.2	13.7	13.5	**14.4**	11.7	**11.8**	10.4	13.8	13.4	**14.2**	13.9	13.9	**14**	3.8	14.4	14.3	**15.5**	13.9
Yellowness		-25.1	-24.3	-24.2	-12.3	-24.6	**-24.7**	-22.4	**-20.6**	-16.5	-25.0	-25.8	**-26.0**	-24.6	-24.6	**-25.9**	-23.9	-25.2	-25.5	**-26.4**	-25.8
L*		97.6	97.3	96.9	97.0	97.2	**97.0**	97.0	**97.1**	97.0	97.1	97.0	**97.1**	97.2	97.2	**97.1**	97.0	97.3	97.1	**97.3**	97.0
a*		3.42	3.64	3.74	3.79	3.80	**3.83**	1.66	**1.68**	0.56	3.39	3.44	**3.51**	2.79	2.79	**3.79**	2.98	3.67	3.81	**3.88**	3.05
b*		-13.7	-13.3	-13.9	-13.9	-13.9	**-14.1**	-11.7	**-10.9**	-8.5	-13.9	-13.9	**-14.2**	-13.2	-13.2	**-14.2**	-13.0	-13.9	-14.1	**-14.4**	-13.7
Opacity, %		91.2	90.1	89.2	91.0	90.4	**90.1**	89.4	**90.1**	91.3	91.0	90.2	**90.7**	90.0	90.0	**91.4**	89.8	90.2	91.8	**89.7**	90.0
S. Coeff., m^2/kg		72.3	71.2	70.3	71.5	71.0	**70.8**	69.7	**70.4**	71.2	71.6	70.5	**69.9**	70.2	70.2	**71.5**	69.7	70.9	69.4	**70.1**	70.9

Table 53: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

DS2, kg/t		10	7				
OWA in surface sizing, kg/t	Type	--	DS2	TS3	TS1	TS2	DS1
	Dose, kg/t	--	2	3	2	2	2
ISO Brightness, %		102.3	101.9	102.7	101.9	**103.1**	100.8
B. brightness, %		87.3	87.2	87.1	87.2	**87.5**	87.4
CIE Whiteness		155.3	154.9	157.8	155.2	**158.6**	153.8
Fluorescence		28.1	27.8	28.0	27.9	**28.1**	26.01
Fluorescence, C		15.0	14.7	15.6	14.7	**15.6**	13.4
Yellowness		-25.0	-24.9	-25.1	-24.9	**-25.2**	-24.1
L*		97.4	97.2	97.1	97.3	**97.0**	97.1
a*		3.81	3.80	3.78	3.79	**3.81**	3.72
b*		-13.9	-13.5	-13.7	-13.6	**-13.8**	-13.3

Table 54: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

TS3 wet-end, kg/t		**14**	**9**			
OWA in surface sizing, kg/t	**Type**	**--**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**3**	**2**	**2**	**3**
ISO Brightness, %		101.1	100.4	99.6	99.5	**100.6**
B. brightness, %		86.8	86.4	85.9	86.4	**85.7**
CIE Whiteness		154.3	154.9	154.7	153.7	**155.2**
Fluorescence		26.8	26.8	27.8	25.8	**26.2**
Fluorescence, C		14.3	14.0	13.7	13.1	**14.9**
Yellowness		-25.0	-25.7	-25.8	-25.2	**-25.9**
L*		97.2	97.0	97.0	96.9	**97.0**
a*		4.15	4.21	3.70	4.37	**4.29**
b*		-13.7	-14.4	-14.0	-13.9	**-14.9**

Table 55: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

DS1 wet-end, kg/t		**10**	**6**			
OWA in surface sizing, kg/t	**Type**	--	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**2**	**3**	**2**	**2**
ISO Brightness, %		101.1	99.4	99.9	99.8	**100.8**
B. brightness, %		87.1	85.9	85.7	85.8	**85.3**
CIE Whiteness		154.2	154.8	155.0	154.8	**156.0**
Fluorescence		28.50	28.13	28.72	28.70	**28.91**
Fluorescence, C		14.0	13.5	14.2	14	**15.5**
Yellowness		-25.1	-24.7	-26.0	-25.9	**-26.4**
L*		97.6	97.2	97.1	97.1	**97.3**
a*		3.42	3.80	3.51	3.79	**3.88**
b*		-13.7	-14.0	-14.2	-14.2	**-14.4**

With Talc filler

Table 56: Optimization of different OWAs at wet-end

OWA	DS2					TS3				DS1			
Dose, kg/t	**nil**	**4**	**8**	**10**	**12**	**4**	**8**	**10**	**12**	**4**	**8**	**12**	**16**
ISO Brightness, %	85.1	95.1	97.2	**99.4**	98.2	95.1	97.2	**99.0**	98.2	96.8	97.1	**100.0**	98.4
B. brightness, %	84.4	84.3	84.6	**84.3**	85.0	84.3	84.2	**85.1**	85.0	83.9	83.6	**85.1**	85.2
CIE Whiteness	79.0	139.6	146.2	**149.2**	147.7	140.0	146.2	**148.9**	147.7	145.4	149.5	**152.0**	150.1
Fluorescence	1.54	21.9	24.9	**26.5**	26.1	21.8	24.9	**26.4**	26.1	22.9	26.3	**27.8**	25.7
Fluorescence, C	0.7	10.8	12.6	**15.1**	13.2	10.8	13.0	**13.9**	13.2	12.8	13.5	**14.9**	13.2
Yellowness	4.08	-19.9	-22.8	**-23.4**	-23.2	-19.9	-22.8	**-23.3**	-23.2	-21.39	-22.9	**-24.8**	-24.0
L*	93.5	96.2	96.5	**96.2**	96.8	96.2	96.5	**96.5**	96.8	96.9	97.1	**97.4**	97.3
a*	0.04	3.50	3.36	**3.49**	3.11	3.50	3.36	**3.49**	3.11	3.78	3.50	**3.42**	3.02
b*	2.11	-11.1	-12.5	**-13.9**	-12.6	-11.2	-12.5	**-12.8**	-12.6	-12.0	-13.4	**-13.5**	-13.2
Opacity, %	85.9	85.0	86.2	**84.9**	85.1	85.0	86.3	**85.9**	85.1	85.9	85.1	**85.0**	85.4
S. Coeff., m^2/kg	49.7	49.0	50.1	**49.0**	49.2	49.1	50.2	**49.4**	49.0	49.4	49.0	**49.0**	49.4

Split addition of OWAs in wet-end surface sizing

Table 57: Effect of different OWA in surface sizing with DS2 addition of 6 kg/t at wet-end

DS2 at wet-end, kg/t		10	6															
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			DS2			TS1			TS2			HS1		
	Dose, kg/t				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
ISO Brightness, %		99.4	96.2	95.8	96.8	**98.5**	97.9	**96.7**	96.7	95.2	96.4	**98.2**	97.5	97.0	**98.7**	98.0	96.9	**99.1**	98.3
B. brightness, %		84.3	84.1	83.4	83.4	**83.1**	83.3	**83.1**	83.0	83.2	83.2	**83.4**	83.5	83.2	**83.4**	83.2	83.5	**83.6**	83.4
CIE Whiteness		149.2	142.3	144.1	150.2	**152.4**	151.8	**147.6**	146.0	141.4	146.0	**154.5**	149.8	150.4	**154.4**	152.8	149.7	**155.8**	149.8
Fluorescence		26.5	22.3	22.3	26.8	**28.2**	28.1	**26.4**	26.4	22.8	24.4	**27.5**	26.8	27.1	**27.8**	27.9	26.4	**27.9**	27.2
Fluorescence, C		15.1	12.1	12.4	13.4	**15.4**	14.6	**13.6**	13.7	12.0	13.2	**14.8**	14.0	13.8	**15.3**	14.8	13.4	**15.5**	14.9
Yellowness		-23.4	-20.2	-20.3	-26.2	**-26.4**	-26.3	**-24.4**	-23.6	-20.4	-24.9	**-26.2**	-27.1	-26.8	**-26.9**	-26.9	-26.4	**-26.9**	-26.7
L*		96.2	96.2	96.0	95.9	**96.1**	96.0	**95.8**	95.9	96.0	95.8	**96.0**	95.8	95.8	**95.9**	96.0	95.9	**96.1**	96.1
a*		3.49	3.38	3.41	3.66	**3.68**	3.15	**3.37**	2.47	2.14	3.49	**3.59**	3.41	3.61	**3.62**	3.44	3.55	**3.72**	3.28
b*		-13.4	-12.0	-12.4	-14.0	**-14.4**	-13.9	**-13.1**	-12.8	-11.9	-12.9	**-14.3**	-13.7	-14.0	**-14.8**	-14.4	-13.8	**-14.9**	-14.1
Opacity, %		84.9	85.7	85.9	86.1	**85.9**	95.7	**86.1**	84.7	84.9	85.8	**86.0**	86.2	86.2	**85.3**	86.0	86.0	**86.4**	85.8
S. Coeff., m^2/kg		49.0	49.8	50.5	49.8	**49.1**	50.1	**51.1**	49.2	48.7	50.2	**49.9**	50.5	50.5	**49.7**	50.1	50.0	**49.4**	49.9

Table 58: Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

TS3 at wet-end, kg/t		10	6															
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			DS2			TS1			TS2			HS1		
	Dose, kg/t				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
ISO Brightness,		99.0	96.1	95.5	95.9	**97.8**	95.5	**95.4**	95.1	94.1	96.0	**98.1**	96.1	96.1	**97.8**	95.0	96.7	**98.1**	96.0
B. brightness, %		85.1	84.1	83.4	83.2	**83.4**	83.3	**83.0**	83.1	83.0	83.2	**83.4**	83.1	83.5	**83.2**	83.0	83.3	**83.6**	83.0
CIE Whiteness		148.9	145.2	146.1	147.3	**147.9**	145.3	**146.2**	144.2	142.0	147.4	**148.2**	145.3	147.0	**147.9**	146.4	146.8	**148.8**	145.3
Fluorescence		26.4	24.4	24.8	25.1	**25.4**	24.2	**24.8**	24.4	23.9	25.2	**25.6**	24.2	25.1	**25.4**	23.9	25.2	**25.9**	24.9
Fluorescence, C		13.9	12.0	12.1	12.7	**14.4**	12.2	**12.4**	12.0	11.1	12.8	**15.1**	13.0	12.6	**14.6**	12.0	13.4	**14.5**	13.0
Yellowness		-23.3	-22.1	-22.3	-22.9	**-23.0**	-23.3	**-22.4**	-22.2	-22.1	-23.1	**-23.6**	-23.0	-23.0	**-23.4**	-22.9	-22.5	**-23.2**	-22.1
L*		96.5	96.5	95.8	95.6	**95.8**	95.5	**95.4**	95.2	95.1	95.2	**95.5**	95.0	95.4	**95.6**	95.2	95.5	**95.2**	95.1
a*		3.49	3.39	3.41	3.61	**3.64**	3.26	**3.49**	3.12	2.45	3.59	**3.62**	3.23	3.45	**3.51**	3.12	3.37	**3.51**	3.10
b*		-12.8	-12.1	-12.3	-12.5	**-12.6**	-12.1	**-12.3**	-12.0	-11.9	-12.4	**-12.7**	-12.0	-12.3	**-12.5**	-12.2	-12.3	**-12.8**	-12.1
Opacity, %		85.9	86.1	85.8	86.0	**86.4**	85.8	**86.5**	86.0	86.4	86.4	**85.3**	86.0	86.1	**85.8**	86.1	85.4	**86.0**	85.2
S. Coeff., m^2/kg		49.4	50.0	49.5	50.0	**49.4**	49.9	**50.5**	50.3	50.2	50.8	**50.1**	50.1	50.1	**49.6**	50.2	50.1	**50.8**	49.5

Table 59: Effect of different OWA in surface sizing with DS1 addition of 8 kg/t at wet-end

DS1 at wet-end, kg/t		12	8													
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			TS1			TS2			HS1		
	Dose, kg/t				1	2	4	1	2	4	1	2	4	1	2	4
ISO Brightness, %		100.0	97.1	97.0	97.3	**97.6**	97.3	97.3	**98.1**	97.2	97.2	**98.2**	98.0	97.2	97.4	**99.4**
B. brightness, %		85.1	83.6	83.4	83.7	**83.7**	83.6	83.8	**84.5**	84.1	83.7	**84.0**	83.8	83.7	83.8	**85.2**
CIE Whiteness		152.0	149.5	150.1	149.5	**150.9**	147.9	149.4	**149.9**	143.0	149.9	**152.7**	151.2	149.6	149.8	**153.4**
Fluorescence		27.8	26.3	24.8	25.1	**27.2**	26.5	25.2	**25.6**	25.4	26.4	**27.5**	27.3	26.4	26.5	**27.6**
Fluorescence, C		14.9	13.5	12.9	12.7	**14.0**	13.7	12.8	**15.1**	13.14	13.6	**14.1**	14.2	13.5	13.6	**14.20**
Yellowness		-24.8	-22.9	-23.3	-22.9	**-25.4**	-24.4	-23.1	**-23.6**	-21.8	-22.9	**-26.5**	-25.7	-22.9	-24.7	**-25.7**
L*		97.4	97.1	97.0	95.6	**96.1**	96.1	95.2	**95.5**	96.6	97.3	**96.2**	96.1	97.1	96.1	**96.6**
a*		3.42	3.50	3.65	3.61	**3.46**	2.81	3.59	**3.62**	2.31	3.51	**3.63**	3.39	3.52	3.64	**3.83**
b*		-13.5	-13.4	-13.4	-12.5	**-13.7**	-12.2	-12.4	**-12.7**	-11.6	-13.5	**-13.7**	-13.8	-13.4	-13.4	**-14.0**
Opacity, %		85.0	85.1	85.8	86.0	**86.4**	85.8	86.4	**85.3**	86.0	85.1	**85.8**	86.1	85.1	86.0	**85.2**
S. Coeff., m^2/kg		49.0	49.0	50.1	50.0	**49.4**	49.9	50.8	**50.1**	50.1	49.0	**49.6**	50.2	49.0	50.8	**49.5**

Table 60: Best combinations of OWAs at size press and wet-end with 21% ash level of Talc

DS2 wet-end, kg/t		10	6				
OWA in surface sizing, kg/t	Type	--	TS3	DS2	TS1	TS2	HS1
	Dose, kg/t	--	2	2	2	2	2
ISO Brightness, %		99.4	98.5	96.7	98.2	**98.7**	**99.1**
B. brightness, %		84.3	83.1	83.0	83.4	**83.4**	**83.6**
CIE Whiteness		149.2	152.4	146.0	154.5	**154.4**	**155.8**
Fluorescence		26.5	28.2	26.4	27.5	**27.8**	**27.9**
Fluorescence, C		15.1	15.4	13.7	14.8	**15.3**	**15.5**
Yellowness		-23.4	-26.5	-23.6	-26.2	**-26.9**	**-27.0**
L*		96.2	96.1	95.9	96.0	**95.9**	**96.1**
a*		3.49	3.68	2.47	3.59	**3.62**	**3.72**
b*		-13.92	-14.44	-12.87	-14.29	**-14.89**	**-14.99**

Table 61: Best combinations of OWAs at size press and wet-end with 21% ash level of talc

TS3 at wet-end, kg/t		**10**	**6**				
OWA in surface sizing, kg/t	**Type**	**0**	**TS3**	**DS2**	**TS1**	**TS2**	**HS1**
	Dose, kg/t		**2**	**2**	**2**	**2**	**2**
ISO Brightness, %		99.0	97.8	95.4	98.1	**97.8**	**98.1**
B. brightness, %		85.1	83.4	83.0	83.4	**83.2**	**83.6**
CIE Whiteness		148.9	147.9	146.2	148.2	**147.9**	**148.8**
Fluorescence		26.4	25.4	24.8	25.6	**25.4**	**25.9**
Fluorescence, C		13.9	14.4	12.4	15.1	**14.6**	**14.5**
Yellowness		-23.3	-23.0	-22.5	-23.6	**-23.4**	**-23.2**
L*		96.5	95.8	95.4	95.5	**95.6**	**95.2**
a*		3.49	3.64	3.49	3.62	**3.51**	**3.51**
b*		-12.8	-12.6	-12.3	-12.7	**-12.5**	**-12.8**

Table 62: Best combinations of OWAs with DS1 at size press and wet-end with 21% ash level of Talc

DS1 wet-end, kg/t		12	8			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	2	2	2	4
ISO Brightness, %		100.0	97.6	98.1	98.2	99.4
B. brightness, %		85.1	83.7	84.5	84.0	85.2
CIE Whiteness		152.0	150.9	149.9	152.7	153.4
Fluorescence		27.8	27.2	25.6	27.5	27.6
Fluorescence, C		14.9	14.0	15.1	14.1	14.2
Yellowness		-24.8	-25.4	-23.6	-26.5	-25.7
L*		97.4	96.1	95.5	96.2	96.6
a*		3.42	3.46	3.62	3.63	3.83
b*		-13.5	-13.7	-12.7	-13.8	-14.0

With PCC filler

Table 63: Optimization of different OWAs at wet-end

OWA	DS2					TS3					DS1			
Dose, kg/t	**nil**	**4**	**7**	**10**	**12**	**4**	**7**	**9**	**13**	**15**	**4**	**6**	**10**	**12**
ISO Brightness, %	87.5	96.8	100.8	**101.5**	100.1	96.5	98.2	100.2	**101.0**	100.1	97.8	101.5	**101.8**	100.9
B. brightness, %	86.8	87.4	87.5	**87.9**	87.3	87.2	87.1	87.5	**87.1**	88.0	87.9	88.2	**88.2**	87.9
CIE Whiteness	80.6	145.4	153.4	**153.9**	150.1	142.2	144.6	147.8	**149.2**	148.2	149.2	153.2	**154.2**	152.3
Fluorescence	0.70	22.9	26.3	**26.4**	25.7	23.1	22.9	23.3	**23.4**	22.5	26.3	26.2	**26.4**	26.9
Fluorescence, C	0.70	9.40	13.3	**13.6**	12.8	9.3	11.1	12.7	**13.9**	12.1	9.9	13.3	**13.6**	13.0
Yellowness	4.29	-21.4	-24.5	**-24.5**	-24.0	-19.5	19.9	-21.7	**-22.0**	-21.3	-23.5	-24.4	**-23.9**	-22.9
L*	95.5	96.9	97.4	**97.4**	97.3	95.2	95.6	97.5	**97.2**	97.1	97.8	97.6	**97.5**	96.8
a*	0.24	3.78	4.11	**4.12**	3.02	4.12	3.95	4.01	**4.02**	4.01	3.92	3.96	**3.95**	3.96
b*	2.14	-12.0	-13.7	**-13.7**	-13.2	-12.1	-12.4	-12.3	**-11.9**	-11.2	-13.5	-13.6	**-13.3**	-13.2
Opacity, %	89.9	89.6	89.5	**90.9**	90.2	89.6	89.5	90.9	**90.2**	90.0	88.2	88.9	**88.2**	88.3
S. Coeff., m^2/kg	75.4	75.6	75.9	**75.7**	75.8	75.6	75.9	75.7	**75.8**	76.2	79.6	78.2	**77.9**	77.8

Split addition of OWAs in wet-end surface sizing

Table 64: Effect of different OWA in surface sizing with DS2 addition of 7 kg/t at wet-end

DS2 at wet-end, kg/t		10	7												
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			TS1			TS2			HS1		
	Dose, kg/t				1	2	4	1	2	4	1	2	4	1	2	4
ISO Brightness, %		101.5	100.8	100.6	101.2	**101.8**	102.0	100.9	101.4	**101.7**	101.2	**101.9**	101.5	**100.7**	101.0	100.2
B. brightness, %		87.9	87.5	87.3	87.6	**87.8**	87.7	87.7	87.6	**87.5**	87.4	**87.4**	86.8	**86.1**	86.5	85.6
CIE Whiteness		153.9	153.4	153.6	154.1	**156.1**	155.5	153.7	154.1	**154.3**	156.7	**157.7**	156.5	**154.8**	156.8	156.6
Fluorescence		26.4	26.3	25.2	26.2	**27.2**	27.1	26.4	27.1	**27.4**	27.4	**28.6**	28.5	**26.8**	28.1	28.6
Yellowness		-24.5	-24.5	-24.8	-25.1	**-25.8**	-25.6	-24.9	-25.1	**-25.4**	-25.9	**-26.5**	-26.1	**-26.4**	-26.9	-26.4
L*		97.4	97.4	97.2	97.2	**97.5**	97.5	97.4	97.7	**97.9**	97.3	**97.6**	97.4	**97.2**	96.8	97.2
a*		4.12	4.11	4.15	4.15	**4.17**	4.19	4.16	4.18	**4.19**	4.22	**4.33**	4.08	**4.40**	4.05	4.40
b*		-13.7	-13.7	-13.7	-13.9	**-14.3**	-14.1	-13.8	-13.9	**-13.8**	-14.1	**-14.7**	-14.4	**-14.6**	-14.6	-14.6
Opacity, %		90.9	89.5	88.2	88.1	**88.5**	88.4	88.0	88.5	**88.3**	88.2	**88.4**	88.9	**88.5**	88.7	88.5
S. Coeff., m^2/kg		75.7	75.9	75.8	75.1	**74.9**	75.6	74.9	76.1	**75.4**	76.1	**76.0**	75.8	**75.8**	75.9	75.8

Table 65: Effect of different OWA in surface sizing with TS3 addition of 9 kg/t at wet-end

TS3 at wet-end, kg/t		13	9													
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			TS1			TS2			HS1		
	Dose, kg/t				1	2	4	1	2	4	1	2	4	1	2	4
ISO Brightness, %		101.0	100.2	100.1	100.8	101.4	**101.7**	100.6	101.1	**101.3**	101.0	**101.7**	101.4	100.6	101.1	**101.8**
B. brightness, %		87.1	87.5	87.2	87.6	87.6	**87.8**	88.0	88.0	**88.1**	87.3	**87.7**	87.4	88.2	88.1	**88.3**
CIE Whiteness		149.2	147.8	148.5	152.7	156.7	**156.8**	150.8	151.5	**151.8**	155.2	**157.6**	157.2	151.7	153.7	**156.7**
Fluorescence		23.4	23.3	23.1	25.5	27.5	**28.2**	24.3	25.3	**26.3**	26.9	**27.8**	27.5	24.5	25.5	**26.9**
Yellowness		-22.0	-21.7	-21.2	-22.9	-24.9	**-25.1**	-22.9	-23.6	**-23.9**	-24.2	**-26.5**	-26.5	-23.6	-24.4	**-25.7**
L*		97.2	97.5	97.2	97.2	97.5	**97.8**	97.5	97.6	**97.8**	97.2	**97.6**	97.5	97.2	97.5	**97.6**
a*		4.02	4.01	4.05	4.12	4.30	**4.35**	4.10	4.15	**4.21**	4.30	**4.47**	4.34	4.19	4.30	**4.40**
b*		-11.9	-12.3	-12.4	-13.1	-13.6	**-14.3**	-12.8	-13.0	**-13.1**	-14.3	**-14.6**	-14.5	-13.5	-13.7	**-14.3**
Opacity, %		90.2	90.9	90.9	90.1	89.6	**89.7**	90.1	90.4	**90.3**	90.1	**90.3**	90.5	90.3	90.8	**90.0**
S. Coeff., m^2/kg		75.8	75.7	76.1	76.2	76.1	**76.0**	76.0	76.5	**76.2**	76.0	**76.2**	76.5	76.2	76.2	**76.5**

Table 66: Effect of different OWA in surface sizing with DS1 addition of 6 kg/t at wet-end

DS1 at wet-end, kg/t		10	6														
OWA in surface sizing, kg/t	Type	0	0	Only starch	TS3			TS1			TS2				HS1			
	Dose, kg/t				1	2	4	1	2	4	1	2	4	5	1	2	4	5
ISO Brightness, %		101.8	101.2	101.2	101.6	**102.1**	102.0	101.2	**101.4**	101.0	101.8	102.2	**102.5**	101.7	**102.6**	102.0	102.2	102.0
B. brightness, %		88.2	88.2	88.1	88.1	**88.2**	88.1	88.0	**87.0**	87.0	88.2	88.4	**88.7**	88.6	**88.0**	88.2	87.8	88.1
CIE Whiteness		154.2	153.2	153.6	153.8	**154.8**	154.6	153.9	**154.2**	153.9	153.9	155.4	**156.3**	154.3	**154.2**	155.1	156.9	154.7
Fluorescence		26.4	26.2	25.9	26.2	**27.3**	27.2	26.5	**27.8**	27.4	26.1	26.9	**27.6**	26.3	**26.4**	26.9	28.1	26.2
Yellowness		-23.9	-24.4	-24.3	-24.5	**-25.0**	-24.8	-24.6	**-24.8**	-24.7	-24.3	-25.3	**-25.6**	-25.4	**-24.6**	-25.1	-26.1	-24.6
L*		97.5	97.6	97.4	97.6	**97.8**	97.8	97.5	**97.6**	97.5	97.5	97.7	**97.9**	97.4	**97.5**	97.7	97.7	97.4
a*		3.95	3.96	3.98	3.99	**4.05**	4.04	3.99	**4.11**	4.01	4.02	4.05	**4.02**	4.02	**3.99**	4.02	4.09	3.98
b*		-13.2	-13.5	-13.5	-13.6	**-13.8**	-13.6	-13.4	**-13.5**	-13.4	-13.7	-14.1	**-14.1**	-13.8	**-13.8**	-13.9	-14.4	-13.9
Opacity, %		88.2	88.9	88.7	88.5	**88.5**	88.6	88.2	**88.0**	88.9	88.5	88.2	**88.0**	88.4	**88.2**	88.5	88.6	88.2
S. Coeff., m^2/kg		77.9	78.2	78.6	78.2	**77.9**	78.6	78.2	**78.3**	78.9	78.2	78.9	**78.6**	78.2	**79.1**	78.6	78.9	79.0

Table 67: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

DS2 at wet-end, kg/t		**10**	**7**			
OWA in surface sizing, kg/t	**Type**	**nil**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t		**4**	**4**	**2**	**2**
ISO Brightness, %		101.5	102.0	101.7	**101.9**	101.0
B. brightness, %		87.9	87.7	87.5	**87.4**	86.5
CIE Whiteness		153.9	155.5	154.3	**157.7**	156.8
Fluorescence		26.4	27.1	27.4	**28.6**	28.1
Yellowness		-24.5	-25.6	-25.4	**-26.5**	-26.4
L*		97.4	97.5	97.9	**97.6**	97.2
a*		4.12	4.19	4.19	**4.33**	4.40
b*		-13.7	-14.1	-13.8	**-14.7**	-14.6

Table 68: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

TS3 wet-end, kg/t		**13**	**9**			
OWA in surface sizing, kg/t	**Type**	**--**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**4**	**4**	**2**	**4**
ISO Brightness, %		101.0	101.7	101.3	101.7	101.8
B. brightness, %		87.1	87.8	88.1	87.7	88.3
CIE Whiteness		149.2	156.8	151.8	157.6	156.7
Fluorescence		23.4	28.2	26.3	27.8	26.9
Yellowness		-22.0	-25.1	-23.9	-26.5	-25.7
L*		97.2	97.8	97.8	97.6	97.6
a*		4.02	4.35	4.21	4.47	4.40
b*		-11.9	-14.3	-13.1	-14.6	-14.3

Table 69: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

DS1 wet-end, kg/t		10	6			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	2	2	4	4
ISO Brightness, %		101.8	102.1	101.4	102.5	102.2
B. brightness, %		88.2	88.2	87.0	88.7	87.8
CIE Whiteness		154.2	154.8	154.2	156.3	156.9
Fluorescence		26.4	27.3	27.8	27.6	28.1
Yellowness		-23.9	-25.0	-24.8	-25.6	-26.1
L*		97.5	97.8	97.6	97.9	97.7
a*		3.95	4.05	4.11	4.02	4.09
b*		-13.3	-13.9	-13.5	-14.1	-14.4

CHAPTER – 3

Recycled pulp

(RCL)

RESULTS & DISCUSSION

3 Effect of different OWAs in wet-end and in surface sizing application (At 21% ash level using different fillers)

Study was done using bleached recycled pulp and each OWA after dose optimization at wet-end was fixed for wet-end addition while other OWAs were added in surface sizing at different doses followed by selection of best combination of that particular OWA at wet-end with other OWAs at surface sizing on the basis of cost reduction without compromising the optical properties of paper.

3.1 With GCC filler

3.1.1 Optimization of different OWAs at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 86.0, whiteness was 114.8 and fluorescence was 14.36. At minimum dose of 3 kg/t of DS2 the brightness was 87.6%, CIE whiteness and fluorescence was 128.2 and 19.36 respectively. The optimum dose was 8 kg/t at which brightness was 91.02%, CIE whiteness and fluorescence was 139.2 and 21.55 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 3 kg/t of TS3 the brightness was 87.2%, CIE whiteness and fluorescence was 130.1 and 17.11 respectively. The optimum dose was 8 kg/t at which brightness was 89.9%, CIE whiteness and fluorescence was 139.5 and 20.67 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. At maximum dose of 10 kg/t of TS3 the brightness was reduced to 89.4%, CIE whiteness and fluorescence was 138.2 and 19.85 respectively. DS1 was added in wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 88.1%, CIE whiteness and fluorescence was 134.5 and 20.12 respectively. The optimum dose was 11 kg/t at which brightness was 91.3%, CIE whiteness and fluorescence was 142.8 and 24.38 respectively. On further increasing the dose beyond 11 kg/t the reduction in values of brightness whiteness, a* and b* was observed. At this dose, the brightness was reduced to 90.9%, CIE whiteness and fluorescence was 140.1 and 24.21 respectively as shown in Table 70.

3.1.2 Split addition of OWAs in wet-end and surface sizing

3.1.2.1 Effect of different OWA in surface sizing with DS2 addition of 5 kg/t at wet-end

TS3 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 89.6%, CIE whiteness and fluorescence was 138.2 and 22.92 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 90.7%, CIE whiteness and fluorescence was 141.2 and 24.98 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness was 90.4%, CIE whiteness and fluorescence was 140.9 and 24.67 respectively. TS1 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 89.3%, CIE whiteness and fluorescence was 138.1 and 23.62 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.6%, CIE whiteness and fluorescence was 139.5 and 24.67 respectively. TS2 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 89.1%, CIE whiteness and fluorescence was 138.2 and 23.81 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 89.9% and CIE whiteness was 140.3 and fluorescence was 24.85. On further increasing the dose of TS2 to 5 kg/t, the reduction in optical properties was observed. DS1 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 89.5%, CIE whiteness and fluorescence was 138.9 and 23.90 respectively. The optimum dose of DS1 in surface sizing was 4 kg/t on which the brightness was 90.8% and CIE whiteness was 143.68 and fluorescence was 26.18. On further increasing the dose of DS1 to 5 kg/t, the reduction in optical properties was observed as shown in Table 71.

3.1.2.2 Effect of different OWA in surface sizing with TS3 addition of 5 kg/t at wet-end

TS3 was added in surface sizing along with 5 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 89.0%, CIE whiteness and fluorescence was 137.2 and 21.23 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 89.5%, CIE whiteness and fluorescence was 139.5 and 23.62 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 88.9%, CIE whiteness and fluorescence was 141.1 and 24.30 respectively. TS1 was added in surface sizing along with 5 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 88.9%, CIE whiteness and fluorescence was 135.9 and 21.16 respectively. The optimum dose of TS1 in surface sizing was 4 kg/t. On further increasing the dose of TS1 to 5 kg/t, the reduction in optical properties was observed. TS2 was added in surface sizing along with 5 kg/t of TS3 at

wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 89.1%, CIE whiteness and fluorescence was 136.2 and 21.31 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 89.9% and CIE whiteness was 141.4 and fluorescence was 26.64. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 89.1%, CIE whiteness and fluorescence was 137.8 and 24.38 respectively. HS1 was added in surface sizing along with 5 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 89.1%, CIE whiteness and fluorescence was 138.2 and 20.98 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t, on which brightness was 90.6, whiteness and fluorescence was 145.4 and 26.24 respectively. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 72.

3.1.2.3 Effect of different OWA in surface sizing with DS1 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 89.5%, CIE whiteness and fluorescence was 138.1 and 24.10 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 90.8%, CIE whiteness and fluorescence was 142.9 and 26.12 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 90.2%, CIE whiteness and fluorescence was 140.3 and 25.83 respectively. TS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 89.6%, CIE whiteness and fluorescence was 138.9 and 24.90 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 88.6%, CIE whiteness and fluorescence was 137.9 and 25.23 respectively. TS2 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 89.4%, CIE whiteness and fluorescence was 138.1 and 24.10 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 90.7% and CIE whiteness was 142.9 and fluorescence was 25.63. On further increasing the dose of TS2 to 5 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 89.5%, CIE whiteness and fluorescence was 138.6 and 24.13 respectively. The optimum dose of HS1 in surface sizing was 3 kg/t. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 73.

3.1.3 Best Combinations of different OWAs at wet and size press

3.1.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 8 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.0% and CIE whiteness and fluorescence were 139.2 and 21.55 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 5 kg/t of DS2 at wet-end with 3 kg/t of TS3 in surface sizing, 5 kg/t of DS2 at wet-end with 3 kg/t of TS1 in surface sizing, 5 kg/t of DS2 in wet-end and 4 kg/t of TS2 in surface sizing, 5 kg/t of DS2 in wet-end along with 4 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 5kg/t of DS2 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 74.

3.1.3.2 TS3 at wet-end with different OWAs at size press

Adding TS3 at a dose of 8 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 89.9% and CIE whiteness and fluorescence were 139.4 and 20.67 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 5 kg/t of TS3 at wet-end with 3 kg/t of TS3 in surface sizing, 5 kg/t of TS3 at wet-end with 4 kg/t of TS1 in surface sizing, 5 kg/t of TS3 in wet-end and 4 kg/t of TS2 in surface sizing, 5 kg/t of TS3 in wet-end along with 4 kg/t of HS1 in surface sizing. The best combination among all these was addition of 5 kg/t of TS3 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 75.

3.1.3.3 DS1 at wet-end with different OWAs at size press

Adding DS1 at a dose of 11 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.3% and CIE whiteness and fluorescence were 142.8 and 24.38 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations were 67kg/t of DS1 at wet-end with 3 kg/t of TS3 in surface sizing, 7 kg/t of DS1 at wet-end with 3 kg/t of TS1 in surface sizing, 7 kg/t of DS1 in wet-end and 4 kg/t of TS2 in surface sizing, 7 kg/t of DS1 in wet-end along with 3 kg/t of HS1 in surface sizing. The best combination among all these was addition of 7 kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 76.

3.2 With Talc filler

3.2.1 Optimization of DS2 at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 83.5, whiteness was 110.2 and fluorescence was 13.49. At minimum dose of 4 kg/t of DS2 the brightness was 85.9%, CIE whiteness and fluorescence was 130.1 and 20.12 respectively. The optimum dose was 9 kg/t at which brightness was 87.3%, CIE whiteness and fluorescence was 138.8 and 21.94 respectively. On further increasing the dose beyond 9 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 4 kg/t of TS3 the brightness was 85.9%, CIE whiteness and fluorescence was 128.1 and 18.4 respectively. The optimum dose was 9 kg/t at which brightness was 86.8%, CIE whiteness and fluorescence was 138.6 and 20.11 respectively. On further increasing the dose to 12 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. DS1 was added in wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 86.8%, CIE whiteness and fluorescence was 130.1 and 19.12 respectively. The optimum dose was 11 kg/t at which brightness was 88.2%, CIE whiteness and fluorescence was 137.6 and 23.32 respectively as shown in Table 77

3.2.2 Split addition of OWAs in wet-end and surface sizing

3.2.2.1 Effect of different OWA in surface sizing with DS2 addition of 6 kg/t at wet-end

DS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS2 the brightness was 86.4%, CIE whiteness and fluorescence was 133.4 and 21.3 respectively. The optimum dose of DS2 in surface sizing was 3 kg/t at which brightness was 87.1%, CIE whiteness and fluorescence was 137.9 and 24.4 respectively. On further increasing the dose of DS2 to 4 kg/t, the reduction in optical properties was observed. TS1 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 2 kg/t of TS1 the brightness was 86.9%, CIE whiteness and fluorescence was 136.1 and 22.19 respectively. The optimum dose of TS1 in surface sizing was 4 kg/t. On further increasing the dose of TS1 to 5 kg/t, the reduction in optical properties was observed. TS2 was added in surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 86.3%, CIE whiteness and fluorescence was 134.2 and 21.3 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 86.9% and CIE whiteness was 138.9 and fluorescence was 24.9. On further increasing the dose of TS2 to 3 kg/t, the reduction in optical properties was observed. The brightness was 98.0%, CIE whiteness and fluorescence was 152.8 and 27.9 respectively. DS2 was added in

surface sizing along with 6 kg/t of DS2 at wet-end. At minimum dose of 2 kg/t of DS2 the brightness was 87.3%, CIE whiteness and fluorescence was 137.4 and 24.7 respectively. The optimum dose of DS2 in surface sizing was 2 kg/t. On further increasing the dose of HS1 to 3 kg/t, the reduction in optical properties was observed as shown in Table 78.

3.2.2.2 Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 86.4%, CIE whiteness and fluorescence was 133.9 and 22.16 respectively. The optimum dose of TS3 in surface sizing was 2 kg/t at which brightness was 86.9%, CIE whiteness and fluorescence was 138.9 and 23.54 respectively. On further increasing the dose of TS3 to 4 kg/t the reduction in optical properties was observed. TS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 86.3%, CIE whiteness and fluorescence was 133.4 and 20.92 respectively. The optimum dose of TS1 in surface sizing was 4 kg/t on which the brightness was 86.7% and whiteness and fluorescence was 137.9 and 23.38. TS3 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 2 kg/t of TS2 the brightness was 86.4%, CIE whiteness and fluorescence was 135.3 and 22.3 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 86.7 %and CIE whiteness was 138.2 and fluorescence was 23.36. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 86.6 %, CIE whiteness and fluorescence was 137.5 and 23.26 respectively. HS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 86.1%, CIE whiteness and fluorescence was 133.9 and 22.20 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t, on which brightness was 87.3, whiteness and fluorescence was 139.9 and 25.17 respectively. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 79.

3.2.2.3 Effect of different OWA in surface sizing with DS1 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 87.5%, CIE whiteness and fluorescence was 135.2 and 23.32 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 88.1%, CIE whiteness and fluorescence was 88.1 and 24.15 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness reduced to 88.0%, CIE whiteness and fluorescence was 136.2 and 23.35 respectively. TS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 87.4%, CIE

whiteness and fluorescence was 135.1 and 23.25 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 87.1%, CIE whiteness and fluorescence was 133.0 and 23.10 respectively. TS2 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 87.5%, CIE whiteness and fluorescence was 135.5 and 23.26 respectively. The optimum dose of TS2 in surface sizing was 2 kg/t on which the brightness was 87.9% and CIE whiteness was 134.2 and fluorescence was 24.66. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. The brightness was reduced to 86.9%, CIE whiteness and fluorescence was 134.3 and 23.21 respectively. HS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 87.4%, CIE whiteness and fluorescence was 136.1 and 23.56 respectively. The optimum dose of HS1 in surface sizing was 3 kg/t. On which the brightness was 88.2 and whiteness and fluorescence was 138.5 and 25.12 as shown in Table 80.

3.2.3 Best Combinations of different OWAs at wet and size press

3.2.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 9 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 87.3 %and CIE whiteness and fluorescence were 138.8 and 21.9 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 6 kg/t of DS2 at wet-end with 3 kg/t of TS3 in surface sizing, 6 kg/t of DS2 at wet-end with 4 kg/t of TS1 in surface sizing, 6 kg/t of DS2 in wet-end and 2 kg/t of TS2 in surface sizing, 6 kg/t of DS2 in wet-end along with 2 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction in cost. The best combination among all these was addition of 6kg/t of DS2 at wet-end and 2 kg/t of HS1 in surface sizing along with comparable optical properties as shown in table 81.

3.2.3.2 Best combinations of different OWAs at surface sizing with TS3 at wet-end

Adding TS3 at a dose of 9 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 86.8% and CIE whiteness and fluorescence were 138.6 and 20.11 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 6 kg/t of TS3 at wet-end with 2 kg/t of TS3 in surface sizing, 6 kg/t of TS3 at wet-end with 4kg/t of TS1 in surface sizing, 6 kg/t of TS3 in wet-end and 3 kg/t of TS2 in surface sizing, 6 kg/t of TS3 in wet-end along with 4 kg/t of HS1

in surface sizing. The best combination among all these was addition of 6kg/t of TS3 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 82.

3.2.3.3 Best combinations of different OWAs at surface sizing with DS1 at wet-end

Adding DS1 at a dose of 11 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 88.2% and CIE whiteness and fluorescence were 137.6 and 23.32 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations with 7 kg/t of DS1 at wet-end were 3 kg/t of TS3, 3 kg/t of TS1, 2 kg/t of TS2 and 3 kg/t of HS1 in surface sizing. The best combination among all these was addition of 7kg/t of DS1 at wet-end and 3 kg/t of TS3 in surface sizing along with comparable optical properties as shown in Table 83.

3.3 With PCC filler

3.3.1 Optimization of DS2 at wet-end

DS2 was added in wet-end at different doses. Without adding DS2 at wet-end the brightness of paper was 86.5, whiteness was 115.8 and fluorescence was 14.36. At minimum dose of 4 kg/t of DS2 the brightness was 88.8%, CIE whiteness and fluorescence was 129.5 and 19.8 respectively. The optimum dose was 8 kg/t at which brightness was 91.8%, CIE whiteness and fluorescence was 140.5 and 21.40 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness whiteness, a* and b* was observed. TS3 was added in wet-end at different doses. At minimum dose of 4 kg/t of TS3 the brightness was 88.1%, CIE whiteness and fluorescence was 128.1 and 16.12 respectively. The optimum dose was 9 kg/t at which brightness was 91.4 %, CIE whiteness and fluorescence was 141.6 and 19.21 respectively. On further increasing the dose to 12 kg/t the reduction in values of brightness, whiteness, a* and b* was observed. DS1 was added at wet-end at different doses. At minimum dose of 4 kg/t of DS1 the brightness was 90.5%, CIE whiteness and fluorescence was 130.1 and 20.12 respectively. The optimum dose was 11 kg/t at which brightness was 91.9%, CIE whiteness and fluorescence was 142.1 and 23.32 respectively. On further increasing the dose beyond 11 kg/t the reduction in values of brightness whiteness, a* and b* was observed as shown in Table 84.

3.3.2 Split addition of OWAs in wet-end and surface sizing

3.3.2.1 Effect of different OWA in surface sizing with DS2 addition of 5 kg/t at wet-end

TS3 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 90.3%, CIE whiteness and fluorescence was 137.5 and 22.45 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 91.3%, CIE whiteness and fluorescence was 142.1 and 24.90 respectively. On further increasing the dose of TS3 to 4 kg/t, the brightness was 91.2%, CIE whiteness and fluorescence was 141.1 and 24.82 respectively. TS1 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 90.2%, CIE whiteness and fluorescence was 136.9 and 21.22 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. The brightness was 91.4%, CIE whiteness and fluorescence was 141.2 and 24.40 respectively. TS2 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 90.4 %, CIE whiteness and fluorescence was 135.6 and 22.90 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 91.7 %and CIE whiteness was 140.3 and fluorescence was 24.42. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 5 kg/t of DS2 at wet-end. At minimum dose of 1 kg/t of DS1 the brightness was 90.5 %, CIE whiteness and fluorescence was 139.1 and 24.12 respectively. The optimum dose of DS1 in surface sizing was 4 kg/t on which the brightness was 92.0 %and CIE whiteness was 143.0 and fluorescence was 25.64. On further increasing the dose of HS1 to 4 kg/t, the reduction in optical properties was observed as shown in Table 85.

3.3.2.2 Effect of different OWA in surface sizing with TS3 addition of 6 kg/t at wet-end

TS3 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 90.0%, CIE whiteness and fluorescence was 140.0 and 18.86 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 91.2%, CIE whiteness and fluorescence was 141.2 and 24.15 respectively. TS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 89.9%, CIE whiteness and fluorescence was 140.1 and 21.12 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. TS2 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 89.7%, CIE whiteness and fluorescence was 140.1 and 21.12 respectively. The optimum dose of TS2 in surface sizing was 4 kg/t on which the brightness was 91.5% and CIE whiteness was 141.9 and fluorescence was 23.9. On further increasing the dose of TS2 to 4

kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 6 kg/t of TS3 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 89.9%, CIE whiteness and fluorescence was 141.2 and 22.10 respectively. The optimum dose of HS1 in surface sizing was 4 kg/t, on which brightness was 91.6, whiteness and fluorescence was 145.4 and 26.10 respectively as shown in Table 86.

3.3.2.3 Effect of different OWA in surface sizing with DS1 addition of 7 kg/t at wet-end

TS3 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS3 the brightness was 91.2%, CIE whiteness and fluorescence was 139.1 and 23.50 respectively. The optimum dose of TS3 in surface sizing was 3 kg/t at which brightness was 91.6%, CIE whiteness and fluorescence was 141.9 and 25.12 respectively. On further increasing the dose of TS3 to 4 kg/t, slight reduction in optical properties was observed. TS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS1 the brightness was 91.2%, CIE whiteness and fluorescence was 139.1 and 24.10 respectively. The optimum dose of TS1 in surface sizing was 3 kg/t. On further increasing the dose of TS1 to 4 kg/t, the reduction in optical properties was observed. TS2 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1 kg/t of TS2 the brightness was 91.2%, CIE whiteness and fluorescence was 140.1 and 23.90 respectively. The optimum dose of TS2 in surface sizing was 3 kg/t on which the brightness was 91.8% and CIE whiteness was 140.9 and fluorescence was 24.95. On further increasing the dose of TS2 to 4 kg/t, the reduction in optical properties was observed. HS1 was added in surface sizing along with 7 kg/t of DS1 at wet-end. At minimum dose of 1.0 kg/t of HS1 the brightness was 91.3%, CIE whiteness and fluorescence was 139.1 and 23.50 respectively. The optimum dose of HS1 in surface sizing was 3 kg/t. On which the brightness was 91.8 and whiteness and fluorescence was 142.5 and 24.90 as shown in Table 87.

3.3.3 Best Combinations of different OWAs at wet and size press

3.3.3.1 DS2 at wet-end with different OWAs at size press

Adding DS2 at a dose of 8 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.8% and CIE whiteness and fluorescence were 140.5 and 21.40 respectively. Various OWAs at different doses were added in surface sizing along with DS2 addition at wet-end. The best combinations were 5 kg/t of DS2 at wet-end with 3 kg/t of TS3 in surface sizing, 5 kg/t of DS2 at wet-end with 3kg/t of TS1 in surface sizing, 5 kg/t of DS2 in wet-end and 4 kg/t of TS2 in surface sizing, 5 kg/t of DS2 in wet-end along with 4 kg/t of HS1 in surface sizing with slight improvement in optical properties along with significant reduction

in cost. The best combination among all these was addition of 7kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties. The reduction is cost at this combination was 494 Rs/t of paper as shown in Table 88.

3.3.3.2 Best combinations of different OWAs at surface sizing with TS3 at wet-end

Adding TS3 at a dose of 9 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.4% and CIE whiteness and fluorescence were 141.6 and 19.21 respectively. Various OWAs at different doses were added in surface sizing along with TS3 addition at wet-end. The best combinations were 6 kg/t of TS3 at wet-end with 3 kg/t of TS3 in surface sizing, 6 kg/t of TS3 in wet-end and 3 kg/t of TS1 in surface sizing, 6 kg/t of TS3 in wet-end along with 4 kg/t of TS2 in surface sizing, 6 kg/t of TS3 in wet-end along with 4 kg/t of HS1 in surface sizing. Addition of 6 kg/t of TS3 in wet-end along with 4 kg/t of TS2 in surface sizing was the best combination among all these along with comparable optical properties as shown in Table 89.

3.3.3.3 Best combinations of different OWAs at surface sizing with DS1 at wet-end

Adding DS1 at a dose of 11 kg/t in wet-end, without addition of any OWA in surface sizing and the brightness was 91.9% and CIE whiteness and fluorescence were 142.1 and 23.32 respectively. Various OWAs at different doses were added in surface sizing along with DS1 addition at wet-end. The best combinations with 7 kg/t of DS1 at wet-end were 3 kg/t of TS3, 3 kg/t of TS1, 3 kg/t of TS2 and 3 kg/t of HS1 in surface sizing. The best combination among all these was addition of 7 kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties as shown in Table 90.

Effect of different OWAs in wet-end and in surface sizing application at 21% ash level using different fillers

With GCC filler

Table 70: Optimization of different OWAs at wet-end

OWA	DS2					TS3				DS1			
Dose, kg/t	**Nil**	**3**	**5**	**8**	**10**	**3**	**5**	**8**	**10**	**4**	**7**	**11**	**13**
ISO Brightness, %	86.0	87.6	89.2	**91.0**	90.9	87.2	88.9	**89.9**	89.4	88.1	89.7	**91.3**	90.9
B. brightness, %	78.9	78.2	79.5	**79.6**	79.2	79.1	79.2	**79.5**	79.4	78.1	78.6	**78.5**	78.4
CIE Whiteness	114.8	128.2	137.2	**139.2**	137.3	130.1	133.5	**139.5**	138.2	134.5	137.8	**142.8**	140.1
Fluorescence	14.4	19.4	21.4	**21.5**	21.5	17.1	19.7	**20.7**	19.8	20.1	24.1	**24.4**	24.2
Yellowness	-11.6	-16.1	-21.3	**-21.4**	-21.3	-16.1	-19.6	**-19.8**	-19.7	-18.9	-22.5	**-22.8**	-22.6
L*	93.8	93.9	94.1	**94.2**	94.2	93.9	94.3	**95.2**	95.9	94.1	94.3	**94.4**	94.3
a*	2.22	2.45	2.93	**2.98**	2.94	2.46	3.05	**3.11**	3.07	2.46	2.52	**2.61**	2.56
b*	-6.60	-8.90	-11.4	**-11.5**	-11.4	-8.9	-10.7	**-11.1**	-11.0	-10.6	-11.8	**-12.0**	-11.9
Opacity, %	87.6	87.2	87.1	**87.3**	87.2	87.7	87.9	**87.8**	87.2	**4**	**7**	**11**	**13**
S. Coeff., m^2/kg	69.2	68.9	68.9	**68.8**	68.9	68.3	67.9	**68.1**	68.2	88.1	89.7	**91.3**	90.9

Split addition of OWAs in wet-end surface sizing

Table 71: Effect of different OWAs in surface sizing

DS2 at wet-end, kg/t		5																	
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**				**TS1**				**TS2**				**HS1**			
	Dose, kg/t			**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
ISO Brightness, %		89.2	89.1	89.6	90.1	**90.7**	90.4	89.3	89.5	**90.5**	89.6	89.3	89.5	**89.9**	89.2	89.5	90.3	90.5	**90.8**	89.7
B. brightness, %		79.5	79.2	79.2	78.93	**78.76**	78.70	78.5	78.6	**78.9**	79.0	78.9	79.22	**79.05**	78.9	79.2	79.42	79.2	**79.3**	79.2
CIE Whiteness		137.2	137.6	138.2	140.61	**141.2**	140.9	138.1	138.2	**141.2**	139.5	138.2	139.5	**140.3**	138.1	138.9	142.51	142.9	**143.7**	138.8
Fluorescence		21.5	21.6	22.9	23.8	**24.9**	24.7	23.6	24.6	**24.7**	24.7	23.81	23.9	**24.9**	23.8	23.9	25.0	25.5	**26.2**	23.9
Yellowness		-21.3	-21.4	-21.5	-23.5	**-23.9**	-23.8	-22.1	-23.1	**-23.4**	-23.4	-23.0	-23.3	**-23.7**	-23.0	-23.5	-24.5	-24.6	**-25.1**	-23.5
L*		94.1	94.2	94.3	94.6	**94.9**	94.7	94.1	94.2	**94.2**	93.1	93.1	93.4	**93.4**	93. 1	94.2	93.5	93.6	**93.7**	-94.2
a*		2.93	2.95	2.99	3.04	**3.14**	2.74	2.49	2.59	**2.64**	2.54	2.85	2.91	**2.69**	2.84	2.96	3.09	3.02	**2.83**	2.95
b*		-11.4	-11.4	-12.1	-12.4	**-12.7**	-12.4	-12.0	-12.4	**-12.5**	-12.2	-12.4	-12.4	**-12.4**	12.3	-12.0	-12.9	-12.9	**-13.0**	-12.0
Opacity, %		87.1	87.2	87.1	87.3	**87.2**	87.2	87.3	87.2	**87.4**	87.4	87.5	87.5	**87.8**	87.6	87.1	87.4	87.6	**87.4**	87.3
S. Coeff., m^2/kg		68.9	68.8	68.2	68.5	**68.9**	68.4	68.2	68.5	**68.4**	68.7	68.7	68.8	**68.5**	68.5	68.5	68.4	68.7	**68.8**	68.4

Table 72: Effect of different OWAs in surface sizing

TS3 at wet-end, kg/t		**5**																	
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**				**TS1**					**TS2**				**HS1**			
	Dose, kg/t			**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
ISO Brightness, %		88.9	88.8	89.0	89.3	**89.5**	88.9	88.9	88.9	89.1	**89.2**	88.7	89.1	89.3	**89.9**	89.1	89.1	89.7	90.2	**90.6**
B. brightness, %		79.2	79.1	79.2	79.62	**79.2**	79.54	78.4	78.1	78.2	**78.8**	78.2	79.1	79.1	**79.3**	78.9	79.1	78.2	78.3	**78.6**
CIE Whiteness		133.5	134.2	137.2	139.1	**139.5**	141.06	135.9	137.9	139.1	**139.3**	136.2	136.2	140.4	**141.4**	137.8	138.2	142.4	144.2	**145.4**
Fluorescence		19.6	20.1	21.2	22.8	**23.6**	24.3	21.1	23.7	24.2	**24.6**	21.9	21.3	23.9	**26.6**	24.3	20.9	24.5	24.9	**26.2**
Yellowness		-19.6	-19.6	-20.9	-22.7	**-22.9**	-23.8	-21.1	-22.9	-23.1	**-23.3**	-22.9	-21.9	-23.6	**-24.0**	-22.9	-20.9	-24.4	-24.9	**-25.8**
L*		94.3	94.3	94.3	94.40	**94.42**	94.55	94.3	94.5	94.52	**94.59**	94.6	94.21	94.31	**94.51**	94.23	94.6	94.36	94.39	**94.51**
a*		3.05	3.06	3.11	3.30	**3.31**	3.00	3.10	3.01	2.96	**2.98**	3.11	3.12	3.18	**2.94**	3.15	3.11	3.25	3.29	**3.24**
b*		-10.6	-10.8	-11.5	-12.1	**-12.3**	-12.5	-10.9	-11.5	-12.1	**-12.1**	-10.8	-11.9	-12.4	**-12.6**	11.9	-11.2	-12.9	-12.9	**-13.5**
Opacity, %		87.9	87.8	87.7	87.2	**87.6**	87.8	87.5	87.6	87.7	**87.8**	87.5	87.2	87.5	**87.6**	87.3	87.5	87.6	87.8	**87.6**
S. Coeff., m^2/kg		67.9	67.5	68.1	67.8	**67.8**	67.7	67.5	67.8	67.7	**67.8**	67.5	67.4	67.6	**67.8**	67.8	67.6	67.6	67.7	**67.8**

Table 73: Effect of different OWAs in surface sizing

DS1 at wet-end, kg/t		7															
OWA in surface sizing, kg/t	Type	0	Only starch	TS3				TS1				TS2			HS1			
	Dose, kg/t			1	2	3	4	1	2	3	4	1	2	4	1	2	3	4
ISO Brightness, %		89.7	89.5	89.5	90.1	**90.8**	90.2	89.6	90.3	**90.4**	88.6	89.4	89.7	**90.7**	89.5	89.7	**91.0**	89.6
B. brightness, %		78.6	79.1	79.2	78.9	**78.5**	78.9	78.9	79.2	**79.1**	78.6	78.5	78.5	**78.5**	79.2	78.9	**79.1**	78.9
CIE Whiteness		137.8	138.1	138.6	141.05	**142.9**	140.3	138.9	140.2	**140.5**	137.9	138.9	138.9	**142.9**	138.6	140.7	**143.1**	139.97
Fluorescence		24.1	24.1	24.1	25.4	**26.1**	25.8	24.9	25.1	**25.1**	25.2	25.4	25.5	**25.6**	24.1	25.6	**26.8**	26.1
Yellowness		-22.5	-22.5	-22.6	-23.9	**-24.1**	-23.7	-22.9	-23.1	**-23.3**	-22.9	-23.7	-23.2	**-23.6**	-22.5	-23.9	**-24.1**	-23.8
L*		94.2	94.2	94.3	94.6	**94.7**	94.7	94.3	94.6	**94.6**	93.2	93.3	93.5	**93.79**	94.24	93.4	**94.6**	93.4
a*		2.52	2.63	2.64	2.67	**2.72**	2.60	2.64	2.64	**2.68**	2.13	2.54	2.59	**2.62**	2.64	2.64	**2.71**	2.29
b*		-11.8	-11.7	-11.8	-12.1	**-12.3**	-12.2	-11.9	-12.1	**-12.1**	-11.7	-12.3	-12.3	**-12.4**	-12.1	-12.4	**-13.1**	-12.2
Opacity, %		87.3	87.4	87.5	87.5	**87.7**	87.5	87.4	87.5	**87.5**	87.6	87.4	87.5	**87.5**	87.5	87.6	**87.4**	87.2
S. Coeff., m^2/kg		69.5	69.2	69.4	69.4	**69.7**	69.4	69.2	69.5	**69.4**	69.4	69.1	69.2	**69.3**	69.9	68.9	**68.9**	68.9

Table 74: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

DS2 wet-end, kg/t		8	5			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	3	3	4	4
ISO Brightness, %		91.0	90.7	90.5	89.9	**90.8**
B. brightness, %		79.6	78.76	78.9	79.05	**79.30**
CIE Whiteness		139.2	141.2	141.2	140.25	**143.68**
Fluorescence		21.55	24.98	24.71	24.85	**26.18**
Yellowness		-21.35	-23.91	-23.43	-23.66	**-25.09**
L*		94.20	94.90	94.20	93.54	**93.69**
a*		2.98	3.14	2.64	2.69	**2.83**
b*		-11.49	-12.69	-12.47	-12.34	**-13.05**

Table 75: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

TS3 at wet-end, kg/t		**8**	**5**			
OWA in surface sizing, kg/t	**Type**	**0**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t		**3**	**4**	**4**	**4**
ISO Brightness, %		89.9	89.5	89.2	89.9	**90.6**
B. brightness, %		79.5	79.2	78.8	79.3	**78.6**
CIE Whiteness		139.4	139.5	139.3	141.4	**145.3**
Fluorescence		20.6	23.6	24.3	26.6	**26.2**
Yellowness		-19.8	-22.9	-23.3	-24.0	**-25.8**
L*		95.2	94.42	94.59	94.51	**94.51**
a*		3.11	3.31	2.98	2.94	**3.24**
b*		-11.1	-12.3	-12.3	-12.6	**-13.5**

Table 76: Best combinations of OWAs at size press and wet-end with 21% ash level of GCC

DS1 at wet-end, kg/t		**11**	**7**			
OWA in surface sizing, kg/t	**Type**	**--**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**3**	**3**	**4**	**3**
ISO Brightness, %		91.3	90.8	90.4	90.7	**91.0**
B. brightness, %		78.5	78.5	79.1	78.5	**79.1**
CIE Whiteness		142.8	142.9	140.5	142.9	**143.1**
Fluorescence		24.4	26.1	25.1	25.6	**26.8**
Yellowness		-22.8	-24.1	-23.3	-23.6	**-24.1**
L*		94.4	94.8	94.7	93.8	**94.6**
a*		2.61	2.72	2.68	2.62	**2.71**
b*		-12.0	-12.3	-12.1	-12.4	**-13.1**

With Talc filler

Table 77: Optimization of different OWAs at wet-end

OWA	DS2					TS3				DS1			
Dose, kg/t	**Nil**	**4**	**6**	**9**	**12**	**4**	**6**	**9**	**12**	**4**	**7**	**11**	**13**
ISO Brightness, %	83.5	85.9	86.5	**87.3**	86.8	85.9	86.3	**86.8**	86.5	86.8	87.5	**88.2**	87.4
B. brightness, %	76.6	76.5	76.4	**76.5**	76.4	76.1	76.7	**76.5**	76.4	76.4	76.7	**76.9**	76.4
CIE Whiteness	110.2	130.1	132.9	**138.8**	136.1	128.1	128.7	**138.6**	137.1	130.1	134.5	**137.6**	133.9
Fluorescence	13.5	20.1	21.7	**21.9**	21.8	18.4	19.14	**20.1**	20.0	19.1	23.2	**23.3**	23.2
Yellowness	-10.4	-18.1	-20.5	**-20.6**	-20.6	-15.1	-18.6	**-18.9**	18.7	-18.1	-21.4	**-21.6**	-21.4
L*	92.9	92.9	92.9	**93.2**	93.1	92.9	93.2	**93.4**	93.3	93.1	93.2	**93.6**	93.1
a*	2.02	2.62	2.82	**2.92**	2.95	2.42	2.89	**2.95**	2.92	2.18	2.26	**2.35**	2.24
b*	-5.96	-9.12	-10.9	**-11.4**	-11.2	-8.42	-10.0	**-10.1**	-10.1	-9.1	-11.1	**-11.6**	-11.0
Opacity, %	82.5	82.3	82.4	**82.3**	82.7	82.4	82.6	**82.7**	82.4	82.6	82.6	**82.4**	82.3
S. Coeff., m^2/kg	46.5	47.1	47.2	**46.9**	46.8	46.1	46.3	**46.5**	46.7	46.5	46.8	**46.2**	46.4

Split addition of OWAs in wet-end surface sizing

Table 78: Effect of different OWAs in surface sizing

DS2 at wet-end, kg/t		6											
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**			**TS1**			**TS2**			**HS1**	
	Dose, kg/t			**1**	**2**	**3**	**4**	**2**	**4**	**1**	**2**	**4**	**2**	**4**
ISO Brightness, %		86.5	86.3	86.4	86.8	**87.1**	86.9	86.9	**87.1**	86.3	**86.9**	86.6	**87.3**	87.2
B. brightness, %		76.4	76.2	76.1	76.8	**76.4**	76.4	76.2	**76.4**	76.1	**76.2**	76.3	**74.6**	74.4
CIE Whiteness		132.9	133.2	133.4	135.5	**137.9**	136.2	136.1	**138.6**	134.2	**138.2**	136.8	**137.4**	137.9
Fluorescence		21.7	20.9	21.3	23.5	**24.4**	24.3	22.19	**24.12**	21.3	**24.9**	24.4	**24.7**	25.46
Yellowness		-20.6	-21.0	-21.2	-22.2	**-22.9**	-22.8	-21.1	**-22.1**	-21.9	**-22.2**	-22.1	**-23.0**	-23.4
L*		92.9	93.0	93.12	93.5	**93.6**	93.5	92.7	**93.2**	93.1	**93.2**	93.1	**92.7**	92.7
a*		2.82	2.91	2.86	2.85	**2.75**	2.55	2.98	**3.12**	2.92	**3.16**	3.06	**2.90**	2.63
b*		-10.9	-10.9	-11.0	-11.6	**-12.0**	-11.8	-11.1	**-11.2**	-11.1.	**-11.6**	-11.4	**-12.0**	-12.1
Opacity, %		82.4	82.2	82.4	82.4	**82.3**	82.5	82.5	**82.3**	82.1	**82.2**	82.2	**82.5**	82.2
S. Coeff., m^2/kg		47.2	46.8	46.5	46.1	**45.9**	47.1	47.1	**46.8**	46.8	**46.9**	46.8	**46.8**	46.8

Table 79: Effect of different OWAs in surface sizing

TS3 at wet-end, kg/t		6															
OWA in surface sizing, kg/t	Type	0	Only starch	TS3				TS1				TS2			HS1			
	Dose, kg/t			1	2	3	4	1	2	3	4	2	3	4	1	2	3	4
ISO Brightness, %		86.3	86.3	86.4	**86.9**	86.4	86.7	86.3	86.4	86.5	**86.7**	86.4	**86.7**	86.6	86.1	86.2	86.4	**87.3**
B. brightness, %		76.7	76.7	76.1	**76.2**	76.1	76.1	76.1	76.2	76.5	**76.8**	76.5	**76.5**	76.4	77.1	77.2	77.1	**77.2**
CIE Whiteness		128.9	129.2	133.9	**138.9**	134.6	137.6	133.4	134.5	135.9	**137.9**	135.3	**138.2**	137.5	133.9	134.6	136.6	**139.9**
Fluorescence		19.1	19.1	22.6	**23.4**	22.2	22.2	20.2	21.2	22.9	**23.3**	22.2	**23.3**	23.2	22.2	22.5	23.9	**25.1**
Yellowness		-18.4	-18.4	-20.2	**-22.6**	-21.8	-21.2	-20.4	-20.5	-21.1	**-22.1**	-21.1	**-22.5**	-22.5	-20.1	-21.9	-22.9	**-24.4**
L*		92.3	92.1	92.3	**93.0**	92.4	92.9	93.0	93.0	93.1	**93.2**	92.4	**93.4**	93.0	91.5	92.7	93.7	**93.4**
a*		2.89	2.92	2.95	**2.99**	2.98	2.98	2.89	2.96	2.96	**2.97**	2.93	**2.95**	2.92	3.03	3.05	3.08	**3.11**
b*		-10.7	-10.8	-11.5	**-11.4**	-11.4	-11.4	-10.8	-10.0	-11.5	**-11.9**	-11.0	**-11.5**	--11.5	-11.5	-11.7	-11.7	**-12.0**
Opacity, %		82.6	82.6	82.6	**82.5**	82.5	82.3	82.3	82.5	82.4	**82.7**	82.6	**82.6**	82.1	82.3	82.4	82.4	**82.3**
S. Coeff., m^2/kg		46.3	46.2	46.5	**46.5**	46.2	46.8	46.2	46.3	46.4	**46.5**	46.5	**46.4**	46.5	46.1	46.2	46.2	**46.7**

Table 80: Effect of different OWAs in surface sizing

DS1 at wet-end, kg/t		7															
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**				**TS1**				**TS2**			**HS1**			
	Dose, kg/t			**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**	**1**	**2**	**3**	**4**
ISO Brightness, %		87.5	87.4	87.5	87.9	**88.1**	88.0	87.4	87.8	**88.0**	87.1	87.5	**87.9**	86.9	87.4	87.6	**88.2**	87.7
B. brightness, %		76.7	76.1	76.1	76.7	**76.8**	76.8	76.2	76.2	**76.8**	76.6	76.7	**76.8**	76.2	76.2	76.4	**76.3**	76.4
CIE Whiteness		134.5	135.1	135.2	136.3	**137.2**	136.2	135.1	135.5	**136.5**	133.0	135.5	**134.2**	134.3	136.1	137.0	**138.5**	136.2
Fluorescence		23.2	23.1	23.3	23.3	**24.1**	23.3	23.2	23.2	**24.1**	23.1	23.2	**24.6**	23.2	23.5	24.6	**25.1**	25.3
Yellowness		-21.4	-21.49	-21.5	-21.5	**-21.6**	-21.5	-21.4	-21.5	**-21.6**	-21.4	-21.5	**-22.6**	-22.2	-22.2	-22.9	**-23.6**	-23.0
L*		93.2	93.3	93.4	93.5	**93.5**	93.4	93.3	93.5	**93.6**	93.3	93.3	**92.5**	92.3	93.4	93.1	**93.5**	92.7
a*		2.26	2.27	2.32	2.32	**2.34**	2.31	2.27	2.30	**2.32**	2.25	2.28	**2.34**	2.26	2.30	2.36	**2.42**	2.32
b*		-11.1	-11.2	-11.3	-11.4	**-11.5**	-11.6	-11.1	-11.4	**-11.6**	-11.2	-11.2	**-11.6**	-11.3	-11.3	-11.7	**-11.6**	-11.7
Opacity, %		82.6	82.3	82.1	82.4	**82.3**	82.4	82.4	82.3	**82.5**	82.4	82.4	**82.3**	82.4	82.1	82.5	**82.4**	82.4
S. Coeff., m^2/kg		46.8	46.5	46.5	46.4	**46.7**	46.5	46.5	46.7	**46.8**	46.7	46.5	**46.6**	46.7	46.5	46.4	**46.5**	46.5

Table 81: Best combinations of OWAs at size press and wet-end with 21% ash level of Talc

DS2 wet-end, kg/t		**9**	**6**			
OWA in surface sizing, kg/t	**Type**	**--**	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**3**	**4**	**2**	**2**
ISO Brightness, %		87.3	87.1	87.1	86.9	**87.3**
B. brightness, %		76.5	76.4	76.4	76.2	**74.6**
CIE Whiteness		138.8	137.9	138.6	138.2	**137.4**
Fluorescence		21.9	24.4	24.12	24.89	**24.69**
Yellowness		-20.6	-22.9	-22.1	-22.4	**-23.0**
L*		93.21	93.6	93.2	93.2	**92.7**
a*		2.92	2.75	3.12	3.16	**2.90**
b*		-11.4	-12.0	-11.2	-11.6	**-12.0**

Table 82: Best combinations of OWAs at size press and wet-end with 21% ash level of Talc

TS3 wet-end, kg/t		**9**	**6**			
OWA in surface sizing, kg/t	**Type**	--	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**2**	**4**	**3**	**4**
ISO Brightness, %		86.8	86.9	86.7	86.7	**87.3**
B. brightness, %		76.5	76.2	76.8	76.5	**77.2**
CIE Whiteness		138.6	138.9	137.9	138.2	**139.9**
Fluorescence		20.11	23.5	23.3	23.3	**25.1**
Yellowness		-18.94	-22.8	-22.1	-22.5	**-24.4**
L*		93.0	93.1	93.1	93.5	**93.4**
a*		2.95	2.99	2.97	2.95	**3.11**
b*		-10.1	-11.9	-11.5	-11.8	**-12.7**

Table 83: Best combinations of OWAs at size press and wet-end with 21% ash level of talc

DS1 wet-end, kg/t		11	7			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	3	3	2	3
ISO Brightness, %		88.2	**88.1**	88.0	87.9	87.7
B. brightness, %		76.9	**76.8**	76.8	76.8	76.4
CIE Whiteness		137.6	**137.2**	136.5	134.2	136.2
Fluorescence		23.3	**24.1**	24.1	24.6	25.3
Yellowness		-21.7	**-21.6**	-21.6	-22.6	-23.0
L*		93.6	**93.5**	93.6	92.5	92.7
a*		2.35	**2.34**	2.32	2.34	2.32
b*		-11.6	**-11.5**	-11.6	-11.6	-11.7

With PCC filler

Table 84: Optimization of DS2 in wet-end

OWA	DS2					TS3				DS1			
Dose, kg/t	**Nil**	**4**	**5**	**8**	**12**	**4**	**6**	**9**	**12**	**4**	**7**	**11**	**13**
ISO Brightness, %	86.5	88.8	89.9	**91.8**	91.6	88.1	89.6	**91.4**	91.2	90.5	91.1	**91.9**	92.7
B. brightness, %	78.9	79.1	79.7	**79.1**	78.9	78.9	79.4	**79.4**	79.5	78.9	79.3	**79.1**	79.2
CIE Whiteness	115.8	129.5	135.4	**140.5**	139.5	128.1	139.6	**141.6**	140.9	130.1	138.5	**142.1**	141.2
Fluorescence	14.3	19.8	21.0	**21.4**	21.1	16.1	18.6	**19.2**	19.1	20.1	23.20	**23.3**	23.2
Yellowness	-11.5	-17.1	-20.0	**-21.4**	-21.3	-15.1	-17.8	**-21.1**	-20.8	--18.9	-21.6	**-22.1**	-22.0
L*	93.7	93.9	94.5	**94.6**	94.4	93.8	94.3	**94.3**	94.6	93.7	94.7	**94.8**	94.7
a*	2.22	2.49	2.75	**2.84**	2.81	2.52	2.80	**2.85**	2.90	2.40	2.47	**2.52**	2.50
b*	-6.6	-9.0	-10.8	**-11.4**	-11.4	-8.71	-9.79	**-11.1**	-11.0	-9.12	-11.5	**-11.5**	-11.5
Opacity, %	88.6	88.5	88.9	**88.8**	88.7	88.1	88.2	**88.7**	88.2	88.4	88.9	**88.3**	88.5
S. Coeff., m^2/kg	69.4	68.9	69.1	**69.2**	69.0	69.2	69.5	**69.3**	69.7	69.3	69.1	**69.5**	69.4

Split addition of OWAs in wet-end surface sizing

Table 85: Effect of different OWAs in surface sizing

DS2 at wet-end, kg/t		5															
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**				**TS1**				**TS2**			**`HS1**			
	Dose, kg/t			**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**	**1**	**2**	**3**	**4**
ISO Brightness, %		89.9	89.8	90.3	90.5	**91.3**	91.2	90.2	90.7	**91.4**	91.1	90.4	91.3	**91.7**	90.5	91.3	91.6	**92.0**
B. brightness, %		79.7	79.8	79.6	78.9	**79.1**	78.9	79.5	79.5	**79.1**	78.9	79.5	78.9	**79.2**	79.1	78.4	79.5	**78.8**
CIE Whiteness		135.4	135.6	137.5	139.3	**142.1**	141.1	136.9	138.1	**141.2**	139.1	138.1	140.5	**140.3**	139.1	141.8	142.1	**143.0**
Fluorescence		21.0	21.1	22.4	23.3	**24.9**	24.8	21.2	23.4	**24.4**	24.3	22.9	24.1	**24.4**	24.1	25.0	25.4	**25.6**
Yellowness		-20.0	-20.1	-21.5	-22.3	**-22.4**	-22.9	-20.2	-21.4	**-22.5**	-22.4	-21.4	-22.9	**-22.8**	-22.9	-23.5	23.6	**-24.0**
L*		94.5	94.6	94.5	94.1	**94.4**	94.3	94.6	94.7	**94.8**	94.7	94.6	94.2	**94.3**	94.6	94.6	94.7	**94.7**
a*		2.75	2.77	2.79	2.91	**2.90**	2.79	2.79	2.81	**2.83**	2.81	2.79	2.84	**2.54**	2.81	2.95	2.85	**2.73**
b*		-10.8	-10.8	-11.1	-11.8	**-11.9**	-11.7	-11.1	-11.4	**-11.9**	-11.8	-11.5	-12.1	**-12.0**	-11.5	-12.4	-12.4	**-12.6**
Opacity, %		88.9	88.9	88.5	88.4	**88.9**	88.2	88.5	88.6	**88.4**	88.3	88.3	88.5	**88.7**	88.1	88.6	88.5	**88.7**
S. Coeff., m^2/kg		69.1	69.2	69.1	69.0	**69.0**	69.2	69.3	69.7	**69.5**	69.1	69.4	69.1	**69.5**	69.5	69.3	69.4	**69.1**

Table 86: Effect of different OWAs in surface sizing

TS3 at wet-end, kg/t		**6**															
OWA in surface sizing, kg/t	**Type**	**0**	**Only starch**	**TS3**				**TS1**				**TS2**			**HS1**			
	Dose, kg/t			**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**	**1**	**2**	**3**	**4**
ISO Brightness, %		89.6	89.5	90.0	90.5	**91.2**	91.1	89.9	90.5	**91.2**	90.9	89.7	90.7	**91.5**	89.9	90.6	91.1	**91.6**
B. brightness, %		79.4	79.1	79.2	79.4	**79.2**	79.2	79.2	79.3	**79.5**	78.34	79.1	78.9	**78.7**	79.2	79.0	79.1	**79.2**
CIE Whiteness		139.6	139.8	140.0	140.1	**141.2**	142.3	140.1	140.5	**141.1**	139.9	140.1	140.8	**141.9**	141.2	142.30	144.1	**145.4**
Fluorescence		18.66	18.86	21.12	23.18	**24.15**	24.77	21.12	23.45	**24.44**	24.34	21.12	23.58	**23.9**	22.10	24.40	25.50	**26.10**
Yellowness		-17.84	-18.15	-20.52	-22.35	**-23.49**	-23.69	-19.90	-21.85	**-22.80**	-22.70	-19.45	-22.41	**-23.52**	-21.45	-23.48	24.10	**-24.88**
L*		94.30	94.32	94.30	94.25	**94.30**	94.32	94.35	94.40	**94.54**	94.44	94.39	94.09	**94.25**	94.35	94.40	94.41	**94.42**
a*		2.80	2.83	2.92	3.11	**3.12**	3.15	2.84	2.86	**2.92**	2.71	2.90	2.95	**2.98**	2.95	3.23	3.24	**3.34**
b*		-9.79	-9.90	-10.19	-11.97	**-12.10**	-12.49	-10.12	-11.52	**-12.10**	-12.07	-10.12	-11.96	**-12.43**	-11.25	-12.53	-12.60	**-12.74**
Opacity, %		88.2	88.3	88.5	88.4	**88.9**	88.2	88.4	88.5	**88.8**	88.1	88.3	88.5	**88.7**	88.2	88.3	88.5	**88.0**
S. Coeff., m^2/kg		69.5	68.9	68.2	68.5	**68.1**	69.4	68.3	68.4	**68.5**	69.1	68.1	68.2	**68.4**	68.2	68.1	68.3	**68.5**

Table 87: Effect of different OWAs in surface sizing

DS1, at wet-end, kg/t		7															
OWA in surface sizing, kg/t	Type	0	Only starch	TS3				TS1				TS2			HS1			
	Dose, kg/t			1	2	3	4	1	2	3	4	1	3	4	1	2	3	4
ISO Brightness, %		91.1	91.1	91.2	91.3	**91.6**	91.4	91.2	91.3	**91.5**	91.1	91.2	91.3	**91.5**	91.3	91.4	**91.8**	91.7
B. brightness, %		79.3	79.1	79.2	79.3	**79.2**	79.1	79.1	79.2	**78.9**	78.9	79.1	79.2	**78.9**	79.2	79.4	**79.1**	78.5
CIE Whiteness		138.5	138.9	139.1	141.3	**141.9**	140.8	139.1	140.2	**142.5**	137.6	139.1	140.2	**142.5**	139.1	139.5	**142.5**	140.5
Fluorescence		23.2	23.3	23.5	24.8	**25.1**	25.4	24.1	24.3	**24.5**	24.3	24.1	24.2	**24.5**	23.5	24.6	**24.9**	24.7
Yellowness		-21.6	-21.7	-22.3	-23.2	**-23.3**	-23.2	-21.7	-21.9	**-22.2**	-22.1	-21.7	-21.9	**-22.2**	-21.7	-22.7	**-23.1**	-23.3
L*		94.7	94.7	94.8	94.9	**94.9**	94.9	94.8	94.9	**94.9**	94.1	94.8	94.9	**94.9**	94.8	93.9	**94.1**	94.0
a*		2.47	2.48	2.52	2.61	**2.70**	2.25	2.49	2.52	**2.53**	2.10	2.49	2.52	**2.53**	2.50	2.54	**2.65**	2.28
b*		-11.5	-11.5	-11.6	-12.2	**-12.3**	-12.1	-11.6	-11.6	**-11.7**	-11.5	-11.6	-11.6	**-11.7**	-11.5	-11.9	**-12.2**	-12.1
Opacity, %		88.9	88.5	88.4	88.3	**88.1**	88.9	88.3	88.2	**88.0**	88.7	88.3	88.2	**88.0**	88.3	88.5	**88.1**	88.7
S. Coeff., m^2/kg		69.1	68.9	68.7	67.9	**68.0**	69.1	68.9	67.7	**68.2**	69.0	68.9	67.7	**68.2**	69.0	67.7	**68.8**	69.2

Table 88: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

DS2 at wet-end, kg/t		8	5			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	3	3	4	4
ISO Brightness, %		91.8	91.3	91.4	91.7	**92.0**
B. brightness, %		79.1	79.1	79.1	79.2	**78.8**
CIE Whiteness		140.5	142.1	141.2	140.3	**143.0**
Fluorescence		21.4	24.9	24.4	24.4	**25.6**
Yellowness		-21.4	-22.4	-22.4	-22.8	**-24.0**
L*		94.6	94.4	94.8	94.4	**94.7**
a*		2.84	2.90	2.83	2.54	**2.73**
b*		-11.4	-11.9	-11.9	-12.0	**-12.6**

Table 89: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

TS3 wet-end, kg/t		**9**	**6**			
OWA in surface sizing, kg/t	**Type**	--	**TS3**	**TS1**	**TS2**	**HS1**
	Dose, kg/t	**--**	**3**	**3**	**4**	**4**
ISO Brightness, %		91.4	91.2	91.2	**91.5**	91.6
B. brightness, %		79.4	79.2	79.5	**78.7**	79.2
CIE Whiteness		141.6	141.2	141.1	**141.9**	145.4
Fluorescence		19.2	24.1	24.4	**23.9**	26.10
Yellowness		-21.1	-23.5	-22.8	**-23.5**	-24.9
L*		94.4	94.3	94.5	**94.2**	94.4
a*		2.85	3.12	2.92	**2.98**	3.34
b*		-11.1	-12.1	-12.1	**-12.4**	-12.7

Table 90: Best combinations of OWAs at size press and wet-end with 21% ash level of PCC

DS1 Powder wet-end, kg/t		11	7			
OWA in surface sizing, kg/t	Type	--	TS3	TS1	TS2	HS1
	Dose, kg/t	--	3	3	3	3
ISO Brightness, %		91.9	91.6	91.5	91.8	**91.8**
B. brightness, %		79.1	79.2	78.9	78.6	**79.1**
CIE Whiteness		142.1	141.9	142.5	140.9	**142.5**
Fluorescence		23.3	25.1	24.5	24.9	**24.9**
Yellowness		-22.1	-23.2	-22.2	-23.0	**-23.1**
L*		94.8	94.9	94.9	94.8	**94.1**
a*		2.52	2.70	2.53	2.52	**2.65**
b*		-11.5	-12.3	-11.6	-12.1	**-12.2**

Identification of new OWAs in place of commercially available OWAs and their effect on optical properties of paper using MHW pulp furnish

4. Identification of new OWAs in place of commercially available OWAs and their effect on optical properties of paper using MHW pulp furnish

4.1 Characterization of OWAs

Two OWAs were identified other than commercially available OWAs and were characterized in terms of e- value. First one was AAMD which was disulphoned OWA having e value of 505 1%/1cm, other OWA was APOH which was hexasulphonated OWA having e value 483 1%/1 cm as shown in Table 91

4.2 Optimization of AAMD in wet-end with GCC at 21% ash level

AAMD was added at wet-end at different doses. At minimum dose of 4 kg/t of AAMD the brightness was 92.6%, CIE whiteness and fluorescence was 136.6 and 20.91 respectively. The optimum dose was 6 kg/t at which brightness was 93.6%, CIE whiteness and fluorescence was 139.5 and 22.83 respectively. On further increasing the dose beyond 8 kg/t the reduction in values of brightness whiteness, a* and b* was observed as shown in Table 92.

4.3 Split addition of OWAs in wet-end surface sizing

AAMD was fixed for wet-end addition at a dose of 4 kg/t while other OWA i.e. APOH were varied at different doses in surface sizing.

4.3.1 Effect of APOH in surface sizing

APOH was added in surface sizing along with 4 kg/t of AAMD at wet-end. At minimum dose of 0.5 kg/t of APOH the brightness was 93.3%, CIE whiteness and fluorescence was 139.0 and 22.12 respectively. The same was the optimum dose of APOH in surface sizing. On further increasing the dose of APOH to 4 kg/t, slight reduction in optical properties was observed as shown in Table93.

It was observed that on adding 0.5 kg /t of APOH which is a hexa-sulphonated OWA in surface sizing along with 4 kg/t of AAMD (Di-sulphonated OWA) at wet-end gives comparable optical properties to that of adding 6 kg/t of AAMD at wet-end.

Identification of new OWAs in place of commercially available OWAs and their effect on optical properties of paper

Table 91: Characterization of different OWAs

Name of OWA (% Solids)	Type of OWA	E-value (1%/1 cm)
AAMD (99.9)	Di- sulphonated	505
APOH (99.9)	Hexa- sulphonated	483

Table 92: Optimization of AAMD in wet-end with GCC at 21% ash level

AAMD, kg/t	4	6	8
ISO Brightness, %	92.6	**93.6**	93.2
B. brightness, %	84.4	**84.5**	84.6
CIE Whiteness	136.6	**139.5**	139.1
Fluorescence	20.9	**22.8**	23.6
Fluorescence, C	10.2	**11.3**	11.6
Yellowness	-19.3	**-20.5**	-20.5
L*	95.3	**95.6**	95.7
a*	3.50	**3.37**	3.06
b*	-10.8	**-11.3**	-11.2
Opacity, %	88.5	**88.6**	88.8
S. Coeff., m2/kg	55.7	**56.2**	57.2

Split addition of OWAs in wet-end surface sizing

Table 93: Effect of APOH in surface sizing

AAMD, kg/t	**4**		
APOH, kg/t	**Only starch**	**0.5**	**1**
ISO Brightness, %	91.9	**93.3**	93.1
B. brightness, %	84.4	**84.5**	84.6
CIE Whiteness	136.9	**139.0**	139.1
Fluorescence	21.0	**22.1**	22.1
Fluorescence, C	10.	**11.0**	11.0
Yellowness	-19.9	**-20.4**	-20.1
L*	94.9	**94.9**	94.9
a*	3.60	**3.63**	3.62
b*	-4.08	**-4.07**	-4.08

Validation studies on selected combination of OWAs at CPPRI

5. Validation of the results carried out by CPPRI with selected OWA on mixed hard wood pulp and different fillers

Studies carried out by ACIRD, six different OBA were used on bleached mixed had wood pulp and bleached bagasse pulp along with GCC and Talc as fillers in various combinations maintaining 21% ash level. CPPRI selected four best combinations and carried out lab experiments at CPPRI laboratory as per details given below:

Table 1: Addition of OWA (DS2) in wet-end application with GCC filler

DS2 at wet-end, kg/t		**6**	
At size press	**OWA**	**-**	
	Dose	**-**	
		Control ACIRD	**Control CPPRI**
Basic ISO Brightness, %		81.8	76.8
ISO Brightness, %		94.4	94.2
CIE Whiteness		138.3	130.6
Fluorescence		22.3	30.1
Fluorescence, C		11.2	13.1
Yellowness		-20.3	-9.9
L*		95.3	94.5
a*		3.12	3.27
b*		-10.9	-6.1
Opacity, %		87.2	79.4
Cost, Rs/t of paper		1530	

5.1 Observations:

1. The B. brightness of control sample (mixed hard wood bleached pulp) taken for experiment at CPPRI was 76.8% ISO, whereas the pulp brightness of control sample was 81.8% at ACIRD.
2. While addition of OWA (DS2) in wet-end @ 6.0 kg/t using GCC as filler maintaining 21% ash in paper achieved an increment of 17.4% brightness at CPPRI against 12.6% brightness at ACIRD.

Table 2: Split addition of OWAs in wet-end and surface sizing application with GCC filler (DS2 at wet-end and TS1 at size press)

DS2 at wet-end, kg/t		**3**	
At size press	**OWA/ Dose, kg/t**	**TS1/ 2**	
		ACIRD	**CPPRI**
Basic ISO Brightness, %		82.6	76.8
ISO Brightness, %		94.6	93.8
CIE Whiteness		141.8	128.0
Fluorescence		22.2	40.5
Fluorescence, C		12.0	11.6
Yellowness		-21.3	-8.61
L*		95.6	94.5
a*		3.45	3.01
b*		-12.2	-5.42
Opacity, %		86.1	82.1
Cost, Rs/t of paper		915 (-615)	

5.2 Observations:

1. The B. brightness of control sample (mixed hard wood bleached pulp) taken for experiment at CPPRI was 76.8 %, whereas the pulp brightness of control sample was 82.6% at ACIRD.
2. While addition of OWA (DS2) in wet-end @ 3.0 kg/t and addition of OWA (TS1) in surface sizing application @ 2.0 kg/t using GCC as filler, maintaining 21% ash in paper achieved an increment of 17.05% brightness at CPPRI against 12.00% brightness at ACIRD along with cost reduction of 615 Rs/t of paper.

Table 3: Addition of OWA (DS2) in wet-end application with talc filler

DS2 at wet-end, kg/t		**8**	
At size press	**OWA**	**-**	
	Dose, kg/t	**-**	
		Control ACIRD	**Control CPPRI**
Basic ISO Brightness, %		79.0	76.8
ISO Brightness, %		91.9	92.1
CIE Whiteness		139.3	128.4
Fluorescence		25.2	46.3
Fluorescence, C		12.9	13.3
Yellowness		-20.6	-9.94
L*		94.3	93.8
a*		3.29	3.13
b*		-11.4	-6.11
Opacity, %		84.7	81.0
Cost, Rs/t of paper		2040	

5.3 Observations:

1. The B. brightness of control sample (mixed hard wood bleached pulp) taken for experiment at CPPRI was 76.8%, whereas the pulp brightness of control sample was 79.0 % at ACIRD.
2. While addition of OWA (DS2) in wet-end @ 8.0 kg/t using talc as filler maintaining 21% ash in paper achieved an increment of 15.35% brightness at CPPRI against 12.9% brightness at ACIRD.

Table 4: Split addition of OWAs in wet-end and surface sizing application with talc filler (DS2 at wet-end and TS2 at size press)

DS2 at wet-end, kg/t		**6**	
At size press	**OWA/ dose, kg/t**	**TS2/ 2**	
		ACIRD	**CPPRI**
Basic ISO Brightness, %		78.1	76.8
ISO Brightness, %		92.2	94.2
`CIE Whiteness		141.0	132.5
Fluorescence		24.3	46.1
Fluorescence, C		14.1	12.6
Yellowness		-21.7	-10.9
L*		94.1	94.2
a*		3.10	3.36
b*		-12.0	-6.64
Opacity, %		83.1	79.3
Cost, Rs/t of paper		1640 (-400)	

5.4 Observations:

1. The B. brightness of control sample (mixed hard wood bleached pulp) taken for experiment at CPPRI was 76.79% ISO, whereas the pulp brightness of control sample was 78.10% at ACIRD.
2. While addition of OWA (DS2) in wet-end @ 6.0 kg/t and addition of OWA (TS2) in surface sizing application @ 2.0 kg/t using talc as filler maintaining 21% ash in paper achieved an increment of 17.37% brightness at CPPRI against 14.1% brightness at ACIRD along with cost reduction of 400 Rs/t of paper

5.5 RESULTS

In all the four sets of experiments carried out at CPPRI shows better results than experiments carried out at ACIRD.

5.6 RECOMMENDATION

It is recommended that the plant trial with the use of selected OWA with suitable filler may be carried out at TNPL/ BILT.

Pre plant trial studies at ACIRD

6. Pre plant trial studies at ACIRD

6.1 Mixed hardwood pulp

A meeting was conducted with BILT personal to discuss the outcome of the project entitled "Achievement of highest brightness and whiteness in cost effective manner through selective addition of OWA at wet-end and size press" (CESS sponsored). Following members were present in the meeting:

ACIRD	BILT, SGU - Yamunanagar
Dr. N.K. Bhardwaj, Joint Director	Mr. M.K. Gupta, Unit Head
Mr. Ashish Sharma, Research Engineer	Mr. Shamim Ahmad, Manager R&D

During the meeting it was decided to carry out lab study using existing plant conditions prior to conducting the plant trial. The best combination of OWAs (in wet-end and size press) optimized in laboratory under this project was tried on two paper grades of BILT unit SGU viz. grade 1 and grade 2 and it was found that there was a cost saving potential of 28-30% to get the comparable optical properties in case of grade 1. The cost saving potential in case of grade 2 was 4-23% to get the comparable optical properties.

In case of paper grade 1, the brightness was 94.5%, whiteness and fluorescence was 146.2 and 25.7. Handsheets of same grammage and ash content was prepared in lab following the same chemical dosage and dosing sequence with comparable optical properties. According to lab findings the best combinations were addition of 5 kg/t of DS2 with 6 kg/t of TS1 and addition of 5 kg/t of DS2 with 6 kg/t of HS1 at wet-end and size press respectively. The optical properties were found slightly superior than that of lab prepared garde 1 paper along with reduction in cost of 660 Rs/t of paper and 690 Rs/t of paper as shown in Table 1.

In case of paper grade 2, the brightness was 90.0%, whiteness and fluorescence was 130.0 and 18.0. Handsheets of same grammage and ash content was prepared in lab following the same chemical dosage and dosing sequence with comparable optical properties. According to lab findings the best combinations were addition of 3 kg/t of TS1 with 2 kg/t of HS1, 3 kg/t of DS1 with 1 kg/t of HS1 and 2 kg/t of DS1 with 2 kg/t of HS1 at wet-end and size press. The optical properties were found comparable along with reduction in cost of 10 Rs/t, 80 Rs/t and 85 Rs/t of paper at the proposed combinations as shown in Table 2.

Table: 1 Lab study on paper grade 1 for PM-2

Paper samples	In mill	In Lab	Best Combination (Proposed)		
OWA	DS2+TS3	DS2+TS3	DS2+TS1	DS2+HS1	DS2+HS1
Dosage, kg/t (wet-end + size press)	5 kg/t + 6 kg/t	5 kg/t + 6 kg/t	**5 kg/t + 6 kg/t**	**5 kg/t + 6 kg/t**	3.5 kg/t + 6 kg/t
ISO Brightness, %	94.5	95.1	**94.9**	**95.4**	95.4
Ash, %	12.6	**12.1**			
B. brightness, %	--	80.4	**80.3**	**80.6**	81.5
CIE Whiteness	146.2	137.6	**141.1**	**146.0**	144.2
Fluorescence	25.7	27.4	**27.6**	**28.1**	26.3
Yellowness	-13.0	-19.9	**-21.3**	**-23.0**	-22.0
L*	--	96.4	**96.1**	**96.0**	96.1
a*	--	1.53	**2.53**	**3.60**	3.65
b*	--	-10.49	**-11.46**	**-12.62**	-12.17
Cost, Rs./t paper	2385	2385	**1725 (-660)**	**1695 (-690)**	1313 **(-1073)**

Table: 2 Lab study on paper grade 2 for PM-2

Paper samples	In mill	In Lab	Best Combination (Proposed)		
OWA	TS1+TS1	TS1+TS1	TS1+HS1	DS1+ HS1	DS1+ HS1
Dosage, kg/t (wet-end + size press)	3+2	3+2	3+2	**3+1**	**2+2**
Ash, %	16.0	**15.0**			
ISO Brightness, %	90.0	92.2	91.8	**91.5**	**90.9**
B. brightness, %	81.1	81.3	81.6	**81.7**	**80.7**
CIE Whiteness	130.0	132.9	130.3	**128.4**	**129.0**
Fluorescence	18.0	21.5	19.9	**19.4**	**20.1**
Yellowness	-21.5	-17.1	-15.9	**-14.6**	**-14.4**
L*	93.5	95.8	95.7	**95.1**	**95.4**
a*	3.96	3.30	3.44	**3.17**	**3.10**
b*	-11.81	-9.76	-9.20	**-8.46**	**-8.37**
Cost, Rs./t paper	375	375	365 **(-10)**	**295 (-80)**	**290 (-85)**

6.2 Study for agro based mill

Pre-trial lab scale study for Satia Industries Ltd. on writing and printing grade of paper was done following the mill conditions and it was found that with the addition of 2 kg/t of DS2 at wet end and 3 kg/t of HS1 at surface sizing the cost saving potential was 8% and by addition of 1.5 kg/t of DS2 at wet end and 5 kg/t of HS1 in surface sizing the cost saving potential was 7% as shown in table 3.

Table 3: Study on writing and printing grade paper

OWA	BMKD at wet end, kg/t	2.5	2.5		2.0		1.5	
	SPPZH at size press, kg/t	0	2	2 (R)	3	3 (R)	5	5 (R)
CIE Whiteness		146.8	149.7	149.1	148.8	148.1	150.3	148.6
Basic brightness, %ISO		79.9	79.5	79.3	79.4	79.5	79.4	79.6
Brightness, %ISO		90.3	90.3	90.8	90.4	90.8	90.8	91.2
L*		92.2	92.1	92.2	92.3	92.3	92.3	92.3
a*		5.30	5.45	5.32	5.38	5.29	5.43	5.28
b*		-14.4	-15.1	-14.9	-14.8	-14.6	-15.1	-14.7
Fluorescence		20.6	22.1	21.9	21.8	21.6	22.4	21.5
Cost, Rs/t of paper		--	742.5		685 (-57.5)		692.5 (-50)	

Demonstration of results in the plant scale

7. Demonstration of results in the plant scale

7.1 Plant scale trial in hardwood based mill

Based on the encouraging lab results obtained at Avantha Centre for Industrial Research & Development (ACIRD), Yamunanagar using different combination of OWAs at wet-end and size press under the project “Achievement of highest brightness and whiteness in cost effective manner through selective addition of OWA at wet-end and size press” sponsored by IPMA, it was proposed to explore the suitability of any one combination of OWAs on plant scale at Ballarpur Industries Ltd. Unit Shree Gopal, Yamunanagar. Prior to carrying out plant scale trial, validation of the results was done at Central Pulp & Paper Research Institute (CPPRI), Saharanpur. The objective of the plant scale trial was to demonstrate the best combination of commercial OWAs at wet-end and size press to reduce the cost of OWAs without compromising the optical properties of paper. The details of the trial are given below:

Paper M/c No. (Production) :	2 (40 TPD)
Pre trial Period:	February 07, 2017 (9 AM) to February 08, 2017 (9 AM) Total 24 hrs
	Trial Period: February 08, 2017 (12 Noon) to February 09, 2017 (11 PM) Total 35 hrs
Total production during trial:	52.5 T
Paper Product/ Grammage:	Paper grade 2/ 90 GSM
Chemical dosage during pre trial period:	OWAs i.e. TS1 @ 3 kg/t at wet-end and 2 kg/t in size press. Rest of the conditions i.e. chemical, doses and dosing points are same
Chemical dosage during trial period :	OWAs i.e. DS1 @ 3 kg/t at wet-end and HS1 @ 1.5 kg/t at size press (i.e. addition of 6 kg of DS1 in batch of 2T pulp at wet-end and 6 kg HS1 in a batch of 4T starch at size press on as such basis)
Chemical Cost (Rs/kg):	TS1 @73.5, DS1 @74.0 and HS1 @67.0

Dosing points:	DS1 in mixing chest at wet-end, HS1 in size Press
Quantity used:	157.5 kg DS1 and 78.8 kg HS1

7.1.1 Observations:

- Different OWAs were characterized in terms of % solids, E value and colloidal charge demand. It was observed that the DS1 was having the highest E value followed by TS1 and HS1. While TS1 was having the highest charge demand followed by HS1 and DS1 as shown in Table 1.
- During pre trial period, the average values of paper brightness, whiteness, yellowness and fluorescence were 89.9, 135.8, -11.3 and 18.5, respectively.
- With the addition of DS1 at a dose of 3 kg/t at wet-end and HS1 at a dose of 1 kg/t at size press improvement in optical properties was observed.
- The average brightness of paper increased from 89.9 to 90.8 %. The occurrence of higher (≥91) brightness values was 45% during trial period while it was nil during pre trial period. (Please refer Figure A and Table 2)
- During the trial the average value of CIE whiteness of paper increased by 1.4 unit i.e. from 135.8 to 137.2. The occurrence of higher (≥137) whiteness values was improved to 65% from 20%. (Please refer Figure B and Table 3)
- In case of yellowness also, the maximum values during the trial were greater than pre trial values. The average paper yellowness reduced from -11.3 to -11.5 as shown in Figure C.
- Fluorescence of paper increased to 18.8 from 18.5. Almost comparable values of fluorescence were observed before and during the trial as shown in Figure D.
- Reduction in cost of Rs 45/t of paper was observed during the trial. The cost of OWAs before the trial was Rs 375.0/t of paper which was reduced to Rs 330.0/t of paper during the trial as shown in Figure F.

Table 1: Characterization of different OWAs

Name of OWA	Type of OWA	% Solids	E-value (1%/1 cm)	Cationic charge demand, µeq/g
			On solids basis	
TS1	Tetra-sulphonated	25.7	496	2575
DS1	Di- sulphonated	22.4	562	2298
HS1	Hexa-sulphonated	20.7	374	2340

Table 2: Number of occurrence in brightness slabs

Brightness slabs	Pre trial	During trial
≥91	0	9 (45%)
≥90<91	6 (40%)	9 (45%)
≥89<90	9 (60%)	2 (10%)

Table 3: Number of occurrence in CIE whiteness slabs

Whiteness slabs	Pre trial	During trial
≥139	0 (0%)	2 (10.0%)
≥138<139	1 (6.7%)	2 (10.0%)
≥137<138	2 (13.3%)	9 (45.0 %)
≥136<137	3 (20.0 %)	3 (15.0%)
≥134<136	9 (60.0%)	4 (20.0%)

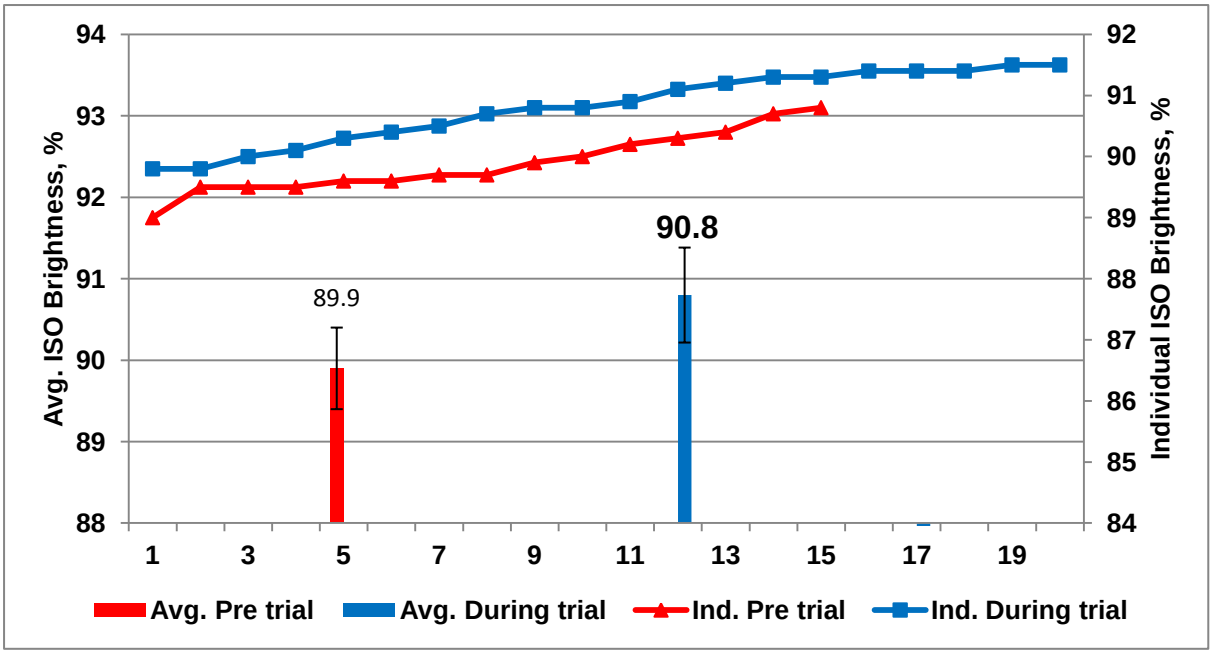

Figure A: Effect on brightness of paper

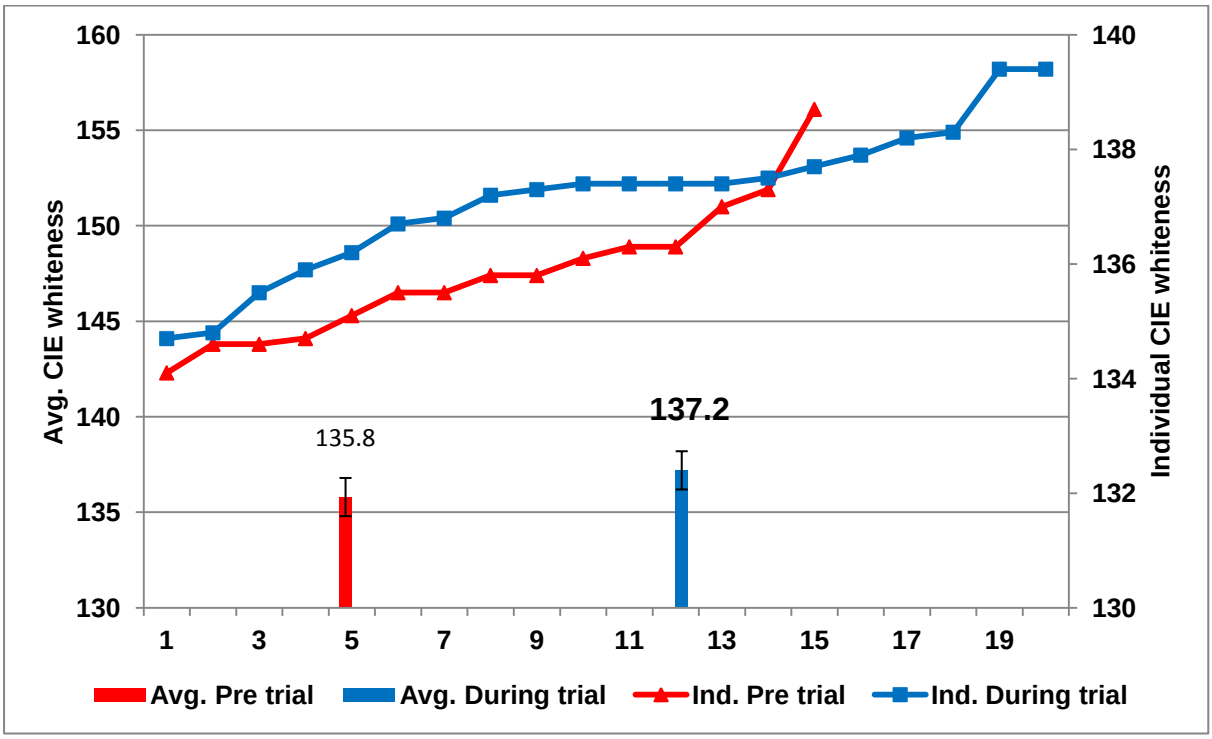

Figure B: Effect on CIE whiteness of paper

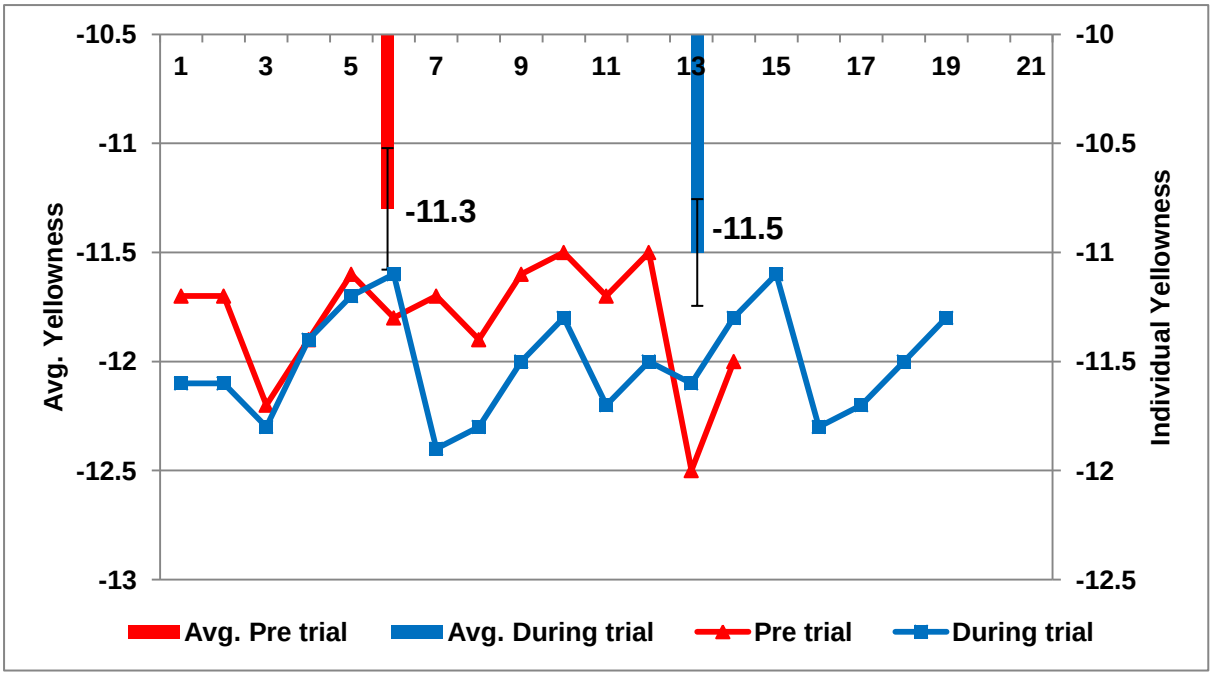

Figure C: Effect on yellowness of paper

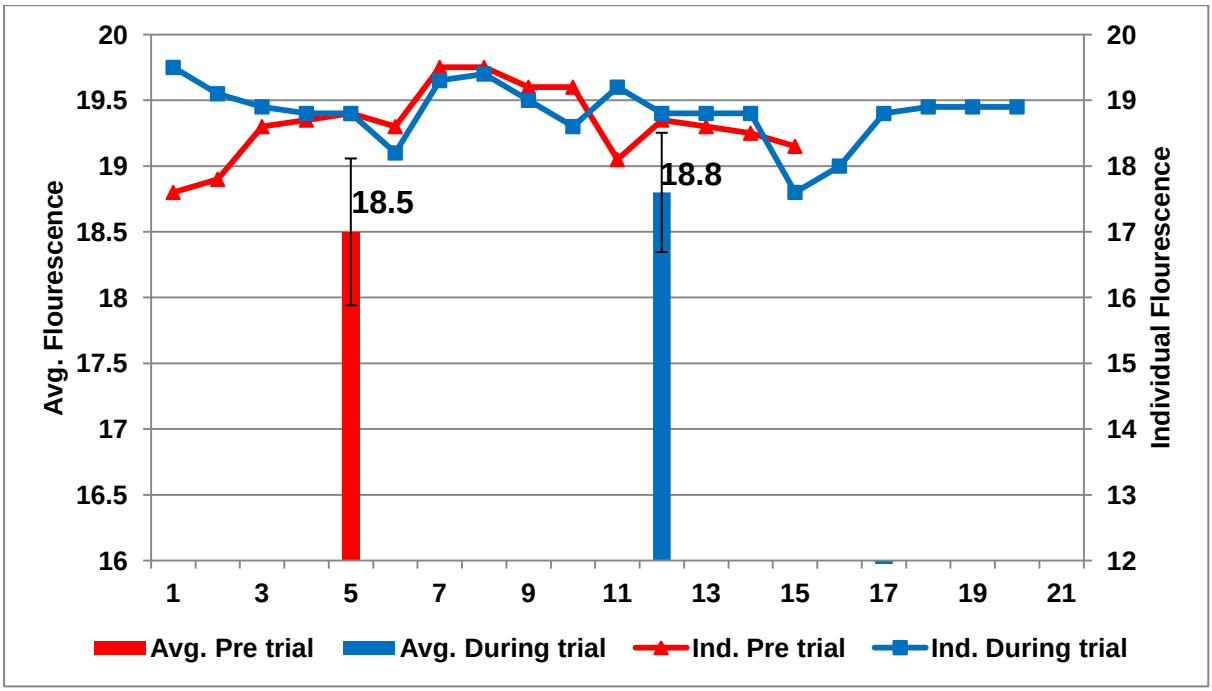

Figure D: Effect on fluorescence of paper

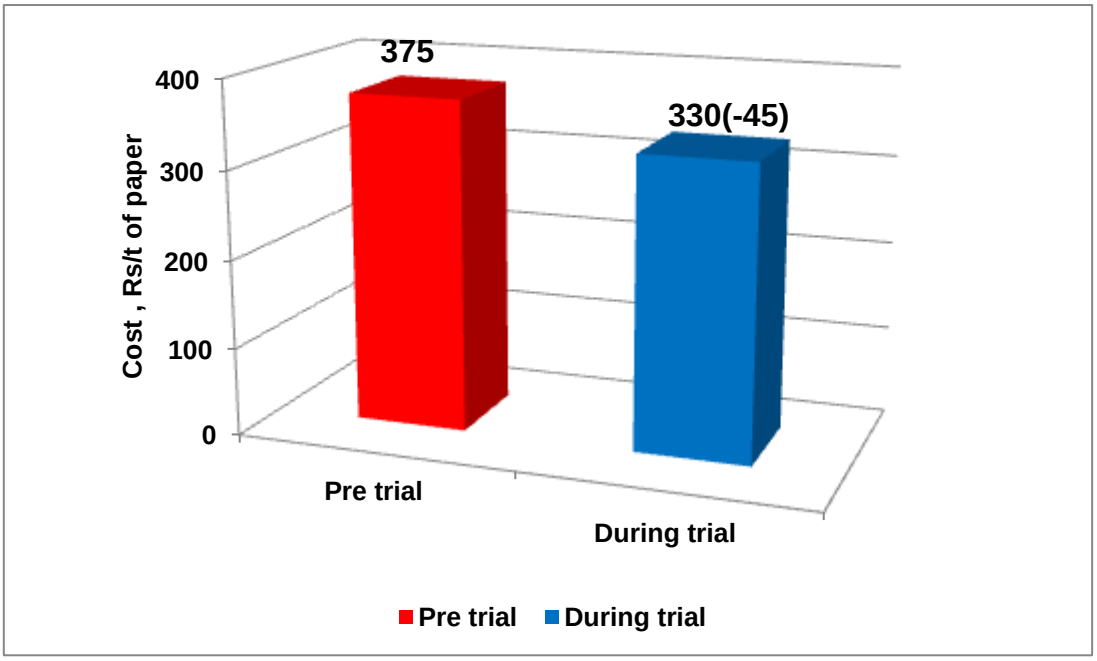

Figure E: Effect on cost of OWAs

7.2 Plant scale for agro based mill

Based on the encouraging lab results obtained at Avantha Centre for Industrial Research & Development (ACIRD), Yamunanagar using different combination of OWAs at wet end and size press under the project and pre-trial study following plant conditions. It was proposed to explore the suitability of any one combination of OWAs on plant scale at Satia Industries Ltd. Muktsar, Punjab. The objective of this plant scale trial was to demonstrate the best combination of commercial OWAs at wet end and size press to reduce the cost of OWAs without compromising the optical properties of paper in agro based mill. The details of the trial are given below:

Paper M/c No. (Production):	**3** (150 TPD)
Trial Period:	**March 30**, 2017 (12 Noon to 6.30 PM) Total 6.5 hrs
Total production during trial:	34.5 T
Paper Product/ Grammage:	Writing and printing paper/ 64 GSM
Reduction in chemical dosage during trial period:	Reduction in dose of OWAs i.e. from 3.5 kg/t to 3.1 kg/t in case of DS2 at wet end along with 4 kg/t of HS1 addition at size press (DS2 was added at a conc. of 75 gpl at wet end monitored by DCS. HS1 was added in size press by preparing solution of 500 gpl and maintaining a flow of 1 lpm in starch slurry on the basis of paper draw of 7.5 t/hr)
Dosing points:	DS2 in mixing chest at wet end, HS1 in size press
Quantity used:	155 kg DS2 and 130 kg HS1

7.2.1 Observations:

- Different OWAs were characterized in terms of % solids, E value and colloidal charge demand. It was observed that the DS2 was having the higher E value than HS1. While HS1 was having the higher cationic charge demand than DS2 as shown in Table no. 1.
- Dose of DS2 at wet end was found higher initially that was 4.5 kg/t of paper and dose of HS1 was 2 kg/t of paper at size press.
- During the trial period, the dose of HS1 was increased by 2 kg/t at size press (i.e. from 2 kg/t to 4 kg/t) with the assumption of improvement in optical properties but not a significant change in optical properties of paper was observed.
- The dose of DS2 was reduced gradually (i.e. from 4 to 3.1 kg/t) at wet end and the comparable optical properties were observed. (Please refer Table 2)
- The average brightness of paper was 89.4 %ISO. The standard deviation in the values of brightness was 0.30. (Please refer Table 3)
- The average CIE whiteness of paper was 145.0. The standard deviation in the values of whiteness was 0.85. (Please refer Table 3)
- The average Yellowness of paper was -29.4. The standard deviation in the values of yellowness was 0.53. (Please refer Table 3)

Table 1: Characterization of different OWAs

Name of OWA	Type of OWA	% Solids	E-value (1%/1 cm)	Cationic charge demand, µeq/g
			On solids basis	
DS2	Di-sulphonated	99.9	493	2145
HS1	Hexa-sulphonated	20.7	374	2340

Table 2: optical properties of paper during trial period

DS2 dose at wet end, kg/t	**4.5**	**4.0**	**4.0**	**3.5**	**3.5**	**3.2**	**3.2**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**
HS1 dose at size press, kg/t	**2.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**
Brightness, %ISO	89.5	89.9	90.0	89.3	89.1	89.3	89.1	89.1	89.3	89.3	89.6	89.4	89.5
CIE Whiteness	145.1	145.8	146.2	144.0	144.1	143.8	145.4	145.1	144.1	144.6	146.2	145.2	145.0
Yellowness	-28.9	-29.0	-29.2	-29.2	-29.0	-28.8	-30.0	-29.0	-29.0	-29.4	-30.2	-30.1	-30.1
L*	89.0	89.1	89.0	89.5	89.5	89.5	89.3	89.4	89.6	89.6	89.6	89.6	89.6
a*	3.14	3.20	3.20	3.20	3.16	3.20	3.20	3.20	3.14	3.15	3.20	3.20	3.20
b*	-10.2	-10.4	-10.5	-10.3	-10.2	-10.1	-10.6	-10.5	-10.2	-10.3	-10.6	-10.5	-10.4

Table 3: Average values of optical properties

Properties	Average	Standard deviation
Brightness, %ISO	89.4	0.30
CIE Whiteness	145.0	0.85
Yellowness	-29.4	0.53
L*	89.4	0.21
a*	3.19	0.02
b*	-10.38	0.16

7. CONCLUSIONS

The E-value determined on the basis of dry solids was the highest for DS1 (562) followed by TS1 (496), DS2 (493), HS1 (374), TS2 (327) and TS3 (265).

The addition point of OWA had slight impact on optical properties of paper though it was also OWA specific. The addition point of DS2 had no much impact on optical properties of paper sheets, whereas addition point of TS1 had slight impact on optical properties of paper sheets.

The choice of addition of several wet-end cationic additives after OWA had impact on zeta potential and cationic charge demand of pulp stock, however, no change in brightness of paper sheets was observed.

The brightness of paper sheets was increased with increase in dosage of OWA. But after a certain addition level of OWA, the brightness either remains constant or reduces due to the greening effect of OWA.

The intrinsic brightness of filler also had significant impact on brightness of paper. At same dosage of OWA, the optical properties including B. brightness were higher with GCC as compared that with talc filler. The less B. brightness with talc filler was mainly responsible for getting the lower brightness in paper sheets as compared with GCC filler. To get the brightness level of about 90% using talc filler, the dosage of DS1, DS2 and TS1 OWAs was comparable (0.17-0.2 kg/t) followed by TS2 (0.27 kg/t) and TS3 (0.45 kg/t). It was observed that to get the brightness level of about 90%, the dosage/ cost of DS1, DS2 and TS1 OWAs was almost comparable for both the fillers separately. At 95% brightness level, the cost of OWA was almost double for talc filler as compared with GCC.

Mixed hard wood pulp

Using GCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 3 kg/t of DS2 at wet-end and 2 kg/t of TS1 in surface sizing along with 3.5 unit gain in whiteness and 0.4 unit gain in brightness.
- Addition of 6 kg/t of TS3 at wet-end and 0.4 kg/t of DS1 in surface sizing along with 1.9 unit gain in whiteness and 0.6 unit gain in brightness.
- Addition of 5 kg/t of DS1 at wet-end and 2 kg/t of DS1 in surface sizing along with comparable optical properties.

Using talc filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 6 kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direction addition of 8 kg/t of DS2 at wet-end .
- Addition of 10 kg/t of TS3 at wet-end and 1 kg/t of TS1 in surface sizing along with comparable optical properties to that of direct addition of 16 kg/t of TS3 at wet-end only.
- Addition of 9 kg/t of DS1 at wet-end with 1 kg/t of HS1 in surface sizing with slight improvement in optical properties to that of direct addition of 12 kg/t of DS1 at wet-end only.

Using PCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 4 kg/t of DS2 at wet-end with 3 kg/t of TS2 in surface sizing and 4 kg/t of DS2 in surface sizing with 3 kg/t of TS1 at size press with slight improvement in optical properties.
- Addition of 6 kg/t of TS3 at wet-end with 4 kg/t of TS2 in surface sizing with slight improvement in optical properties.
- Addition of 6 kg/t of DS1 at wet-end with 2 kg/t of TS2 in surface sizing with slight improvement in optical properties.

Addition of broke (5 to 30%) in the papermaking furnish and its effect on the efficiency of OWAs

Using GCC and talc fillers, there was no adverse effect of broke addition on performance of OWA at wet-end, this may be due to presence of certain quality of OWA already in broke while slight reduction in optical properties of paper were observed in case of surface sizing the sheets having broke %age from 5 to 30.

Bagasse pulp

Using GCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 7kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with improvement in optical properties to that of direct addition of 10 kg/t of DS2 at wet-end only.
- Addition of 9kg/t of TS3 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 14 kg/t of TS3 at wet-end only.
- Addition of 6kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 10 kg/t of DS1 at wet-end only.

Using talc filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 6kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direct addition of 10 kg/t of DS2 at wet-end only.
- Addition of 6kg/t of TS3 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direct addition of 10 kg/t of TS3 at wet-end only.
- Addition of 8kg/t of DS1 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 12 kg/t of DS1 at wet-end only.

Using PCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 7kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direct addition of 10 kg/t of DS1 at wet-end only.
- Addition of 9kg/t of TS3 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direct addition of 13 kg/t of TS3 at wet-end only.
- Addition of 6 kg/t of DS1 at wet-end and 2 kg/t of TS1 in surface sizing along with comparable optical properties to that of direct addition of 10 kg/t of DS1 at wet-end only.

Recycled pulp

Using GCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 5 kg/t of DS2 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 8 kg/t of DS2 at wet-end only.
- Addition of 5 kg/t of TS3 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 8 kg/t of TS3 at wet-end only.
- Addition of 7 kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 11 kg/t of TS3 at wet-end only..

Using talc filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 6 kg/t of DS2 at wet-end and 2 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 9 kg/t of DS2 at wet-end only.
- Addition of 6 kg/t of TS3 at wet-end and 4 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 9 kg/t of TS3 at wet-end only.
- Addition of 7kg/t of DS1 at wet-end and 3 kg/t of TS3 in surface sizing along with comparable optical properties to that of direct addition of 11 kg/t of DS1 at wet-end only.

Using PCC filler, the best combination along with significant reduction in cost of OWA in wet-end and surface sizing were as follows

- Addition of 7 kg/t of DS2 at wet-end and 2 kg/t of TS2 in surface sizing along with comparable optical properties to that of direct addition of 8 kg/t of DS2 at wet-end only.
- Addition of 6 kg/t of TS3 in wet-end along with 4 kg/t of TS2 in surface sizing was the best combination among all these along with comparable optical properties to that of direct addition of 9 kg/t of TS3 at wet-end only..
- Addition of 7 kg/t of DS1 at wet-end and 3 kg/t of HS1 in surface sizing along with comparable optical properties to that of direct addition of 11 kg/t of DS1 at wet-end only.

Identification of OWAs other than commercially available OWAs

The E-values of identified OWAs other than commercially available OWA, determined on the basis of dry solids was the highest for AAMD (505) followed by APOH (483). It was observed that on adding 0.5 kg /t of APOH which is a hexasulphonated OWA in surface sizing along with 4 kg/t of AAMD (Disulphonated OWA) at wet-end gives comparable optical properties to that of adding 6 kg/t of AAMD at wet-end.

Validation of results at CPPRI

Validation of results was done at CPPRI on set of selected experiments using mixed hardwood pulp along with GCC and talc filler. All sets of experiments carried out at CPPRI shows better results than experiments carried out at ACIRD. It was recommended that the plant trial with the use of selected OWA with suitable filler may be carried out at TNPL/ BILT.

Pre plant scale trial study at ACIRD

The pre plant scale trial study was carried out at ACIRD and the best combination of OWAs (in wet-end and size press) optimized in laboratory under this project was tried on two types of paper grades of BILT unit SGU and it was found that there was a cost saving potential of 28-30% to get the comparable optical properties in case of paper grade 1. The cost saving potential in case of paper grade 2 was 4-23% to get the comparable optical properties.

Demonstration of results in the plant scale

Improvement in optical properties of paper along with reduction in cost of Rs 45/t of paper was observed during the trial taken on mixed hardwood based mill i.e. BILT SGU-Yamunanagar

Reduction the dose of OWA at wet end was observed during the plant trial taken at agro based mill i.e. Satia Industries Ltd.-Muktsar

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