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**SOME CHEMICAL ASPECTS OF COLOR REMOVAL
FROM EFFLUENTS OF PAPER INDUSTRY**

**A.G. Kulkarni, R.M. Mathur, Abha Gupta,
S. Naithani and A. Panda**

Central Pulp & Paper Research Institute,
Dehra Dun- (Saharanpur), India

Abstract

Pulp and Paper Industry is one of the highly polluting industries. The waste water from this industry has very high proportion of organic pollutants and significant color loads. Although there is no stringent legislation to the tolerance limits for discharged color in effluents, by Central Pollution Control Agencies but some state pollution control authorities have imposed tolerance limits for the color in discharged effluents. The present practice of color removal involves precipitation and coagulation of colored substances using aluminium salts. Although such chemical treatment methods are expensive but the industry has performed adapted these methods to contain the tolerance limits for color discharge.

Central Pulp & Paper Research Institute took the research project on color removal from effluents of paper industry with the main thrust to understand chemistry and response of different chemicals used as coagulants with an objective to evolve an economic treatment method. Studies were also directed towards the identification of different sources of colour bearing components and their relative colloidal stabilities. From the studies, it was observed that extractives and lignin are the major sources of color. In newsprint industry the color load is mainly due to extractives leached out during during presetaming and refining operations and in other pulp mills the color is mostly due to lignin. In small pulp mills the color load was due to spent pulping liquors discharged.

Studies on chemical treatment included different inorganic salts of Al, Ca, Fe, etc. and Polyelectrolytes like polyethylene oxide (PEO) and Polyacrylamide (PAA). Studies reveal that lignin and extractives differed significantly in their colloidal stability and showed varying response towards precipitation and chemical coagulation on addition of electrolytes. Combination of Alum and CaCl was found to be effective in removing the color over 90 %. It was observed that CaCl₂ prepared from waste lime sludge was equally effective in color removal. The present paper highlights the colloidal chemistry of color bearing components and their response towards different chemical coagulants. The paper also discuss how the ionic strength, particle size of colloids, concentration of colloidal molecules influence the efficiency of color removal.

Introduction

Paper industry is one of the highly polluting industries. The industry uses on an average 250 to 300 cubic meters of fresh water per tonne of paper and nearly 75 % of which is discharged as effluent. The effluent of paper industry contains highly polluting organic components. The Central Pollution Control Board has made tolerance limits for pollutional parameters like pH, temperature, TDS, BOD, COD, etc. The tolerance limits proposed by MINAS for Small Pulp Mills are mentioned in Annexure-I. In addition to high proportion of inorganic and organic pollutants, the effluent from paper industry contains significant color loads. Although there is no stringent legislation for the discharge of color by central pollution agency but some States have imposed tolerance limits for discharge of the color.

The color load varies from mill to mill depending upon the raw material used, process employed, type of the end-products and extent of closure of the system. In newsprint industry, the major color load comes from extractives leached out during presteaming and refining operations. In paper mills producing cultural papers the color load is attributed to discharge of alkaline extracts of bleaching operation. In small pulp and paper mills the origin of the color is from discharged spent pulping liquors.

The present practice of color and suspended solids removal is by chemical treatment methods. Although, the chemical treatment methods are expensive but the industry has perforce adopted such systems to contain the tolerance limits for suspended solids and color. The color can be categorised into two groups:-

1. Color due to colloidal particles (dissolved color)
2. Color due to relatively larger colloidal macromolecules (suspended color).

It is easy to remove the color due to larger colloidal macromolecules, but the dissolved color is very difficult to remove and is sensitive to ionic strength, electrical charge etc. For example, the extractives having particle

size in the range of 10^{-1} microns are quite stable and require very high dosage of chemical coagulants for precipitation and subsequent flocculation. In such a case the chemical treatment process becomes uneconomical and some of the mills are spending nearly Rupees 150 to 200 per tonne of paper for removal of color alone.

Central Pulp and Paper Research Institute undertook the studies on color removal with the main thrust on identifying the color bearing compounds in the effluents and their relative colloidal stabilities. The studies also include color removal using different electrolytes and polyelectrolytes. The present paper highlights the chemical aspects of the color removal and prospects of chemical treatment system for economic removal of color.

Sources and magnitude of color in paper industry

Pulp and paper mill effluents have a characteristic brownish to black color which is mainly due to lignins, tannins and other extractives bearing chromophoric groups. The magnitude of color depends on the raw materials used process employed and type of end-products. Lignin and extractives are highly polymerised substances and are difficult to biodegrade. Major sources and magnitude of color are given below. The color in small mills is mainly due to lignin going through spent liquors. It is estimated that the quantity of lignin going through spent liquors varies from 300-400 Kg/tonne of pulp, generating a color load of about 1400-1500 Kg PCU per tonne of pulp. It was estimated that 90% of the color was due to lignin.

Source	Color l- Pt-Co. Units At 1 % Concentration
Spent Liquors from small Pulp Mills	10,000 - 15,000
Effluent From Alkali Extraction stage	4,000 - 6,000
Washing of Chem-Mechanical Pulps in Newsprint Mills	20,000 - 30,000

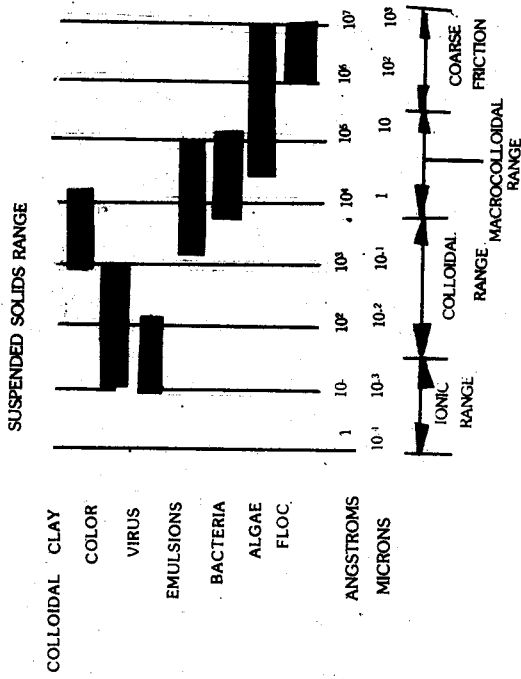


FIG 1 Particle size of some common suspended particles.

In alkali extraction stage effluent only about 50-60 Kg of lignin per tonne of paper (1) is going into effluents and the combined effluents will have color load of about 1500 PCU (2). In newsprint mills where eucalyptus constitute the raw material for production of mechanical pulp component, very high color loads are noticed in the effluents. Eucalyptus contains about 3-6 % extractives, mostly tannins, which are leached out during presteaming and refining stages. The washings of CMP pulp are highly colored and the color intensity is several times when compared to color due to lignin compounds. Hindustan Newsprints Limited at Kerala State, today, is facing serious problems due to high color loads in its effluents and the mill is incurring heavy expenditure for color removal, in order to attain the tolerance limits imposed by state authorities. Small mills with heavy lignin concentration in their effluents, may find it a difficult task to contain the color limits. Although central pollution authorities have not imposed the tolerance limits for color loads in their MINAS, but in the long run these mills will have to think seriously to contain the color loads. Similarly big mills although have relatively low color loads, will be looking forward to economic treatment methods for removal of color.

Results & discussion

1. Chemistry of Color Removal

The particle charge, particle size and concentration of color colloids play a very vital role in the color reduction process, when the interaction is allowed with various electrolytes. The Fig-1 shows the sizes of different particles falling within the category of suspended solids. Normal color bearing substances lie within the range of ionic to colloidal dimension i.e. $10^3 - 10^{-1}$ microns. Particles of the colloidal nature when dispersed in water, can ionise, adsorb and attract low molecular weight ions to its surface, which are held tightly to the colloidal surface, which is known as Stern Layer. The remaining ions will be attracted to the particle and extend into the solution in the diffuse layer also called Gouy-Chapman Layer, until electroneutrality is established (Fig-2). The net charge on the colloidal particle is the strongest force inhibiting their removal. It is the interparticle repulsion that prevents colloids from colliding and forming larger masses. By partial or complete neutralisation of this surface charge, colloids can collide through Brownian motion and mixing, and can be attracted to each other by hydrogen bonding and Van-der-Waal's forces, enabling them to form larger masses. It is also important to consider the degree of hydration, as the particles that are hydrophilic are much harder to remove than those which do not get hydrated or are hydrophobic. Thus the removal of colloidal particles is accomplished in four steps, namely -

- Destabilization involving charge neutralisation
- Microfloc formation
- Agglomeration of microflocs, and
- Physical entrapment by macrofloc formation.

The first three steps are known by familiar terms of coagulation and flocculation. Fig. 3 illustrates this phenomenon very distinctly. In a hydrophilic colloidal system, where colloids are strongly hydrated, it may be necessary to add a chemical that not only neutralises surface charge but also forms an insoluble complex with the colloid for destabilisation. In a destabilised colloidal system collisions can occur and through chemical bridging, hydrogen bonding and Van-der-Waal's forces of attraction, the color bearing particles can form microflocs which on continuous mixing again combine to form macroflocs. A portion of the colloids are removed by being physically entrapped in microflocs already formed.

2. Present Particles and Chemicals used for Color Removal

The most commonly employed method for removal of suspended and colloidal particles is chemical treatment in clariflocculators. Some mills employ one stage clarification and some adopt two stage clarification. Alum is the most commonly used chemical coagulant, because it is relatively cheaper than other chemicals. After removal of suspended matter the clarified effluent is sent for subsequent secondary treatment involving biological methods. Some mills segregate the high color - high solids effluents which are treated separately before mixing with low solids - low color effluents. However, present chemical treatment is capable of partial removal of color, COD and BOD. The dissolved color with micro colloidal particles enters the effluent stream. For instance, Hindustan Newsprint Limited (HNL) at Kerala State, a newsprint unit, is using massive quantities of alum to precipitate and coagulate the color bearing substances, mostly extractives.

Further such colloidal components precipitate as gelatinous and voluminous precipitate and are very difficult to dewater. After looking into various problems faced and heavy operational costs involved it is inferred that till today we do not have an economically viable treatment system for removal of color. Major challenges are to bring down the operational costs, methods for dewatering of precipitated matter and possible utilization of the sludge rich in organic matter.

3. Various Factors Influencing the Efficiency of Color Removal

As discussed in Section-1, it is clear that removal of color due to colloids is a multistep process and careful understanding of the factors influencing each step would be necessary.

a). Role of pH

pH has a strong influence on the precipitation of colloidal particles. In alkaline solution, the colloidal particles whether lignin or extractives exist in

the form of sodium salts and possess a strong electrical charge. For destabilisation it is essential to bring down the pH. Usually this step is accomplished by addition of mineral acids or alum. For instance, the color in CMP effluents could be precipitated only at pH levels around 5.0. The dosage of chemical coagulant would depend on the initial pH of the colored solution. The effect of pH vis-a-vis chemical dosage is discussed in detail in following sections.

b) Relative stabilities of colloidal particles

Lignin and extractives exist as colloidal particles and they possess different molecular size and electrical charge. The colloidal stability would depend upon both molecular size and charge carried by colloidal particles.

During color removal studies it was observed that at same concentration of solids, extractives and lignin required different dosage of electrolyte for precipitation. The results are given in Table-1.

Electrolyte dosage CaCl ₂ ppm	Lignin Solut ion (1 %)		Extractive Solut ion (1 %)	
	Absolute color PUC,	Color reduct- ion, %	Absolute color PUC	Color reduct- ion, %
Nil	21240	--	38570	--
100	12950	40	30812	20
200	8937	58	31250	19
500	8937	58	30812	20
3000	1725	92	5000	84

The extractives were isolated by methanol extraction of wood chips and lignin was extracted by treating with NaOH solution. The CaCl₂ was chosen due to the fact that calcium salts have ability to form water insoluble complexes with extractives (4).

The above results clearly show that extractives were much more colloiddally stable compared to lignin macromolecules. The evidence for effect of molecular size on colloiddal stability was provided by Kulkarni,

etal(5) in their studies on lignin precipitation from black liquors of bagasse and rice straw. They have shown that the bagasse black liquor required 10% lower electrolyte dosage than rice straw black liquor for removal of 86 % color from black liquors. Thus initial pH, molecular size and electrical charge have profound influence on the efficiency of color removal and also influence the chemical dosage required for desired amount of color removal.

c. Role of electrolytes and polyelectrolytes

Various electrolytes and polyelectrolytes are used to coagulate color in the effluents, with an aim to achieve a good reduction of color with minimum dosage of easily available non-toxic electrolyte.

Most widely used inorganics are the di and tri valent metal salts of calcium, aluminium and iron. The principal difference between calcium, aluminium and iron salts is their hydrolysis product. When calcium salts are added to water, the calcium ion is formed. When aluminium or iron salts are added, they form trivalent metal complexes with water. These complexes contain a number of repeating metal ion units and can more properly be referred to as polyaluminium or polyferric hydrates. Polymetal hydrates of significant lengths have been reported. They are cationic and can destabilise a colloidal suspension. They also have a sufficient chain length to bridge the distance between particles. In addition, their strong hydrogen bonding ability enables them to form large macroflocs that can trap other stable colloids.

Metijevic (6, 7) found that hydrolysed aluminium ions behave in a manner consistent with the formula $Al_8(OH)_{20}$ at pH 5.2 which is close to the optimum flocculation point. Organic polyelectrolytes can be either natural or synthetic. Natural products such as starches or gums have been used for years as flocculants or aids to improve treatment with inorganic coagulants. Synthetic organic polyelectrolytes have become predominant in solid/liquid separation. They are generally used in conjunction with inorganic electrolytes and considerably improves both performance and treatment cost. The organic polyelectrolytes have a high molecular weight and contain a variety of ionisable groups that are placed along the polymer chain. These synthetic polyelectrolytes are classified as non-ionic, anionic & cationic. Polyacrylamide & polyethylene oxide are commonly used polyelectrolytes which are non-ionic. Co-polymers of acrylamides and acrylic acid form anionic polyelectrolyte which has an advantage of having large chain length. Thus when an anionic polyelectrolyte is dissolved in water the negative charges repel each other and unwinding of coil occurs, and thus large available chain length makes a more effective bridging agent when charge neutralization is not an important factor in removal of suspended solids. However, sometimes the cost prohibitiveness limits of the scope of application of such polymers.

Studies on color removal in effluents of Hindustan Newsprint Limited (HNL), Kerala --- a case study

Due to stringent legislation by State pollution authorities, today, HNL is incurring significant amount of operational costs particularly in removal of color. In previous sections, it was observed that the extractives which are leached out during presteaming and refining operations are the major source of color in HNL effluents. The mill discharges about 2000-2500 m³ of high colored effluent from washing zone of the CMP plant. The color load due to this high colored effluent accounts to about 97% of the total color load (8). The mill is presently consuming massive quantities of alum and polyelectrolytes for precipitation and subsequent removal of color. Central Pulp and Paper Research Institute undertook the studies on color removal in the effluents of HNL with an objective to understand the basic chemistry of the precipitation of extractives and reduction of overall alum consumption.

The chemical composition of the samples collected from washing effluents is given in Table-2. The results clearly show that extractives constitute the major portion of the washing effluent. During the studies conducted at mill site, it was observed that there was a wide variation in the color of washing effluents and ranged between 12,000 PCU to 30,000 PCU.

Initially studies were started with alum, CaCl₂ and polyaluminium chloride as chemical coagulants. The effectiveness of these electrolytes and polyelectrolytes on the efficiency of color removal is given in Table-3.

TABLE-2

CHEMICAL COMPOSITION OF CHEMIMECHANICAL
PULP WASHING EFFLUENTS

PARTICULARS*	SAMPLE-1 (a)	SAMPLE-2 (b)
pH	8.3	7.9
TOTAL SOLIDS, %, W/W	0.81	0.84
INORGANICS AS NaOH, %	32.20	32.00
LIGNIN, %	3.00	15.6
EXTRACTIVES, % (BY DIFFERENE)	64.70	43.0
COLOR, PCU	29290	19950
COD, mg/l	14230	6446

* EXPRESSED ON DRY SOLIDS, PCU-PLATINUM COBALT UNITS

- (a) SAMPLE COLLECTED WHEN CHIP IMPREGNATION WAS DONE WITH NaOH OF 40 g/l CONCENTRATION.
- (b) SAMPLE COLLECTED WHEN CHIP IMPREGNATION WAS DONE WITH NaOH OF 60 g/l CONCENTRATION.

TABLE-3

EFFECT OF VARIUS ELECTROLYTES ON COLOR REMOVAL
OF CMP WASHING EFFLUENT

ELECTROLYTE	DOSAGE, g/l	COLOR REDUCTION, %	END ph
ALUM	1.0	47.8	5.2
	1.5	92.7	4.8
	2.0	97.3	4.2
CALCIUM CHLORIDE	1.0	35.0	6.4
	2.0	62.5	6.3
	3.0	60.4	6.3
POLYALUMINIUM CHLORIDE	1.0	74.5	5.5
	1.5	96.7	5.1
	2.0	99.0	4.6

INITIAL pH - 8.3

INITIAL COLOR -27260 PCU

pH DURING ADDITION OF ELECTROLYTES - 6.5

The results in Table-3 clearly indicate that the aluminium salts are more effective in colour removal due to the fact that these aluminium ions form trivalent metal complexes with water and these complexes contain number of repeating ion units which facilitate the destabilization step.

TABLE 4

COLOR REMOVAL WITH CALCIUM CHLORIDE & ALUM

CALCIUM CHLORIDE ADDED g/l	1.0		1.5		2.0	
ALUM ADDED, g/l	1.5	2.0	1.5	2.0	1.5	2.0
COLOR REDUCTION, %	96.9	98.0	97.0	98.0	98.0	98.0
FINAL pH	5.9	5.5	5.9	5.5	5.8	5.4

TABLE-5

**COLOR REMOVAL WITH CALCIUM CHLORIDE &
POLYALUMINIUM CHLORIDE**

CALCIUM CHLORIDE ADDED, g/l	1.0		1.5		2.0	
POLYALUMINIUM CHLORIDE ADDED, g/l	1.0	1.5	1.0	1.5	1.0	1.5
COLOR REDUCTION, %	97.6	99.0	98.0	99.0	98.4	99.0
FINAL pH	6.0	5.6	6.0	5.5	5.9	5.4

Use of Electrolytes in Combination

It has been mentioned in earlier sections that the effectivity of electrolytes depends upon the composition of the effluents. The color may be due to the presence of lignins or extractives in an effluent sample and depending upon the pulping technique, one or the other color bearing component may predominate. Alum was found to be very effective in case of effluents rich in lignin and calcium chloride was more effective when used with extractives rich effluents. Thus in case of CMP effluents, for sample (1) (TABLE-2) which is rich in extractives, Calcium chloride alone could be used to bring down the color by 99 %, whereas for the sample (2) alum proved to be more effective, due to the fact that the sample contained substantial quantity of lignin. As most of the effluents from pulping section contain both lignin and extractives and so use of electrolytes in combination may be required. This may also be helpful in regulating the cost of effluent treatment. The results of effluent treatment with electrolytes in combination are recorded in Table-4 & 5. It is seen that total amount of electrolyte required when used in combination is more or less same as in case of individual electrolyte, the benefit drawn could be improved coagulation with faster settling rates and end pH being more close to neutral.

A good coagulation should also be preceded by good settling, so that treated effluent is free from suspended precipitate. In Table-6 results of settling properties of precipitates have been recorded which reveal that good settling could be obtained when Calcium Chloride was used in combination with alum. When alum alone was used the sludge was not compact and separation of clear supernatant could be hindered and this property of sludge did not improve even when alum dosage was increased from 3 to 4 gpl. With introduction of Calcium chloride the sludge was more compact and this could facilitate phase separation more effectively.

Color Removal studies in Soda Pulping Spent Liquors

Number of small pulp mills are operating in the country and most of these mills are discharging their spent pulping liquors which contain more than 50% of dissolved lignin. Nearly 90% of the color is due to lignin. Recently Central Pollution Authorities have laid down MINAS where they have not fixed tolerance limits for COD and color, considering the huge operating costs involved. In the present studies, an attempt was made to estimate the magnitude of color and amount of chemical coagulants required to eliminate the color from spent pulping liquors of two of the widely used raw materials - rice straw and bagasse.

TABLE-6

EFFECT OF ALUM & CALCIUM CHLORIDE COMBINATION IN SETTLING

ALUM ADDED, g/l	3.0	4.0	2.0	1.0
CALCIUM CHLORIDE ADDED, g/l	-	-	1.0	2.0
COLOR REDUCTION, %	98.9	99.5	97.9	97.4
VOLUME OF SLUDGE, %	70	69	56	50
INITIAL pH - 8.51		INITIAL COLOR - 32560 PCU		

Alum was used as the flocculating agent due to its easy availability and lower cost. Both the spent liquors were treated with alum at pH levels brought down to 5.0, 6.0 and 7.0 from original higher pH levels. The results are recorded in Table-7. It was noted that at the same pH level, color reduction in bagasse spent liquor was much more than in rice straw spent liquor. It was also noted that bagasse liquor required more alum to bring it to pH 7.0 due to its higher initial pH (11.8). It was further decided to study the reason for difference in stability of lignin present in bagasse and rice straw spent liquors and molecular weight distribution studies were conducted.

TABLE-7

COLOR REDUCTION STUDIES ON SPENT LIQUOR SAMPLES

	ALUM DOSAGE %	pH	COLOR Reduction, %
BAGASSE SODA	43.2	5.0	97.8
SPENT LIQUOR (pH 11.8)	33.2	6.0	92.0
COLOR - 118,600 PCU	23.6	7.0	88.2
RICE STRAW	21.6	5.0	87.1
SPENT LIQUOR (PH 10.8)	14.0	6.0	20.2
COLOR - 107,000 PCU	4.0	7.0	18.4
BAGASSE SODA	12.0	5.4	95.9
SPENT LIQUOR (MILL SAMPLE)	10.0	5.7	91.4
(pH 8.7) COLOUR -28,000 PCU	8.0+4.0*	5.4	99.0

*4g l CaCl₂ WAS ADDED ALONGWITH ALUM.

It was seen that in case of bagasse there were higher fraction of high molecular weight lignin which can be destabilised easily at pH 7.0, on the other hand rice straw has low proportion of high molecular weight lignin, it makes the lignin more stable and so pH has to be significantly reduced to initiate flocculation of lignin. The ratio of high to low molecular weight in bagasse black liquor was 1.6, whereas it was 1.2 in the case of rice straw spent liquor (9).

Experimental

The effluents generated from cold soda chemi-mechanical pulping of Eucalyptus and chemical pulping of rice straw and bagasse were taken for these studies. The CMP effluent was much emphasised. In the CMP process chips of *E.grandis* or *E.tereticornis* were chemically impregnated under high vacuum and temperature and then refined in the lab Sprout Waldron refiner. These Eucalypts species are rich in extractives like tannins polyphenols, gallic and allelic acids etc. By washing of the refined pulps these colored organic compounds were removed and the dark colored effluent obtained was used in the color reduction studies.

Color reduction in effluent generated from small paper mills which use agricultural residues as their raw material and having no chemical recovery system were also considered. In the chemical pulping, rice straw and bagasse were charged with 10-12 % of alkali and the spent liquor was squeezed out from the pulp. This spent pulping liquor was used for color removal studies.

Determination of Pollutational Parameters

The different pollutational parameters were determined by the methods provided in the "Standard Methods for the Examination of Water and Waste Water" 16th Edition APHA - AWWA WPCF (N.Y.).

Color Measurements

The effluent color intensity was measured using Bausch and Lomb Spectronic 21-UVD Spectrophotometer at 465 nm. The results were expressed in Pt. Co. units. The spectra of both the effluents showed the peak maxima in the region of 465 nm hence this wave-length was opted for. The instrument was standardised by running the Pt. Co. standards.

Experiments for color reduction were carried out in the jar testing machine. The different electrolytes used were alum, iron salts, calcium chloride (CaCl_2) and polyelectrolytes like Polyaluminium chloride (PAC) and polyethylene oxide (PEO). The CaCl_2 used was prepared from the waste lime sludge Gel Chromatography studies were carried out to identify various fractions of lignin and to see their response towards electrolytes.

Conclusion

1. The positive response of color colloids with the cationic coagulants like Alum, Calcium chloride, Polyaluminium chloride, Ferrous sulphate etc. where the trivalent Al & Fe and divalent Ca are predominant show that coloring bodies are negatively charged.
2. The color is present in the effluent as true color in the form of micromolecules or suspended color as macromolecules. It is easier to precipitate the macromolecules by addition of electrolytes as compared to the color due to micro-molecules which need a higher dosage of electrolyte to precipitate.
3. It is the trivalent Al^{+3} ion in the Alum and Polyaluminium chloride which forms trivalent metal complexes with water containing a number of repeating metal ion units known as Polyaluminium hydrates and binds the colored colloids with hydrogen bonds. Calcium ion acts as a nucleus for floc formation and subsequently as weighting agent, which facilitates better settling.
4. Studies conducted on HNL, Kerala effluents indicate that the maximum color is due to extractives and color removal with alum and calcium chloride when used in combination show enhanced efficiency in precipitation of color due to the fact that alum helps in precipitation of macromolecules whereas calcium combines with extractives forming insoluble products.
5. It is easier to coagulate high molecular weight fractions than the lower ones, e.g. lignin present in Bagasse spent liquor having a higher fraction of high molecular weight lignins is easier to decolorise as compared to Rice straw spent liquor which has a lower content of high molecular weight lignins.
6. The above studies on color removal indicate that this is an intricate process and requires further studies particularly on the colloidal aspects.

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ANNEXURE - 1

MINIMAL NATIONAL STANDARDS FOR SMALL PULP AND PAPER INDUSTRY

pH	6.0-9.0
Suspended Solids, mg/l	100
Biochemical Oxygen Demand (BOD) mg/l	50

Economy of Calcium Chloride Production At the Mill Site

For a 250 tpd newsprint mill using Eucalyptus for Chemimechanical pulp production, the total requirement of electrolytes for precipitation of suspended & dissolved color/organics.	- 14 tonnes
Considering 25% substitution of the required electrolytes by calcium chloride, the total CaCl ₂ required	- 3.5 tonnes
Requirement of HCl/tonne of CaCl ₂ production	- 2.19 tonnes
Per cent Assay of Hydrochloric acid	- 30.0
Cost of Hydrochloric acid per tonne of Calcium Chloride production, at the rate of Rs.0.80/kg.	- Rs. 1754/-
It is proposed that lime sludge from Green liquor causticization stage will be used for CaCl ₂ generation.	
Lime sludge (CaCO ₃) required for generation of 3.5 tonnes of calcium chloride.	- 3.2 tonnes
A.D. sludge required at 60% dryness	- 5.33 tonnes
Operational cost in CaCl ₂ production at the rate 10% of chemical inputs.	- Rs. 167/tonne
Saving on lime sludge handling which is used for CaCl ₂ generation at thr rate of Rs 60/- per tonne.	- Rs. 320/- or Rs. 91.50/t
	of CaCl ₂
Cost of Calcium chloride production.	- Rs. 1840/tonne