Chemicals and additives in papermaking-experience at The West Coast Paper Mills Ltd.

BAKSHI, B. K.,* GANDHI, O. P.,* MESHRAMKAR, P. M.*
DEB, U. K.,* JASPAL, N. S.*

SUMMARY

Chemical and additives play vital roles in the process of Papermaking, as they develop properties of paper and board and thus help in meeting the specifications of the consumer industries. This paper describes the experience of The West Cost Paper Mill Ltd in evaluating some important chemicals and additives at the Research Centre and on the plant. There is a scope for products which improve the wet web strength on the paper machine and the strength of paper, retention aids, drainage aids, rosin size substitutes, fixation agents for dyes etc. It is suggested that there should be liaison between Indian Paper Mills and producers or suppliers of these products, which would be helpful in improving the quality of paper and board, and achieving higher profitabiiity.

Various qualities of paper and board are being manufactured in India, with the object of meeting the consumers' needs. In India, the packaging industries are developing rapidly and it is imperative that the paper mills should meet their specifications for paper and board. On the other hand, Indian paper mills are facing acute shortage of pulpable raw materials, especially bamboo, which has been so far the principal raw material for making paper and board. With the increasing use of short fibres, viz. hardwoods and agricultural residues, for papermaking, the Indian paper mills are facing difficulties to meet the specifications for different varieties of paper and board for different consumer industries. With the ultimate aim of meeting the desired specifications of the products, Indian Paper milles are now in search of different chemicals and additives, like synthetic dry and wet strength resins, modified starches, fortified rosins, chemicals for surface sizing, retention and drainage aids etc., These chemicals and additives are readily available and are in use in Western countries. but their availability and use is limited in Indian Paper mills. At the West Coast Paper Mills, Dandeli in the last few years various chemicals and additives have been tried and some of them have been approved. With the use of some of the chemicals/additives, it has been possible, for W.C.P. Mills, to make varieties of paper like, kraft, surface sized litho printing, pulp board etc. This paper deals with the study and evaluation of the followirg chemicals in WCPM Research Centre. and subsequent plant trials at the mills.

1) Guar gums
2) Wax emulsions
3) Starches for internal addition to improve wax pick in pulp board
4) Starch for surface application of paper.

This paper also gives WCPM experience in drainage and retention aids, flocculating agents and dry strength agents.

USE OF GUAR GUMS FOR IMPROVING THE DRY STRENGTH OF PAPER :

Seeds of common leguminous plant guar (*Cyanopsis tetragonoloba*), extensively grown in the Indian sub cantinent, contains this gum. This gum is mainly composed of a straight chain of D-mannose, with D-galactose side chain on approximately every other mannose unit. To control rapid swelling and lump formation during dissolution the commercial guar

*The West Coast Paper Miils Ltd., Dandeli-581 362, Karnataka.

gums are chemically treated. Some commercial gums are blended with starches so as to take advantage of the modified properties. Guar gums are the natural bonding materials which bring about better adhesion between fibres and other components of paper. This is the reason for increased strength properties of paper.

This effect can also be achieved by extensive refining of the fibres. But there are some disadvantages with this, as slow drainage of the stuff on machine wire, and the dimensional instability of paper upon exposure, which increases, due to extensive refining. Moreover, the fibre length is reduced generally in refining which affects tear strength, although burst or tensile strength is increased. Here lies the importance of using guar gums or other compounds which help to increase the dry strength of paper.

Very small amount of gum, say 0.3% to 0.5% on pulp, should give the desired effects. After dispersion and cooking at 80°C, a solution of gum of 0.5 to 0.75% concentration is prepared, which is added to the pulp after beating or ferining. WCPM Research Centre is conducting research work on improving the dry strength of paper. On the recommendations of Research Centre, plant trials of some chemicals/additives are arranged at our Mills.

We have conducted plant trials of five different guar gums supplied by different parties to improve the dry strength of our kraft paper. We faced difficulties regarding the dissolution of two products, as lump formation was taking place during their dissolution. One product was found satisfactory, but its price was quite high. During the plant trial of another guar gum, we observed processing difficulties and transparent spots on kraft paper. Only one commercial product has given satisfactory results, both in Research Centre, as well as on plant. Improvement in dry strength properties, (especially burst factor, which is very imortant for packaging papers) were obtained. Table 1 gives the results of the experiments

TABLE—1

	Blank	Guar qum 0 5% on Pulp
Slowness °SR	30	30
Basis weight	60	60
Breaking length, km	4.3	4.7
Stretch, %	3.1	4.2
Burst factor	29.1	33.8
Tear factor	97.5	98.9
Double folds (MIT)	17	22

Experiments conducted in Research Centre with unbleached pulp consisting of 60% bamboo and 40% mixed hardwoods pulp. Standard hand sheets were prepared, with white water recirculation. 1% rosin was added on pulp, then guar gum, and finally alum to adjust pH to 4.5

conducted in Research Centre[2]. Table 2 gives the results of plant scale trials[3].

TABLE—2

Plant trial with the above mentioned guar gum, for increasing the strength properties of M.G. Plain kraft.

		Blank	Guar gum 0.4% on pulp
Slowness °SR		23	24
Basis weight		99	101
Burst factor		17.4	20.4
Breaking length, Km.	M.D.	5.07	5.33
,, ,,	C.D.	3.60	3.85
Stretch, % ,,	M.D.	1.5	1.8
,,	C.D.	2.7	2.6
Tear factor	M.D.	81	90
,, ,,	C.D.	85	91
Double Folds (MIT)	M.D.	15	21
,, ,,	C.D.	17	22

WCPM experience regarding the use of guar gums shows that as the packing and converting industries, insist on kraft paper with high burst factor, the right type of gum has enough scope. This is especially so when Indian Paper mills are increasingly using short fibred raw materials like hardwoods and agricultural residues, which have low strength properties.

USE OF STARCHES IN PAPERMAKING BY INTERNAL ADDITION :

Starch is a high-polymeric carbohydrate, which can be represented by the formula $(C_6H_{10}O_5)_n$ where n varies from a few hundred to over a million. Starch, which is a natural bonding material, has wide adhesive applications. Starch is effective in increasing the fibre bonding which results in increasing strength of paper. Although theoretically less than one percent starch is required to completely cover and be absorbed by the fibres, in practice, 2% to 3% starch is required for internal addition. Many varieties of modified starches, including oxidised and cationic starches are available, which find wide application, in paper mills all over the world.

Starches are also being used in WCP Mills, to improve the dry steength of paper. WCPM have

found that native and oxidised starches, are effective to this end. A plant trial of Cationic starch, to study its effectiveness for increasing the burst factor and other strength properties of kraft paper gave encouraging results. However, cationic starch is costlier than native and oxidised starches, and also costlier than guar gums.

USE OF OXIDISED STARCH AND CATIONIC STARCH TO IMPROVE WAX PICK VALUE OF WHITE PULP BOARD :

WCP Mills manufacture white pulp board of about 250 gsm, which is a special product, for which the consumers insist on high wax pick value. The wax pick test indicates the surface strength of paper, of its resistance to picking, which is an important printing quality of paper. Oxidised starch and cationic starch have the potential of increasing the wax pick value of paper. Experiments were conducted in Research Centre to verify the effect of the starches for improving the properties, particularly the wax pick value of white pulp board[4] The results of these experiments are given in Table 3. Plant trial was conducted to study the effect of oxidised starch and cationic starch, on the properties of white pulp board by incorporating the starch solution in mixing chest. The results of this trial[5] are given in Table 4.

TABLE—3

Experiments in Research Centre to study the effects on the properties of white pulp board, by the internal addition of native starch and cationic starch.

Bleached pulp consisting of 80% bamboo pulp and 20% Eucalyptus bybrid pulp was used for the experiments. The pulp was beaten to 23°SR in valley beater. The sequence of various chemicals and additives as percent on O.D. pulp is as follows :

Rosin, %	=	0.7
Talcum powder, %	=	15
Native starch %	=	2.0
Alum for pH	=	5.2%

In the experiments with cationic starch, the same was added (0.5% and 1%) after alum as recommended in literature.

Particulars	Blank	Native* Starch 2%	Cationic starch* 0.5%	1%
Final slowness, °SR	23	23	23	23
Basis, Wt. g/m²	240	235	245	244
Bulk, cc/gm	1.38	1.40	1.36	1.39
Breaking length, Km	4.25	4.85	4.80	5.50
Stretch, %	3.0	3.2	2.9	3.2
Burst factor,	24.0	27.4	29	30.2
Tear factor	72.5	74.5	75.0	76.5
Double folds (MIT)	11	9	9	10
Wax pick test (Dennison)	8A	11A	9A	11A
Ash in paper, %	12.8	12.8	13.2	12.7

The results of these experiments indicate improvements in the psoperties of white pulp board, by using native and cationic starch. Native starch was more effective than cationic starch under test in increasing the wax pick value.

*The price of the cationic starch is nearly four times that of the native starch

TABLE—4 PLANT TRIAL OF OXIDISED STARCH AND CATIONIC STARCH FOR INCREASING THE WAX PICK OF WHITE PULP BOARD.

	Blank	Oxidised starch 2% on B.D- Pulp	Cationic starch 0.5% on B.D. Pulp
Slowness, °SR	22	22	22
Basis weight A.D. (gsm)	238	240	240
Bulk, cc/gm	1.55	1.52	1.52
Bursting strength Kg/cm²	2.60	2.80	2.85
Burst factor	11.3	12.2	12.0
Breaking length, Km, MD	3.85	3.95	3.80
CD	2.60	2.70	2.65
Stretch, %, MD	1.5	1.6	1.5
CD	2.8	2.6	2.9
Tear factor : MD	155	175	165
CD	165	185	182
Double folds : MD	27	35	38
Ash, %	14.0	14 0	14.5
Wax pick	5A	6A	6A

These results indicate that the improvements in the properties of white pulp board obtained by the internal addition of 2% oxidised starch (on B.D. pulp) are comparable to those obtained by the addition of 0.5% cationic starch under test.

USE OF WAX EMULSIONS FOR INTERNAL SIZING :

Internal sizing of paper and board is of great practical importance, as it is related to permeability of various liquids, coming into contact with paper and board. The internal sizing process involves the use of rosin size or synthetic sizes or wax emulsions into the stock before formation of web on the paper machine. The desired results from rosin size are obtained only when it is precipitated on the paper-making stock with alum. Rosin size can be partially substituted by wax emulsions for internal sizing of paper and board. This has gained considerable interest recently because of the scareity and rising price of rosin. Because of its inherent property of high water repallency, and relative cheapness, paraffins wax can be considered as a suitable material for internal sizing. In India various manufacturers are trying to make paraffin wax emulsions suitable for internal sizing for paper and board. Commercial wax sizes are available, containing minute particles of wax in emulsion form together with emulsifying agents. Alum is essential for precipitating the wax.

EXPERIMENTAL WORK CARRIED OUT IN RESEARCH CENTRE, TO SUBSTITUTE ROSIN BY WAX EMULSIONS :

Experiments were conducted to study the feasibility of replacing rosin partially or fully by commercially available wax sizes, product 'A' product 'B' and product 'C' (6). Bleached pulp from plant, consisting of 60% bamboo pulp and 40% hardwoods pulp, was beaten to 30°SR. Different concentrations of Product 'A' Product 'B' and Product 'C' and rosin size were added to this pulp after beating and pH was maintained at 4.5 by addition of alum solution. Hand sheets of 60 gsm were prepared on the sheet making machine with white water recirculation. The sheets were pressed and dried at 110°C. Afterwards these sheets were tested for physical properties and sizing The results are recorded in Table 5. and 6. The following conclusions could be drawn :

1) Maximum of 50% rosin could be replaced by Product 'A' Product 'B' or Product 'C', to give the same effect of sizing as with rosin alone

2) 50% of rosin could by replaced be 25 to 50% of any of the wax emulsions, effectively, as seen from the results of sizing*

Considering the economy, and effectiveness of the wax emulsions a plant scale trial was conducted to compare the usefulness of Product 'B' with Product 'C' which is being used in our mill.

TABLE—5 USE OF WAX EMULSION, PRODUCT 'A' AS A ROSIN SUBSTITUTE, FOR INTERNAL SIZING OF PAPER

Sl. No.	I	II	III	IV	V	VI	VII
Rosin added, % on pulp	1.0	Nil	Nil	0.5	0.5	0.25	0.25
Product 'A'	Nil	1.0	2.0	0.5	0.25	0.25	0.75
Alum added, % on pulp (to get 4.5 pH)	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Basis Wt., gsm	58.9	59.5	59.4	57.9	61.0	59.1	59.5
Bulk, cm^3/g.	1.47	1.43	1.44	1.48	1.48	1.46	1.47
Breaking length, km	4.36	4.14	4.04	4.20	4.44	4.34	4.22
Stretch, %	2.6	2.5	2.7	2.6	2.7	2.8	2.8
Tear factor	51.7	51.2	51.3	50.1	53.6	53.3	50.4
Burst factor	26.7	27.4	26.6	26.4	27.4	27.9	27.9
Folding endurance,	14	12	11	12	12	12	12
Strength index	1165	1148	1125	1126	1166	1170	1149
Sizing, seconds	15	Nil	Nil	15	14	7	9
Cobb test, g/m^2	16.7	72.5	73.6	18.3	18.7	23.2	21.6

TABLE—6 USE OF WAX EMULSIONS, PRODUCT 'A', PRODUCT 'B' AND PRODUCT 'C' TO SUBSTITUTE ROSIN FOR INTERNAL SIZING OF PAPER

Sl. No. Wax emulsion added	IV Product 'A'	V Product 'A'	VIII Product 'B'	IX Product 'C'	X Product 'C'
Rosin added, % on pulp	0.5	0 5	0.5	0.5	0.5
Wax emulsion added, % on pulp	0.5	0.25	0.5	0.5	0.5
Alum added, % on pulp (to get 4.5 pH)	5.0	5.0	5.0	5.0	5.0
Basis wt., gsm	57.9	61.0	60.9	59.9	60 6
Bulk, cm^3/g.	1.48	1.48	1.48	1.47	1.47
Breaking length, km	4.20	4.44	4.22	4.22	4.22
Stretch, %	2.6	2.7	2.7	2.6	2.7
Tear factor	50.1	53.6	51.1	50.9	50.0
Burst factor	26.4	27.4	26.5	26.9	26.3
Folding endurance,	12	12	12	14	12
Strength index	1126	1166	1135	1162	1124
Sizing, seconds	15	14	14	15	14
Cobb test, g/m^2	18.3	18.7	18.4	18.6	18.2

*The results also showed that, it is not possible to replace 100% rosin, by any of the wax emulsions.

The results[7] of the plant trial of Product 'B' with comparative values for Product C' are given in Table 7. The economic analysis of plant trials showed that significant savings, in terms of rosin substitution, can be achieved, by replacing wax emulsion Product 'C' by Product 'B'. It was also observed that sizing effects obtained with rosin plus Product 'B' are equal to or better than those achieved with rosin and Product 'C'.

USE OF STARCHES AND OTHER CHEMICALS FOR SURFACE SIZING OF PAPER :

Surface sizing of paper differs from internal sizing, in the former process starch, glue or other suitable chemicals are applied on the surface of the paper, with an aim of depositing a uniform film of the chemical on the surface of paper and binding the fibres to the body of the paper. The advantage of surface sizing is, that the paper becomes more resistant to writing and printing inks. Surface sizing chemicals, such as starches, animal glue polyvinyl alcohol, carboxymethyl cellulose, sodium alginete, wax emulsions, and some synthetic resins can be applied in a size press, or in size tub etc.

At the WCP Mills, map litho paper is generally surface sized with solution of oxidised starch or starches. This is done with the object of getting better printing qualities of the paper.

STUDIES AT WCP MILLS TO IMPROVE THE VARNISHABILITY OF SURFACE SIZED MAP LITHO PAPER

To improve the varnishability of Map Litho paper surface sized with oxidised starch, studies were carried out at the Research Centre and also on plant by incorporating. small amounts of carboxy methyl cellulose, to the surface sizing solution. However, the resultss were not encouraging. A synthetic resin imported from U.S. in the past, was tried for this purpose. The resin, a fine white powder insoluble in cold or hot water, was dispersed in water, to which 25% ammonia was added to get 10% solution. Oxidised starch and the resin solution were mixed together, in the ratio of 2: 0.2 respectively. The mixture was used to surface size Map Litho paper on both sides on Laboratory Air knife Coater to get coat weight of 3—4 g/m^2. The sheets tested on Vanceometer with spirit varnish showed excellent varnishability[8].

Based on the above finding, a plant trial was conducted to study the effects of the resin for improving the varnishability of Map Litho paper. About 6% oxidised starch solution was prepared by cooking at 85°C for half an hour. 10% solution of the resin was prepared by mixing with water, agitating vigorously and adding ammonia. The starch solution and resin solution were mixed in the ratio of about 2 : 0.3, respectively. This mixture was used for surface sizing Map Litho paper on both sides. The results[9] are given in Table 8.

TABLE 7 PLANT TRIAL OF WAX EMULSION, PRODUCT 'B' AND ITS COMPARISON WITH PRODUCT 'C'

Particulars	Percentage added on O.D pulp				White water		Average properties				
	Rosin	Alum	Product 'C'	Product 'B'	pH	Acidity ppm	gsm	Ash %	Cobb T.S.	Value W.S.	Sizing Sec.
Trial No. 1 Machine No. III											
Creamwove (58 gsm)	1.60	4.67	0.106	...	4.1	265	58	11	19	20	7
White Ptg. (60 gsm)	1.18	4.53	—	0.102	4.2	270	59	11.3	19	20	8
	1.85	5.15	...	...	4.1	275	59	11.5	20	21	7
Trial No. 2 Machine No. 1	0.74	2.80	0.143	...	4.2	180	94	17.7	19	23	35
Azurelaid (95 gsm)	0 80	4.30	...	0.137	4.3	190	93	17.7	18	22	34
Azurelaid (82 gsm)	0.89	3.60	...	0.137	4.3	165	82	20.2	18	22	26
	1.00	4.50	0.139	...	4.2	160	82	19.4	18	22	20
	1.26	4.90	...	...	4.2	170	82	18.7	18	22	19

TABLE – 8 PLANT TRIAL FOR IMPROVING THE VARNISHABILITY OF MAP LITHO PAPER BY SURFACE SIZING WITH OXIDISED STARCH SOLUTION PLUS RESIN SOLUTION :

Hourly readings were taken :

Surface sizing solution	Map Litho paper Basis weight	Air Porosity (Bendtsen, ml/min)	Gloss° (Vanceometer) Readings
Oxidised starch	80	650	30
,,	80	600	32
Oxidised starch + Resin	89	320	38
,, ,,	87	300	38
,, ,,	93	400	36
,, ,,	94	320	44
,, ,,	94	340	40
,, ,,	91	440	42
,, ,,	95	300	42
,, ,,	95	290	44
,, ,,	91	230	48

paper production during this trial = 55 tonnes
a) Oxidised starch consumed = 20 Kg/tonne paper
b) Resin consumed = 2.6 Kg/tonne paper
c) Liquor ammonia consumed = 2.61 Lit/tonne paper

Conclusions :

1) With the use of the synthetic resin, varnishability of Map Litho paper was improved, as seen from the gloss readings. Paper surface sized without the synthetic resin, gave low gloss readings, and also in this paper, penetration of varnish was clearly seen. As against this, there was no penetration of varnish in the paper, when synthetic resin was used.
2) The values of air porosity decreased for paper samples surface sized with the synthetic resin along with starch

However, this synthetic resin is not available indigenously.

SURFACE SIZING WITH POLYVINYL ALCOHOL AND OXIDISED STARCH :

Experiments conducted in Research Centre to improve the varnishability of Map Litho paper, showed that, it was necessary to use 20% oxidised starch solution, to get good results of varnishability. Also, by using samples of modified CMC, satisfactory results of varnishability were not obtained[10].

PLANT TRIALS FOR IMPROVING THE VARNISHABILITY OF MAP LITHO PAPER BY USING POLYVINYL ALCOHOL WITH OXIDISED STARCH :

Polyvinyl alcohol was dissolved in hot water at 80°C. Oxidised starch was cooked at 85°C for 30 minutes. The solution of polyvinl alcohol (PVA) was mixed with oxidised starch solution. The mixture contained oxidised starch and PVA in the ratio of 2:0.3. This was used to surface size the Map Litho paper. The results are given in Table 9.

TABLE 9

	Time	Gloss° (Vanceometer readings)	Remarks
Trial No. 1	11.0 A.M.	46	Blank*
	1.0 P.M.	46	,,
	3 0 P.M.	36	,,
	5 0 P.M.	64	PVA used
	7 0 P.M.	55	,,
	9.0 P.M.	54	,,
	11.0 P.M.	62	,,
Trial No. 2	9.0 A.M.	46	Blank
	10.0 A.M.	58	PVA used
	11.0 A.M.	56	,,
	12 0 Noon	56	,,
	1.25P.M.	52	,,
	2.40P M.	55	,,

*Blank – For trial No. 1, oxidised starch + clay was used.
For Trial No. 2 oxidised starch was used.

CONCLUSION :

The results[11] showed that, with the use of PVA varnishability of Map Litho paper was improved, as can be seen from the Table above, and there was no penetration of varnish. As against this, in the blank, the gloss values were lower and penetration of varnish was also observed.

Though PVA is available indigenously, it is very sxpensive.

MISCELLANEOUS :

Experience with CMC and sodium silicate shows that they are not effective, for improving the dry strength of paper. WCPM tried some flocculating agents in Research Centre and also on plant, but their performance was not very satisfactory. Some imported chemicals like dispersing agents surface sizing agents, retention and drainage aids, gave encouraging results in Research Centre but they are not available indigenously. Plant trial of some flocculating agents, available indigenously, did not give satisfactory results. We also conducted plant trials of chemicals termed by the supplier as "Synthetic polyacryla tes", and recommended, as retention aids and drainage aids, and also for improving the dry strength of paper. However, their performance on the plant was far from satisfactory. A chemical, in liquid form, based on PVA, available indigenously, did not give encouraging results on plant for improving the varnishability of Map Litho paper.

WCPM is looking for some chemicals/additives, which would help in reducing the fluff formation, and effective for substantial increase in the folding endurance of paper. WCPM would also like to use efficient wet strength chemicals, retention aids and drainage aids and fixation agents for dyes. Rapid developments are taking place, in Western countries, in chemicals and additives for paper-making. Some synthetic polyacrylides are effectively being used for improvement in the dry strength of paper, and some products as retention aids, thus helping to achieve better quality and higher profitability. In the field of internal sizing of paper and board, apart from wax emulsions, fortified rosin sizes and protected rosin size (like Bewoid size), appear to have better scope, because of the effectiveness of these products. Some latest trends reported are, neutral sizing, alkaline sizing, and noval approach in Aquapel sizing[12] In Aquapel sizing the cellulose pulp can be treated with Aquapel (a patented product involving the reaction of ketene dimer with cationic starch), under certain conditions to produce Aquapel Modified Fibre (AMF). When as little as 5% of this speciality fibre is added to furnish, it produces sizing effect similiar to wet end treatment of the whole furnish. Spraying starch in the slurry form on the paper and board webs, during their formation on the wire, is a modern technique, that is steadily gaining ground for improving the properties of the sheet material, and for better starch retention[13,14].

Most of the chemicals and additives described above are readily available and are in use in Western countries, but their availability and use is limited in Indian Paper mills.

Conclusions :

At WCP Mills, during the last few years, various chemicals and additives have been tried and some of them are in regular use. With these chemicals/additives it has been possible to improve the properties of different varieties of paper like kraft, surface sized maplitho printing, MG and MF pulpboards etc. WCP Mills still needs chemicals/additives for specific purposes. These are :

1) Retention aids and drainage aids
2) Fixing agents for dyes
3) Chemicals for increasing the wet web strength so as to facilitate the use of more short fibres.

It is felt that the manufacturers and suppliers of chemical/additives in India, should give first importance to fundamental studies, related to the manufacture or synthesis, so that the right type of products which are really effective in achieving the objectives under the mill operating conditions are sent to the mills. The parties should be also aware of the problems that may be faced by the mills while using their products so that they can modify and improve them. This could be done by closer liaision between the chemical manufacturers and paper mills. These steps would certainly help the chemical producers and paper mills to meet the specifications of their products for the consnmer industries.

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REFERENCES :

1) Kirk-Othmer Encyclopedia of Chemical Technology, Interscience Publishers, New York (1966 Edition), Vol. 10, page 750.

2) WCPM Research Centre Report (May, 1976).
3) WCPM Plant Trial Report (February, 1977).
4) WCPM Research Centre Report (January, 1977).
5) WCPM Plant Trial Report (April 1977).
6) WCPM Research Centre Reports (June, and July, 1979).
7) WCPM Plant Trial Report (March, 1980).
8) WCPM Research Centre Report, (Feb. 1977).
9) WCPM Plant Trial Report (April, 1977).
10) WCPM Research Centre Report (November, 1976).
11) WCPM Plant Trial Report (August, 1977).
12) *"Pulp and Paper"* 53, (6) : 78 (1979).
13) *"Paper"*, 193, (3) : 124 (1980).
14) Bryn Davies, R.P., Paper Technology and Industry, 18, (6) : 186 (1977).