ISSN: 0379-5462
Indian Pulp and Paper Technical Association

Blending of Melia Dubia with Eucalyptus Tereticornis and Casuarina for Evaluation of Pulp and Paper Making Potential





Deepika *Kumar Anupam* *Arvind Sharma* *Priti Shivhare Lal* *B.P.Thapliyal*

Abstract

The technical paper covers the pulping and bleaching study of three fast growing hardwoods viz. Melia dubia, Eucalyptus tereticornis and Casuarina equisetifolia. The studies on three hardwoods included pulping of individual hardwoods and their blending with M. dubia to assess the pulp and paper making characteristics after mixing the two raw materials. During blending the ratio of M. dubia with E. tereticornis and C. equisetifolia was maintained 50:50. Among the three hardwoods E. tereticornis showed higher basic density 520 kg/m3, with lignin 25.8%, alpha cellulose 42%. In C. equisetifolia the basic density 510 kg/m3, with lignin 24.9%, alpha cellulose 46%. In E. tereticornis the kraft pulping screened yield was 45.1% with brightness 29.2 % while in C. equisetifolia the screened yield was 46.88% and brightness 30.4 %. M. dubia was observed with high alpha cellulose 49.5% and with high screened yield of kraft pulp 51.28% with brightness 32.10%. The blending of M. dubia increased the alpha cellulose content by 3.78% and 2% in E. tereticornis and C. equisetifolia respectively. The final brightness after mixing M. dubia reached 88.20% in E. tereticornis and 90.28% in C. equisetifolia respectively. The physical strength properties of sheet increased after blending and the tensile reached 31.64 Nm/g in E. tereticornis and 41.76 Nm/g in C. equisetifolia. Thus the blend of M. dubia is beneficial to improve E. tereticornis and C. equisetifolia pulp and hand sheet properties.

Key Words: *Blending, hardwood, physiochemical properties, kraft pulp, ECF bleaching*

1. Introduction

Paper mills in India continue to face challenges with forest-based raw material. Out of the annual paper production capacity of nearly 16.9 million tonnes, around 29 % (4.88 million tonnes) is produced by 26 wood and agrobased mills and the rest 69% by recycled fiber based mills and the rest 69% by waste paper and agro-based mills. The present requirement of wood is 9.83 million tonnes (1). The projected demand for paper by 2025 is 24 million with indigenous production of 22 million tones leading to a shortfall of 12 million tonnes of wood. The strategy to be adopted by the paper industry, to meet its ever- growing demand of wood on continuous and sustainable basis is to enlarge social and farm forestry plantation apart from raising plantations by forest development corporations (2).

In India the paper industry mainly depends on raw material in the form of wood and non wood. E. tereticornis, Populous, Pine, C. equisetifolia and Acacia are some commonly used hardwood in paper world. With the GDP expected to average around 9% *, growth in consumption of paper and paperboard is expected to be about 7.8%. The Indian pulp and paper industry mirrors its impressive growth rates in the GDP at 8% CAGR. This translates in to consumption of about 24 million tonnes and production of 22 million tonnes by 2025 resulting in per capita consumption of 17 kg. All this means rapid growth of pulp and paper industry in India that ultimately requires wood as raw material. Indian pulp and paper industry being the 15th largest industry in the world is an important industrial sector having a bearing on the socio economic development of the country as it provides employment to nearly 1.5 million people . (2)

The continuous use of Eucalyptus, Subabul and Casuarina in paper industry had encouraged to search for more fast growing hardwoods. The mixed hardwoods or MHW are fibrous raw materials source being used by wood based Indian Paper Industry in which blending of two or more raw materials (hardwoods) is done to get the desired properties in pulp and paper production. There is always a demand of new wood species which are fast growing and have potential of pulp and paper production. The blending can be performed in 3 different ways likewise chips blending, pulp blending before beating and pulp blending after beating (3).

In Indian paper mill blends of bamboo and hardwoods (75:25), agricultural residues and softwood and softwood or jute (85:15) and waste paper are commonly used for making pulp and paper (4). In the previous studies blending of Bamboo with T. orientalis in different proportion shows increase in yield, decrease in kappa number, and increase in tensile strength and after ECF bleaching increase in brightness (6). The high yield of wood with high strength properties were observed during blending of non wood plants with wood (7).Study on mixed pulping of aspen, birch and maple showed the increase in yield with decrease in pulp viscosity on mixing (8).

The improved strength properties in pulp were observed after mixing of Ipomoea carnea and bamboo (2).

M. dubia being an indigenous species of India is a competing wood species in the pulp and paper sector. Considering the above facts present study explores the upcoming fast growing species of Meliacea family i.e. Melia dubia for its pulp and paper making potential and effect on various pulp properties of mixed pulp with other commonly used raw material E. tereticornis and C. equisetifolia. The three hardwoods were evaluated for their physiochemical analysis together with kraft pulping and ECF bleaching.

Studies on mixed pulping of E. tereticornis and C. equisetifolia are reported in literature but mixed pulping of E. tereticornis and C. equisetifolia with Melia dubia has rarely reported. Attempts were made to produce pulp and paper through Melia dubia, E. tereticornis and C. equisetifolia individually but the mixed pulping of M. dubia with E. tereticornis and C. equisetifolia is first time evaluated through this study.

2 MATERIALS AND METHODS

2.1 Hardwood collection and processing

The logs of hardwood M. dubia, E. tereticornis and C. equisetifolia of five year age were collected from nearby agroforestry farm of CPPRI, Saharanpur, India. The wood logs were debarked manually and converted into chips using laboratory disc chipper and the accepted chips were used for processing of pulp and paper making.

2.2. Blending and raw material characterization

M. dubia wood chips were added to E. tereticornis and C. equisetifolia with 50:50 ratio. Various properties of raw material were analysed following the standard methods. The chips were analysed for bulk density and basic density using standard methods TAPPI method. The proximate analysis of accepted chips was performed by preparing 100g chip's powder (T 257 cm-02) using Wiley - mill (Thomas Scientific). The proximate chemical properties evaluated through powdered accepted chips were: ash (TAPPI T 244 cm-99); cold water solubility, hot water solubility (TAPPI T 207 cm-99); 1% NaOH solubility (TAPPI T 212 om-98); alcohol-benzene solubility (TAPPI T 204 cm-97), holocellulose (TAPPI T 249 cm-00); and klason lignin (TAPPI T 222 om-02), pentosan (T 223 cm-84); alpha cellulose (TAPPI- 203 cm-99).

2.3. Kraft pulping and pulp properties

The accepted chips of hardwoods and their blend were processed for kraft pulp in a series digester (STALSVETS, Alfa Aval Group, Sweden) at laboratory. The pulping process was carried out at 1600C with 16% NaOH charge as Na_2O, 1:3.5 solid to liquid ratio (SLR) and 90 min. time with sulphidity 20%. After cooking the pulp was washed properly and centrifuged and screened in Somerville vibratory screen using the mesh of 0.25 mm to separate the rejects. The unbleached pulp was evaluated for kappa number (TAPPI T 236 om-06), viscosity (SCAN C 15:65), brightness (ISO 2471) and freeness (ISO DP 5269).

2.4 Black liquor characterization

The black liquor obtained after kraft pulping was characterized for pH, total solids (TDS) T-650 pm-84 and residual active alkali (RAA) T-625 cm-85.

2.5 Bleaching

The elemental chlorine free bleaching (ECF) was carried out at laboratory scale following OD0EopD1 sequence to achieve pulp brightness ~85% ISO. The kraft pulp (100 g OD) was oxygen delignified with oxygen pressure (5kg/cm2), NaOH (1%) at 900C for 60 minute. The chemicals applied in ECF bleaching were chlorine dioxide (D0) 2.5% at 700C for 60 minute, pH 3 , extraction with peroxide (Eop) NaOH 2%, H_2O_2 1.5% 800C for 75 min, pH 12 and chlorine dioxide (D1) 1% 750C for 180 minute, pH 3. The polythene bags and hot water bath (Julabo TW 20, Germany) were used for bleaching. The pulp was thoroughly washed in Buchner funnel vacuum pump with tap water after each stage of the bleaching sequence. The pH of the pulp was maintained with H_2SO_4 and NaOH. The bleached pulp kappa number, brightness, viscosity and yield were measured with method as in kraft pulp above.

2.6 Fibre classification and physical testing of sheets

The Bauer McNett fibre classification of unbleached pulp was done according to T 233 cm-82 method. Handsheets of 60 gsm were prepared with British sheet former machine according to the ISO 5364 standard, sheets were evaluated on basis weight (ISO 536), burst index (ISO 2758), tensile index (ISO 1924), tear index (ISO 1974) and fold Kohler Molin (ISO DIS 5626).

3. RESULTS AND DISCUSSION

3.1 Physical Properties

The physiochemical properties of wood chips were analysed as shown in figure 1. Wood density is considered an essential parameter and affects the strength and physical characteristics of paper sheet (9). It was observed that M. dubia wood carry a low basic and bulk density followed by C. equisetifolia and E. tereticornis. However the after blend of M. dubia with E. tereticornis and C. equisetifolia the chips basic density decrease by 3.8% and 1.96 % and bulk density 3.04% and 0.90% respectively. According to different studies on hardwoods, the wood having basic density near 500 kg/m3 has positive influence on pulping due to easily liquor penetration, low vessel or parenchyma content, low amount of rejects and good resistance of the pulp (10).

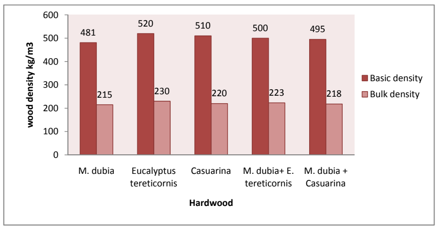

Figure 1: *Wood density of hardwoods*

The chemical properties of hardwood are given in table 1. The ash content comprises of SiO_2, Ca, Mg, Fe, Co, K and Mn and a high amount of ash has effect on recovery plant (11-12). Here in E. tereticornis the ash was lowest while highest for M. dubia. After blending of M. dubia the ash increased in E. tereticornis by 0.03% and in C. equisetifolia by 0.02%. The low ash content in raw material is preferred to decrease the scaling and corrosion problem during recovery operation (13). The lignin content influences the pulping time and chemical charge. High lignin corresponds to more pulping time and more chemical charge during bleaching (14). Klason Lignin is slightly high in M. dubia as compared to E. tereticornis and C. equisetifolia and after blending lignin increases by 1.8 % in E. tereticornis and 0.64 % in C. equisetifolia. Pentosan content was highest for M. dubia and lowest in C. equisetifolia. The pentosan shows increase of 1.72% in E. tereticornis and 1.1% in C. equisetifolia after blending. The water solubility of E. tereticornis is high followed by C. equisetifolia and M. dubia and after blending water solubility shows a decrease of 0.05% in E. tereticornis and 0.29% in C. equisetifolia. The alcohol benzene solubility and 1% NaOH solubility is lowest in M. dubia as compare to E .tereticornis and C. equisetifolia. After blending C. equisetifolia and E. tereticornis shows decrease of alcohol benzene solubility by 0.09%, 0.04% and NaOH solubility 0.16% and 0.09% respectively. The lower extractives are preferred in pulping as these create lesser pitch problems and generate more clean paper sheet (15-16).

Table 1: *Physical and chemical characteristics M. dubia, E. tereticornis and C. equisetifolia*

Parameters	M. dubia	E. tereticornis t	C. equisetifolia	M. dubia+ E. tereticornis	M. dubia + C. equisetifolia
Ash	0.65	0.60	0.62	0.63	0.64
Lignin	26.27	25.8	24.96	26	25.6
Pentosan	16.60	13.38	14.6	15.1	15.7
Hot water	4.12	4.26	4.85	4.21	4.56
Cold water	0.56	0.61	0.52	0.58	0.54
1% NaOH	15.7	16.04	15.89	15.88	15.80
Alcohol Benzene	3.52	3.66	3.58	3.57	3.54
Cellulose Holo	82.5	71.3	80	77	81.3
Alpha	49.5	42	46	45.78	48

The total cellulose content shows highest percentage in M. dubia. After blending the cellulose content increases in E. Tereticornis substantially 6.35% and marginally in C. equisetifolia 1.3%, alpha cellulose increases by 3.78% and 2%.

3.3 Kraft pulping

Table 2 shows the kraft pulping results of the individual and mixed hardwood. The carbohydrate content in raw material pulp is represented by yield of pulp and it is high in M. dubia with low rejects as compare to E. tereticornis and C. equisetifolia. After blending of M. dubia in E. tereticornis and C. equisetifolia the yield increases 4.96 % and 4.55 % respectively and the rejects decreases by 0.4 % in both E. tereticornis and C. equisetifolia. The kappa number and the viscosity are low in M. dubia followed by C. equisetifolia and E. tereticornis. After blending kappa number reduces by 8.46 % and 9.14 %, viscosity by 2.46 % in E. tereticornis and 1.9 % in C. equisetifolia respectively. The brightness of the pulp is high in M. dubia and low in E. tereticornis and after the blending brightness increases in E. tereticornis by 1.45 % and C. equisetifolia by 0.85 %. The increase in brightness and decrease in viscosity corresponds to low kappa number which represents the lignin in pulp.

Table 2: *Kraft pulp properties of hardwoods*

Kraft pulp	M. dubia	E. tereticornis	C. equisetifolia	M. Dubia + E. tereticornis (50:50)	M. dubia+ C. equisetifolia (50:50)
Unscreened pulp yield%	51.63	46.6	47.18	51.16	52.23
Screen rejects%	0.25	1.5	1.2	1.1	0.80
Screened Yield %	51.28	45.1	46.88	50.06	51.43
Kappa number	15.10	18.2	17.5	16.66	15.9
Brightness ISO%	32.10	29.2	30.4	30.65	31.25
Viscosity	785	812	804	792	788
Black liquor properties					
pH	12.85	13.22	13.37	13.39	13.44
RAA, gpl as Na_2O	7.56	5.95	5.33	6.74	6.68
Total solids %	16.6	18.64	16.96	17.8	16.7

The black liquor pH was observed ~13 in the studied individual hardwoods and in the blend sample. The RAA was high in M. dubia as compare to E. tereticornis and C. equisetifolia and after the blending RAA increases 0.79 % and 1.35 % in E. tereticornis and C. equisetifolia respectively. The total solid percentage was high in E. tereticornis and low in M. dubia and after blending decrease by 0.84 % and 0.26% respectively in E. tereticornis and C. equisetifolia.

3.4 ECF bleaching

In table 3 the results of elemental chlorine free bleaching (OD0EopD1) are given. The first stage of ECF bleaching with oxygen shows increase in brightness (M. dubia 8.85%, E. tereticornis 8.86 % and C. equisetifolia 9.42 %) with decrease of kappa number (M. dubia 45.36%, E. tereticornis 44.39% and C. equisetifolia 31.01%) and drop in viscosity (M. dubia 13.69%, E. tereticornis 15.64% and C. equisetifolia 15.84%). The outcomes of oxygen delignification are affected by the initial pulp kappa number, pulp pH, consistency, oxygen pressure and duration of delignification (17).

ODL is followed by D0EopD1 bleaching. After first stage of bleaching i.e. chlorine dioxide (D0) treatment the brightness increases (M. dubia 11.4%, E. tereticornis 11.9% and C. equisetifolia 11.7%) with decrease in kappa number (M. dubia 30.95%, E. tereticornis 48.78% and C. equisetifolia 47.29%) and viscosity (M. dubia 10.72%, E. tereticornis 16.13% and C. equisetifolia 14.45%).

After second stage of bleaching i.e Eop stage there is increase in brightness (M. dubia 29.7 %, E. tereticornis 26.9% and C. equisetifolia 27.1 %) with decrease in kappa number (M. dubia 50.8 %, E. tereticornis 48.8% and C. equisetifolia 47.3 %) and viscosity (M. dubia 12.7%, E. tereticornis 6 % and C. equisetifolia 8.5%).

In the final chlorine dioxide stage the brightness increases (M. dubia 8.34%, E. tereticornis 10.34% and C. equisetifolia 10.59%) with decreases in kappa number (M. dubia 35.48%, E. tereticornis 14.28 % and C. equisetifolia 17.94 %) and viscosity (M. dubia 15.7 %, E. tereticornis 14.43 % and C. equisetifolia 15.6%).

After blending of M. dubia to E. tereticornis and C. equisetifolia the brightness increases by 2.15% and 2.08 % respectively in the final stage with decrease in kappa number by 13.33% and 31.25% and viscosity by 0.9 % and 0.14% respectively. M. dubia shows a higher yield after bleaching and its blending increase the yield of E. tereticornis by 0.6 % and C. equisetifolia by 0.5 %.

3.5 Bauer Mcnett Classification And Physical Strength Properties

Table 4 shows the Bauer McNett fibre classification based on the weighted average fibre length. Fibre length is the fundamental property of pulp and its distribution through different mesh size

Table 3: *ECF bleaching of kraft pulp of hardwoods using OD0EopD1 sequence*

Oxygen Delignification	M. dubia	E. tereticornis	C. equisetifolia	E. tereticornis +M.dubia (50:50)	C. equisetifolia +M. dubia (50:50)
Brightness, %ISO	40.95	37.80	39.82	38.82	40
Kappa number	8.25	10.12	8.49	9. 67	8.3
Viscosity, mPa.S	677. 52	685	676.6	683.5	677
D0 Stage					
Brightness, %ISO	52.35	49.7	51.6	50.5	52
Kappa number	6.3	8.2	6.9	7.4	6.45
Viscosity, mPa.S	604.88	574.5	598.4	584.7	602.2
Eop Stage					
Brightness, %ISO	82.06	76.60	80.28	77.61	81.41
Kappa number	3.1	4.2	3.4	3.9	3.25
Viscosity, mPa.S	528.25	540	531	535	529
D1 Stage					
Brightness, %ISO	90.40	86.94	89.09	88.20	90.28
Kappa number	2	3.6	3.12	3.2	2.2
Viscosity, mPa.S	445.3	462.06	458.07	451.47	449.8
Yield%	95	93.6	94	94.2	94.5

(+30 to -200) shows percentage of fibre at each mesh. The +30 fraction is an indication of presence of coarse fibre in pulp sample and considered as a hindrance in paper sheet formation and smoothness properties, while + 50 and +100 are referred as useful fibres. The normally considered useful fibre at +50 is high in all studied hardwoods and their blends. In case of M. dubia and C.equisetifolia the percentage is more than 60% at + 50 while in E.tereticornis it is 50%. After blending the percentage of fibre increased at +50 mesh size in E.tereticornis by 7.8% and C.equisetifolia by 1.5%. In E. tereticornis and C. equisetifolia the second level of high fibre % is at +30 mesh sizes and for M. dubia it is at +100 mesh size. While the blending of M. dubia shows a 3.1 % decrease in fibre at +30 mesh size in E. tereticornis and 5.7%. in C. equisetifolia by The sum of each hardwood fibre in different mesh size is observed 100, which shows the accuracy in fibre distribution through Bauer McNett classifier.

In the physical strength properties as shown in table 5 the basis weight i.e. weight in grams per unit area of the paper is high in C. equisetifolia followed by M. dubia and E. tereticornis. The burst index in M. dubia and C. equisetifolia pulp sheet is high as compared to E. tereticornis. The tensile index is high in M. dubia followed by C. equisetifolia and E. tereticornis. The fold Kohler molin log value is high for M. dubia as comparing to E. tereticornis and C. equisetifolia. The tear index is less in M. dubia and after blending the tear index of E. tereticornis and C. equisetifolia decreased.

Table 4: *Bauer McNett classification of unbleached kraft pulp with 450 CSF*

Raw material	+30	+50	+100	+200	-200
M. dubia	7	68.2	12.4	5.3	7.1
E.tereticornis	17.6	50.2	11.2	10	11
E. tereticornis+M. dubia	14.5	58	8.2	9.8	9.5
C. equisetifolia	19.5	62.9	4.5	0.4	12.7
C. equisetifolia + M. dubia	13.8	64.4	8.3	3.2	10.3

Table 5: *Physical strength properties of mixed hardwood pulp at 400 CSF*

Material	Basis weight g/m^2	Burst index k $Pa.m^2/g$	Tensile Index Nm/g	Fold kohler molin (log)	Tear Index $mN.m^2/g$
MD	63.65±0.16	5.5±0.30	75.90±0.4	4±0.0	7.58±0.14
ET	63.32±0.14	4.09±0.27	74.27±0.9	3±0.0	7.92±0.15
CE	65.24±0.11	5.19±0.17	75.25±0.4	3±0.0	7.69±0.12
Blend 1	63.46±0.14	4.79±0.22	75.61±0.6	4±0.0	7.60±0.11
Blend 2	65.34±0.24	4.89±0.19	75.75±0.3	4±0.0	7.64±0.13

MD: M. dubia, ET: Eucalyptus tereticornis, CE: C.equsetifolia, Blend 1: MD+ ET, Blend 2: MD+CE

CONCLUSIONS

The studied hardwood shows the suitability in making the good quality pulp suitable for writing grade paper. After blending of M. dubia in E.tereticornis tereticornis and C. equisetifolia following satisfactory improvements were concluded:

The impact of M. dubia blending on E.tereticornis tereticornis showed more impact as compared to C. equisetifolia. In proximate analysis after blending the amount of pentosan increased in E.tereticornis and C.equisetifolia which reveals the presence of hemicelluloses in material which helps in retaining the strength in pulp during refining. The decrease in extractives after blending contributes to formation of more homogeneous pulp sheet.

After blending the increase in brightness in kraft pulp and during ECF bleaching with decrease in kappa number and increase in yield contribute to improved pulp properties of E.tereticornis and C.equisetifolia.

The black Liquor RAA increase after blending and is useful during recovery as it get precipitated at low solids concentration during evaporation, which eventually increases black liquor viscosity.

Bauer McNett fibre classification shows increase in useful fibre length in E.tereticornis and C.equisetifolia.

In a nut shell M. dubia is a very potential alternate hardwood being used in pulp and paper industry. It is also a fast growing species, and has a very easily adoptable option before pulp and paper industry.

ACKNOWLEDGEMENT

Deepika would like to express her gratitude to University Grants Commission, India for awarding Ph D research fellowship. Authors also express their thankfulness to Mr. Vinay Swaroop (JRF), Ms. Gunjan (JRF), Mr. Mussadilal Semwal (Lab Technician) at PCPB lab and all the divisions of Central Pulp and Paper Research Institute, Himmat Nagar, Saharanpur, 247001, Uttar Pradesh India for their technical and analytical support in lab work.

REFERENCES:

1. Central Pulp and Paper Research Institute, Annual Report (2017-18). Saharanpur (Uttar Pradesh), India.
2. B.P.Thapliyal, K.Singh and R.Tandon, Census Survey of Indian

pulp and Paper Industry, International Conference,PAPEREX-2017.

3. Kulkarni H. D. (2013). Pulp and Paper Industry Raw Material Scenario - ITC Plantation A Case Study, IPPTA, 25.

4. Nandkumar P., (2009): Effects of Pulp Blending on Strength Properties of Ipomoea carnea Jacq, Asian Journal of Chemistry, 21, 4571-4576.

5. Sood, Y. V., Pande, P. C., Tyagi, S., Payra, I., Nisha, Kulkarni, A.G., 2005. Quality improvement paper from bamboo and hardwood furnish through fibre fractionantion. Journal of scientific and Industrial Research, 64, 299-305.

6. Jahan, M.S., Sarkar, M., Rahman, M. (2015): Mixed Cooking of Bamboo with Hardwood. Cellulose Chemistry and Technology, 51(3-4),307-312.

7. Goswami, T., Saikia, C.N. (2000): Mixed pulping of certain annual non-wood plants with wood and bamboo: Evaluation of pulp properties.

8. Ahvazi, B., Radiotis, T., Bouchard, J. (2007): Chemical Pulping of Steam-Exploded Mixed Hardwood Chips. Journal of Wood Chemistry and Technology, 27, 49–63.

9. Sankaralingam, P., Chinnaraj, S., Subramanian, S. (2017): Pulping and bleaching of Melia dubia clone k10: a short rotation pulp wood clone to improve environmental and economical performance. IPPTA, 29, 1-8.

10. Resquin, F., Barrichelo L.E.G., Junior F.G.D., Brito J.O., Sansigolo C.A. (2006): Wood quality for kraft pulping of E. tereticornis globulus origins planted in Uruguay. Scientia Forestalis 72, 57-66.

11. Dutt, D., Tyagi, C.H. (2011): Comparison of various E.tereticornis species for their morphological, chemical, pulp and paper making characteristics. Indian Journal of Chemical technology, 18, 145-151.

12. Goel, V.L. and Behl, H.M. (1996): Fuelwood quality of promising species for alkaline soil sites in relation to tree age, Biomass Bioenergy, 10, 57-61.

13. Sharma, A. K., Anupam, K., Swaroop, V., Lal, P., S., Bist, V., (2014). Pilot scale soda anthraquinone pulping of palm oil empty fruit bunches and elemental chlorine free bleaching of resulting pulp. Journal of Cleaner Production, 106, 422-429.

14. Khristova P., Kordsachia O., Khider T., (2005): Alkaline pulping with additives of date palm rachis and leaves from Sudan, Bioresources Technology, 96, 79-85.

15. Anupam, K., Swaroop, V., Sharma, A., K., Lal, P., S., Vimlesh, B. (2015): Sustainable Raw material selection for pulp and paper using SAW Multiple Criteria Decision Making Design. IPPTA, 67-76.

16. Kasiviswanathan, K.S., (1998): Utilization of bagasse for paper making- An overview, IPPTA, 10, 9 – 14.

17. Anupam, K., Deepika, Swaroop, V., Lal, P.S. (2018): Antagonistic synergistic and interaction effects process parameters during oxygen delignification of M. dubia kraft pulp. Journal of Cleaner Production, 199, 420-430.