Cost-Effective Production Of Handmade Paper Through Recycling Of Shredded Currency Waste Of Reserve Bank Of India- An Enzymatic Route

Chauhan Sunita, Khan M.E., Sharma A.K., Jain R.K., Hussain G.

ABSTRACT

With the growing demand of handmade paper both in the domestic and export markets, the Indian handmade paper industry has been confronting with the major issue of scarce availability and cost prohibitiveness of the cotton hosiery waste, the traditionally used principal raw material for making handmade paper. As a result of the exhaustive R&D work carried out at Kumarappa National Handmade Paper Institute, various ligno-cellulosic raw materials available as waste biomass in different parts of country and the recycled waste paper particularly the shredded currency waste of Reserve Bank of India has been found to be very good and cost effective raw material for making good quality handmade paper.

The recently developed process of recycling the shredded currency waste through bio-enzymatic pulping produces not only a quality handmade paper but also resulted in a large saving of the precious resources like water, energy and chemicals. Physical strength properties of the handmade paper developed from shredded currency waste were found to be better than that produced from mixed office waste (MOW). Besides, Shredded currency waste is available at a much cheaper rate than the waste paper. The strength of the paper produced from it could be improved further by blending it with the pulps prepared from mixed hosiery waste or other long fiber pulps. The paper thus produced can be utilized for making strong carry bags so as to substitute the polythene bags that are going to be banned because of their recalcitrant nature. The process has been successfully up-scaled to the pilot-plant level and is also found to be economical. Thus the adoption of the shredded currency waste as a raw material and its processing through enzymatic route might help in improving the cost-competitiveness and environmental status of the Indian handmade paper industry.

INTRODUCTION

The new millennium is going to be the millennium of literacy. So demand for paper would go on increasing in times to come. In view of paper industry's strategic role for the society and also for the overall industrial growth, it is necessary that the paper industry performs well. The demand for upstream market of paper products, like, tissue paper, tea bags, filter paper, light weight online coated paper, medical grade coated paper, etc., is growing up. These developments are expected to give stimulus to the industry in the present period of recession.

Unlike the mill made paper, handmade paper is produced by hand at much slower speeds.
Handmade paper units are defined essentially by the fact that their operations are carried out manually. But the handmade paper has several excellent qualities when contrasted with those of mill-made paper. It is elegant in appearance and provides an exquisite surface for writing. It has good strength and is practically indestructible; it actually has double the strength of mill-made paper and does not turn brittle with age. It can be used for several artistic and decorative purposes. For these reasons, it fetches a better price than mill-made paper. The handmade-paper industry is a good example of a sustainable model of development which meets several desirable criteria: it is eco-friendly and provides rural employment for both men and women, usually near their homes, since the industry can be located near villages. Various kinds of handmade papers such as bond paper, drawing paper, superior card paper, filter paper/board, watermark paper etc., can be manufactured by units in small scale sector using easy techniques.

The Indian handmade paper industry has been confronting with various issues like scarce availability and cost prohibitiveness of the cotton hosiery waste, being used traditionally as the major raw material, inconsistent quality and cost effective production of Handmade paper. Rags are traditionally used principle raw material for making handmade paper but with the growing demand of handmade papers, the availability of rags is getting limited therefore the adoption and utilization of alternative raw materials is getting impetus. With the extensive R & D efforts carried out at KNHPI, it has been found that a number of ligno-cellulosic raw materials available as waste biomass in different parts of the country viz. banana waste leaves/fiber , Pineapple fiber and leaves (**Ananas Comosus**), sunn hemp (**Crotolaria Juncea**), jute (**Corchorus Capsularis**) , Bhimal (**Grewia Oppositifolia**) and Ankara (**Calotropis Procera**), certain forest weeds like bodha grass(**Chloroxylon coloratus**) or Mentha (**Mentha Piperita**), non-woody agro residues like straws, recycled waste paper and shredded currency waste of Reserve Bank of

Kumarappa National Handmade Paper Institute
Ramsinghpura- Sikarpur Road,
Sanganer, Jaipur (Raj)

India, etc. have been identified as alternative raw materials for making handmade paper. Among the recycled fibers, shredded currency waste has been identified as a good source of cellulosic fiber for making handmade paper.

Keeping in view all the above, the present study was taken up to explore and establish the utility of shredded currency waste of Reserve Bank of India (RBI) for making quality handmade paper through evaluation of the raw material as such and development of its recycling procedure in a cost-effective and ecofriendly manner.

REVIEW OF LITERATURE

As far as waste paper in the form of shredded currency waste of Reserve Bank of India is concerned, its effective disposal has been one of the major challenges before Reserve Bank of India. There are nearly 19 branches of Reserve Bank of India located in the metro & other big cities of India (e.g. Jaipur, Chennai, Kolkata, Luknow etc.) that are generating significant quantities of shredded currency paper waste in the form of compressed briquettes. As per the estimates, 10,000T / annum of shredded currency in the form of briquettes which has not been effectively disposed creates problem of solid waste disposal pollution.

The earlier method of disposal of shredded currency waste was a tedious task wherein the punched notes & bits had to be burnt within RBI premises under the supervision of team of senior officials of Reserve Bank of India. In this process, the torn notes used to be destroyed by incinerators in brick kiln incinerator & through water-jacketed fire incinerator. Incineration had been the most costly discard management option producing toxic ash. The process of burning the currency notes was causing the problem of air pollution since the currency notes coated with chemicals, pigments & colours release toxic gaseous & harmful pollutants. This method of disposal was in no way eco-friendly.

Subsequently, at the intervention of pollution control authorities, the currency waste paper was shredded to $1/10^{th}$ mm size to convert into the briquettes employing the briquetting plant imported from Germany, which used a very high pressure to convert shredded currency waste into briquettes. Having set up a briquetting plant imported from Germany to convert the shredded currency waste into solid briquettes of size 15 cmX 8.75 cmX 6 cm, Reserve Bank of India was facing the problem of storage of huge heaps of briquettes that did not find an effective way to utilize and its disposal in an economical way. Subsequently Reserve Bank of India approached Kumarappa National Handmade Paper Institute to explore the potential of converting the waste material into handmade paper /handmade paper products. Having done extensive Research & Development work, Kumarappa National Handmade Paper Institute could develop a technology for conversion of the shredded currency waste into a good quality handmade paper. The handmade paper and paper board produced was converted into file covers, envelopes, pamphlets & other stationery items which were supplied continuously to various branches of Reserve Bank of India and KVIC offices.

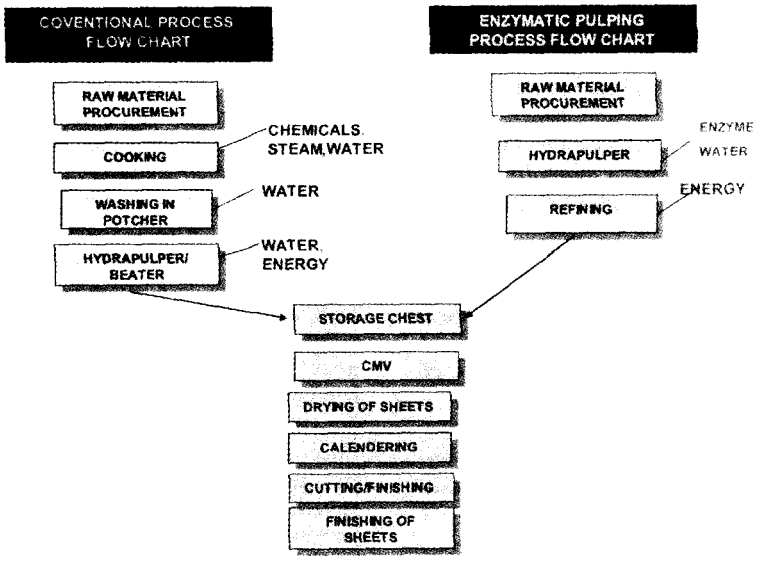
The process developed utilizes cooking of the raw material in rotary digester & the cooked pulp is washed in the Potcher washer with the help of a rotating drum washer provided with a wire mesh and sent to Hydra-pulper for shredding the larger chips to smaller size. The pulp is then taken to beater followed by Cylinder Mould Vat Machine for sheet making. The rest of the procedure is followed as per the Process Flow Chart given below. Thus, this process involves a stage of pressurized digestion, washing, processing in hydra-pulper, beating and sheet making.

On having a look at the process technology, it could be realized that the amount of energy, chemicals and water consumed is much more and there might be the possibilities of conserving all such valuable resources through the utilization of certain enzymes. Further looking into the interaction with the industry personnel and requirements of the industry to improve its status in terms of ecofriendly credentials, it was conceptualized to explore the possibilities of biotechnological implications (enzymatic treatment of the raw material i.e. shredded currency waste) to partially/wholly replace the use of chemicals and steam energy and thereby making the process more ecofriendly to produce ecofriendly handmade paper /board/ its products.

Therefore, possibilities of incorporating certain enzymes during recycling of the currency waste were explored in the present study.

EXPERIMENTAL

Looking into the extensive use of steam, beating energy, chemicals and



water during pulping, hydrapulping and beating process of the recycling of shredded currency waste of RBI through the conventionally used process developed at KNHPI in the past, the present study was carried out with an aim to conserve the valuable resources of water and energy besides saving chemicals. For this, various permutation and combination of different enzyme samples under different operating conditions with different samples of surfactant were studied besides conducting the proximate analysis of the shredded currency waste of Reserve Bank of India. The present study was carried out under the following lines of investigation:

- Proximate analysis of the shredded currency waste of RBI
- Effect of beating and refining on the currency waste
- Optimization of the conditions of enzyme treatment
  - Effect of different pretreatments before the enzyme action
  - Effect of fibrillation on enzyme treatment
  - Effect of different surfactants on enzyme treatment
  - Effect of soaking time period on enzyme action
- Comparison of the pulp prepared by enzymatic pulping with that prepared from pressurized digestion
- Fiber morphological studies of the pulps prepared
- Pilot plant trial of the process
- Calculation of enzyme-economics

RESULTS & DISCUSSION

Proximate Analysis of the shredded currency waste (SCW): On evaluation of the currency waste for its proximate analysis, it was found to be having a very high content of holocellulose to the level of more than 88%. There was about 84% alpha cellulose with merely 1.2% of the Klason lignin (table-1). This implies that the SCW can be a very good source of cellulosic raw material for papermaking.

Effect of Beating and Refining On the Currency Waste:

The enzyme treated shredded currency waste was subjected to the mechanical action in the Hollander Beater for preparing pulp but it was found that even after extensive beating operation, proper pulp could not be formed. There were lot of chips in the pulp obtained and suitable bonding could not occur among the pulp-fibers so sheet formation was showing difficulties. It was impossible to couch an unbroken sheet. Edges of the sheets formed were also not proper. Therefore, refiner was introduced to prepare pulp from the enzyme-treated currency waste. With the help of mechanical action provided through refiner, a very good bonding effect could be seen as it resulted into a better sheet formation without broken edges. It was easy to couch also. Therefore, in all the subsequent experiments, refiner was used for preparing the pulp from enzymatically treated currency waste and the whole process was regarded as the bio-enzymatic pulping.

Effect of Different Pretreatments before Enzyme Action:

To improve the efficacy of enzyme treatment or action of enzymes on the SCW, different kinds of pretreatments like boiling in water for a period of 1.5 hrs, Acidic treatment of currency waste with 2% Sulfuric acid at 50° C were tried. The strength properties of the paper obtained are given in table-2. It is obvious from the table that boiling of the shredded currency waste prior to enzyme treatment was quite effective for a better action of enzyme because it resulted into the best properties of strength.

Effect of Fibrillation on Enzyme Treatment:

Having seen that boiling is giving best results for softening of the currency waste, it was examined whether a slight fibrillating action on the boiled currency waste has any effect on enzyme action. For this, the shredded currency obtained after boiling was divided into two fractions, one was subjected to a slight fibrillation in the beater and another was not. Both the fractions were then soaked with the similar doses of enzymes and surfactant for the overnight period. Both the treated currencies were then processed for making paper and strength

Table-2: Effect of Different Pretreatments before Enzyme Treatment

Parameters	B Boiling-Fibrillation-Enzyme soaking	C Acid (2% at 50deg.C) - Fibrillation-Enzyme soaking
Enzyme Dose	0.5% E_B, 0.25% E_D	0.5% E_B, 0.25% E_D
Tensile index	14.31	13.77
Tear index	6.20	5.56
Burst index	0.857	0.622
Double fold	27	12

Table-3: Effect of Fibrillation on Enzyme Treatment

Parameters	Boiling-Fibrillation-Enzyme soaking (A)	Boiling-Enzyme soaking Without fibrillation (B)
Enzyme Dose	0.5 % E_B, 0.25% E_D	0.5 % E_B,0.25% E_D
Tensile index	18.50	10.37
Tear index	6.20	4.56
Burst index	1.39	0.41
Double fold	62	06

Table-1: Proximate Analysis of Shredded Currency Waste of RBI

S.N	Particulars	Result
1	Cold water solubility, %	5.0
2	Hot water solubility, %	12.5
3	1 N NaOH solubility, %	18.5
4	Alcohol-Benzene solubility, %	6.0
5	Holocellulose, %	88.32
6	α - Cellulose, %	83.66
7	Klasson Lignin, %	1.2
8	Ash, %	3.70

properties were evaluated. From the table-3, it is obvious that the fibrillation has a very positive role in enzyme action as it gives a better quality pulp in terms of physical strength properties. It has been also reported in the literature that the most important basic elements defining the success in enzyme-fiber interactions are the enzyme and fiber characteristics. The source and history of the fiber e.g. the delignification method and drying, the extent of fibrillation and presence of fines, have a significant role in controlling the binding and accessibility of enzymes on the external and internal surfaces of the porous fibers. In mill conditions, mechanical forces and process additives can also have effects on the enzyme reactions.

Effect of Different Surfactants on Enzyme Treatment:

Three different kinds of surfactants available commercially were added during enzymatic treatment of the shredded currency waste under optimized conditions. The physical strength properties of the pulps obtained were compared and given in table-4. It was found that surfactant-B is most effective for improving the enzyme action on shredded currency waste.

Effect of Soaking-Time Period on Enzyme Action:

With an aim to reduce the soaking time of enzyme treatment of the currency waste, one lot of shredded currency after a period of 3 hrs. was taken out to process for making paper and the rest was processed similarly after the overnight soaking and strength properties of both the pulps were compared together as given in table-5. It was observed that a soaking time of 3hrs. is sufficient enough for the enzyme action as the strength properties were found to be more or less equivalent, rather a shorter period of soaking showed a slightly better results in terms of burst index.

Final Optimized Conditions of Enzyme Treatment:

With the optimization studies carried out as above, the treatment conditions optimized for enzyme treatment were as below (Table-6)

Comparison of the strength properties of the pulps prepared from enzymatic pulping and from pressurized digestion of shredded currency waste:

Both the pulps obtained from enzymatic pulping of shredded currency waste and from the pressurized digestion of shredded currency waste were evaluated for their physical strength properties as given in table-7. As could be seen from the table, pulp obtained from the enzymatic pulping gave better strength properties as compared to the conventionally obtained pulp. In the conventionally used recycling process of shredded currency waste, beater is used for preparing the pulp obtained from pressurized digestion, while in the present process of enzymatic pulping, beater was not found to be suitable for preparing the pulp because lot of chips were there even after extensive beating action. Therefore, refiner was used and this could give a very good quality of pulp as is obvious from the table. Refining resulted in a better pulp in the case of conventionally cooked pulp also.

Table-7: Comparison of the pulp prepared from enzymatic pulping and from pressurized digestion of the shredded currency waste

Sample code	Sample	Brightness, % ISO	Tear index	Tensile Index	Double fold	Burst index
SCW-T	Enzyme treated, refined	50.9	5.25	23.01	13	1.25
SCW-CB	Cooked pulp, beating	52.02	4.13	16.70	6	0.72
SCW-CR	Cooked pulp, refining	52.4	5.21	16.26	6	0.81

Table-4: Effect of Different Surfactants on Enzyme Treatment of SCW

Parameters	A Boiling-Fibrillation-Enzyme soaking	B Boiling-Fibrillation-Enzyme soaking	C Boiling-Fibrillation-Enzyme soaking
Enzyme Dose	0.5% E_B,0.25% E_D	0.5% E_B,0.25% E_D	0.5% E_B,0.25% E_D
Surfactant used	A, 0.2%	B, 0.2%	C, 0.2%
Tensile index	14.31	19.95	16.54
Tear index	6.2	6.38	6.31
Burst index	0.857	1.04	0.87
Double fold	27	37	36

Table-5: Effect of Soaking Time Period on Enzyme Action

Parameters	A	B
Soaking period	3 Hrs.	Overnight
Tensile index	20.3	19.95
Tear index	6.5	6.38
Burst index	1.24	1.04
Double fold	40	37

Table-6: Optimized Conditions for Enzymatic Treatment of SCW

Enzyme dose	**0.5% E_B, 0.25% E_D**
Surfactant	**0.1%**

Pilot-Plant Trial

Using the conditions as optimized above, plant trial of recycling shredded currency waste of RBI with the application of enzymes was carried out in the Hydrapulper. After the enzymatic pulping, the treated currency waste thus obtained was passed through refiner to reach a CSF level of around 225-250ml. This pulp was then used to make sheets both on the Auto vat and Cylinder Mould Vat. Physical strength properties of the paper developed are given in table-8.

Table-8: Physical Strength Properties of the Pulp Obtained From Plant Trial

Parameters	Values
Tensile index	21.67
Tear index	6.99
Burst index	1.11
Double fold	62

Table-9: Characterization of effluents generated

Parameters	Black liquor generated from conventional pulping	Liquor generated from enzyme treatment of shredded currency waste
Total solids, %	3	0.68
Suspended solids,%	0.17	0.10
RAA, gpl	0.896	n.a.
COD, ppm	38,000	8800

Characterization of the effluents generated:

The effluents generated from the two processes were characterized in respect of Total solids, suspended solids, COD, Residual Active Alkali (RAA). Results are shown in table-9. From the results, it is obvious that reduction in COD to the tune of more than 75% could be obtained in the case of the enzymatic pulping process as compared to the pressurized digestion process. A similar trend was observed for reduction in total solids and other parameters.

Photomicrography of the pulps obtained from enzymatic route and conventionally used pressurized digestion:

In order to understand the actual mechanism of enzyme behavior involved and the noble action played by these specific enzymes, the fiber morphological studies using 'Fiber Analyzer' and the images of the pulp produced from the pressurized digestion of the shredded currency waste and the enzymes treated and control samples were carried out.

As evident from the photomicrographs, it has been observed that a higher degree of fibrillation was there in the enzyme treated and refined fiber compared to the fiber obtained from cooking of the shredded currency waste under alkaline conditions. Further, the effect and advantage of refining can also be seen from the photomicrographs shown in the figure wherein, it can be clearly visualized that the refining increased the fibrillation over the beating operation. The photomicrographs further showed fibrils forming bonds between adjacent or crossing fibers stretching out and forming a bond to the carbon base. In many cases, instead of thread like fibrils, very thin surfaces of planar fragments were found. Part of the fibers

Figure-a

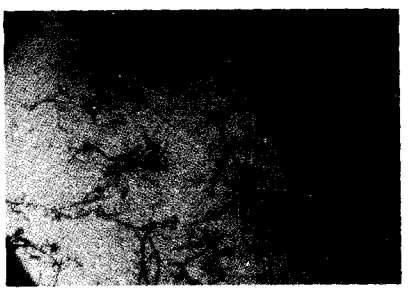


Figure-b

Figure-c

Fiber photomicrographs of shredded currency pulp

Figure-d

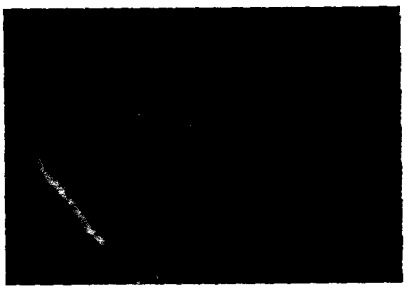


Figure-e

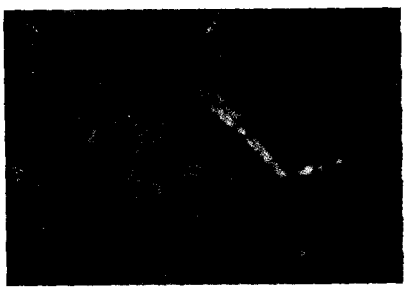


Figure-f

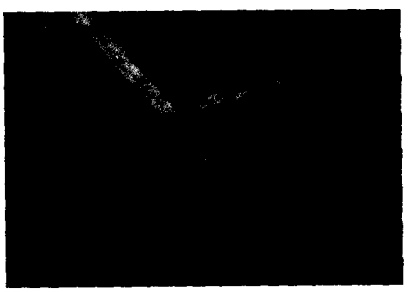


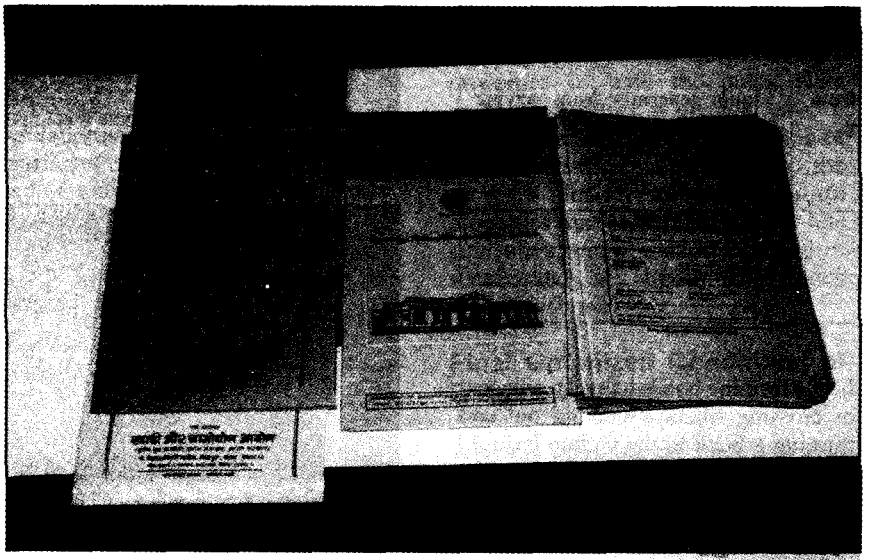
Figure-g

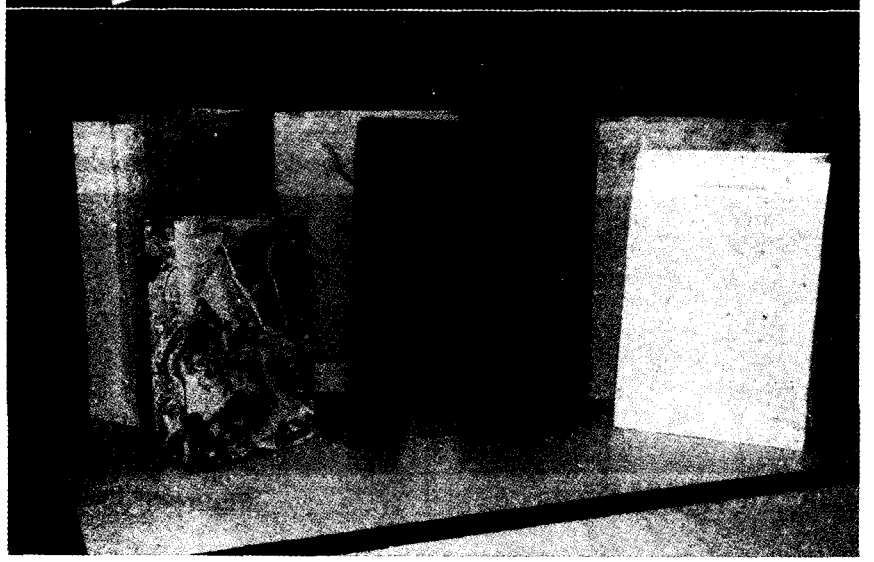
Figure-h

were still intact even after refining probably due to the inhomogeneous nature of the pulp produced from shredded currency waste using the above said processes. Based on the physicochemical properties, it appears to be possible that improved sheet properties from enzyme treated refined pulp resulted from improved fibrillation during refining process due to a modification of the fiber surface by the combination of enzymes used.

Table-10: Blending Characteristics of the pulp obtained through enzymatic route

Parameters	SCW-100%	WP-100%	SCW+WP (50%+50%)	MH-100%	SCW+MH (50%+50%)	BG-100%	SCW+BG (50%+50%)
Brightness,% ISO	45.06	49	38.2	32.3	36	17.9	25.2
Tensile index	18.65	12	14.41	15.53	15.64	20	15.9
Tear index	5.82	5.06	5.27	18.35	14.39	4.68	4.30
Burst index	1.0	0.30	0.62	0.78	0.76	0.85	0.84





Blending Characteristics of the pulp obtained through enzymatic route:

The pulp obtained from the enzymatically processed shredded currency waste was further subjected to blending with the pulps obtained from different fibers like banana garbage, waste paper (road sweep) and mixed hosiery waste to study its blending characteristics. Results of physical strength properties are being given in the table-10. From the table, it can be seen that the strength properties of the paper produced from bioenzymatic pulping of SCW were much better than that prepared from waste paper or the banana garbage pulp. Blending of the SCW pulp with that prepared from mixed hosiery waste resulted into improved properties of the physical strength.

Handmade Paper Products developed:

The handmade paper developed from the bioenzymatic pulping of the shredded currency waste of RBI could be used to prepare different kinds of products like file covers, pen stand, photo frame, lamp shades, folders, diary, letter pads etc. With blending of the mixed hosiery pulp, good quality, cost-effective and strong carry bags can also be prepared that can substitute the environmentally-unsafe polythene bags from the market.

CONCLUSION

Thus the cellulose/hemicellulase mixture can significantly improve the beatability of the recycled or secondary fiber of the shredded currency waste of RBI and also result in improved strength properties of the handmade paper produced from the enzymatic treatment followed by refining. In order to avoid strength losses, a careful optimization of the enzyme doses, treatment conditions and the sequence of operations are very important.

Comparative Economics of the process of enzymatic pulping and pressurized digestion of shredded currency waste of RBI

S.No.	Parameters	Chemical pulping	Enzymatic Pulping
1.	Raw material cost (@Rs.1/-kg)	Rs.200.00 for 200kg	Rs.200.00 for 200kg
2.	Chemical cost NaOH-4% (@ Rs.28/- per kg)	Rs.224.00	Nil
3.	Enzyme cost (@ Rs.50/- per kg)	Nil	Rs.10.00
4.	Steam cost (@ Rs.35/- per lt.)	Rs.315.00	Rs.70.00
5.	Yield	80%	85%
6.	Beating/Refining cost (20 HP x 0.746 x 2hrsx Rs.5)	Rs.149.20 = Rs.150.00	Rs.149.20 Rs.150
7.	Sheet making for CMV 12 HPx.746x4hrsxRs.5)	Rs.180.00	Rs.180.00
8.	Drying and Calendaring (5 HPx0.746x1hrsxRs.5)	Rs.74.60 =Rs.75.00	Rs.74.60 =Rs.75.00
9.	Cutting (5 HPx0.746x1hrsxRs.5)	Rs.18.60 =Rs.19.00	Rs.18.60 =Rs.19.00
10.	Total	Rs.1163.00	704.00
11.	Labour cost (@ 30% of total cost)	Rs.349.00	Rs. 211.00
12.	Grand total	Rs.1512.00	Rs.915.00
13.	Paper cost	Rs.9.45 per kg	Rs.5.38 per kg

From the present study, this can be concluded that the application of enzymes proved to be very effective in the processing of shredded currency waste of RBI because this could totally eliminate the process of pressurized digestion, washing in the potcher washer and beating. Thus a great saving of the precious resources like water and energy could be possible through enzymatic route of recycling the shredded currency waste of RBI with a total elimination of expensive chemicals like NaOH, Hydrogen peroxide and Sodium Silicate. Moreover, the quality of paper obtained with the application of enzymes was also better in terms of physical strength properties as compared to that obtained from the conventionally used process developed by this institute in the past. Thus the shredded currency waste of RBI proved to be a cost-effective alternative raw material for making handmade paper and adoption of the enzymatic route for its recycling can result into a good quality paper in an eco-friendly way and thus its implementation might help in improving the cost-competitiveness and environmental status of the Indian handmade paper industry.

Acknowledgement:

The authors are thankful to the Dept. of Science & Technology, KVIC, Mumbai for the funding of this study in the form of an S&T project. Authors are also grateful to Dr.T.K.Roy,Ex-Director, CPPRI for providing the available facilities and to Shri Arvind Sharma, Scientist, CPPRI for helping during the fiber-morphological studies.

REFERENCES

- Singh, S.N.; Khandekar,V.; Asthana,R. and Raj, Kamal (1997) "Handmade papermaking from shredded currency notes" Hath Kagaz, vol5, no.5&6: 4-7 (Sept-Oct.1997)
- Jackson,L.S.; Heitmann,J.A. and Joyce, T.W. (1993) "Enzymatic modifications of secondary fiber" TAPPI J. 76(3) : 147-154
- Oltus,E.; Mato, J.; Baurer,S. (1987) Cell Chem.Technol.21 : 663
- Pommier, J.C.; Fuentes, J.L. and Goma, G. (1989) TAPPI J., 72 (6):187.
- Noe,P. ; Chevalier,J.; Mora, F. (1986) Wood Chem.Tech. 6 (2): 167
- Franks,N.E.; Holm, C.C. and Munk, N. (1994) "Enzyme facilitated deinking of mixed office waste: the use of alkaline cellulases" Paper presented at the 'Paper recycling-94 conference', 8-10 Nov,1994, London, UK.
- Jeffries, T.W.; Sykes, M.S.; Cropsey, K.R.; Klungness, J.R. and Abubakr,S. (1996) "Enhanced removal of toners from office waste papers by microbial cellulases" Proceedings of the 6th international conference on biotechnology in the pulp and paper industry: advances in applied and fundamental research, ed. E.Srebotnik, Vienna, Austria: 141-144.
- Jain,R.K.; Mathur, R.M. and Kulkarni, A.G. "Enzymatic deinking of mixed office waste paper: an overview"
- Tandon,R.; Thakur, V.V.; Chisty, Mohd,; Mathur, R.M. and Kulkarni, A.G. (2005) "Enzymatic deinking: an alternative technology for quality upgradation of mixed office waste" IPPTA J.no.3 : 51-52
- Tandon,R.; Mathur, R.M.; Kulkarni, A.G. (2005) "Practices prevailing in collection , sorting and grading of recovered paper-a comparison" IPPTA J. : 93
- Tandon,R.; Mathur, R.M.; Prajapati, M. and Kulkarni, A.G. (2001) "Recovery and reuse of waste paper in Indian paper industry" Interaction meet of recycled fiber in paper and newsprint, 12th Apr.,2001.
- Jain, R.K.; Sharma, A.K.; Kumar,A.; Khan, M.E.; Agarwal, S. and Chauhan, S. (2007) "Improved process for conversion of shredded currency waste into different varieties of handmade paper" Paper circulated during the national workshop organized by KNHPI during the period from 14th May-16th May,07 at Jaipur.