

Present Status of 'DARS' Technology And Perspectives of Its Application to Small Pulp Mills

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ABSTRACT

Since last one decade, during which large number of small mills were installed, efforts have been continued for the development of suitable chemical recovery system for these mills. Though there are different process technologies existing, but no system is available to offer to these mills due to high capital input and complexity in operation.

In early 80's, Central Pulp & Paper Research Institute (CPPRI), Independently, worked on ferrite auto-causticizing process and it was shown that the process has a potential for application in small mills. Extensive studies conducted in Australia has led to the development of the process on a commercial scale and a 200 tpd recovery unit, based on this process, has been commissioned in early '86.

CPPRI continued efforts, in its endeavour, to further develop this process to suit our silica rich spent. Preliminary plant scale studies conducted on a soda based bagasse pulp mill gave fair degree of confidence in potential application of this process. Silica is undesirable non-process element in all the spent liquors from pulping of agricultural residues. Extensive studies on the effect of presence of silica during recovery loop were conducted. Studies revealed that during ferrite auto-causticization process only minor proportion of silica passes into white liquor. This is an added advantage of the process and unlike conventional recovery it may not be necessary to go in for additional stage of desilication of spent liquor prior to recovery operation.

Further studies on responses to auto-causticization towards hematite ore samples collected from different regions with different particle size were also carried out. Soda recovery with different particle size of ore sample gave an idea of the optimum size of the ore sample to be selected. Thermal analysis carried out indicated that rate of thermal decomposition of black liquor in presence of ore was not affected. Useful data collected further support the various advantages the process has over conventional recovery system.

Chemical recovery is one of the most capital intensive sections of a pulp mill and also has one of the shortest economic lives. Thus the size of the mill has a profound influence on the economics of Chemical Recovery System. Conventional recovery system involving concentration and pyrolysis of black liquor followed by lime causticization of dissolved smelt forms the bottleneck of economics of the Paper Industry throughout the world. Paper Industry has been looking forward for an alternate Chemical Recovery process technology to overcome the problems like complexity of operations involved, limited flexibility in operations with low solids concentration, hazards in smelt handling and inherent malodorous problems associated with conventional chemical recovery process. In the recent years development of DARS (Direct Alkali Regeneration System) process technology is an outstanding achievement in the field of chemical recovery technology.

Patented process of Nagano, et al¹ of Toyo Pulp Company was the first reference to the use of ferric oxide for the treatment of soda spent liquors by prem-

ixing the ore with liquor and carrying out the combustion and causticization in one step in a single reaction vessel. Since then the process was investigated independently by various research workers in Australia, Finland and India. In Australia, this process for Soda-AQ spent liquor was studied on pilot plant scale and as a result of their investigations a commercial unit of DARS process, of 200 tpd capacity was developed and commissioned in Burnie (Australia) in the early 86².

In India, this process (Ferrite) was studied, independently, by Central Pulp and Paper Research Institute. Extensive studies on the application of the ferrite process for the treatment of soda spent liquors from agricultural residues were carried out. Findings of these investigations clearly indicate advantages the process has over the conventional recovery system particularly for small mills using silica rich non-woody raw materials.

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Preliminary findings were presented in IPPTA Annual Meeting in 1983³ and there was a profound response particularly from small mills. Since then CPPRI concentrated its efforts to further generate more realistic data on the process with emphasis on the build-up of silica during the recovery loop of ferrite process. This paper discusses the present status of technology, further studies carried out at CPPRI and perspectives of applying this process to small mills.

Present Status of "DARS" Technology

The basic principle of the process involving production of sodium ferrite by auto-causticization of sodium carbonate with ferric oxide and subsequently to obtain sodium hydroxide by hydrolysing the sodium ferrite was patented by Lowig⁴ in 1883. Since then extensive research work was carried out on the application of this principle for the recovery of sodium hydroxide from spent pulping liquors. The reactions involved were studied thoroughly and various modifications and improvements in the steps involved were suggested. Nagano, et al¹ of Toyo Pulp Co. (Japan) suggested, for the first time, that sodium hydroxide can be recovered by pyrolysing the mixture of black liquor and ferric oxide followed by hydrolysis of sodium ferrite, the combustion product. Australians obtained a licence from Toyo Pulp Co. (Japan) for the commercial exploitation of this process and the process was termed as DARS process. As a result of five years of extensive research work on pilot plant scale by Covey, et al⁶ a 200 tpd capacity commercial DARS plant was developed and commissioned in the early 1986 at Burnie (Australia). Based on these pilot plant investigations, it has been reported that the relative capital cost of DARS vs. Conventional technology varies considerably from mill to mill but as a guideline, about one third of capital can be expected to be reduced. CPPRI also did a preliminary work-out of the cost benefits and they arrived at capital reduction of about 37% due to elimination of lime causticization and reduced operational costs³. Pilot Plant studies in Australia and laboratory studies at CPPRI clearly indicate the following various advantages the process has over conventional recovery system.

- The process has operational flexibility.
- The process is compact and simple in operation and also requires less space.

- The process permits most economic use of fuel by way of minimized quantity of high cost fuel.
- High degree of process automation is not required.
- Unlike the smelt in conventional recovery the combustion product is solid, so the process is safe.
- Low capital cost.

Since early 80's CPPRI carried out independently, extensive studies on the application of this process for the treatment of spent pulping liquors from agricultural residues. Process parameters for efficient chemical conversion during combustion and hydrolysis were optimized. It was shown that high degree of causticity can be obtained for straw spent liquors by ferrite process³. Encouraged by the laboratory scale findings the studies were extended to plant scale trials in a bagasse based mill. The details of the findings of plant scale trials are discussed in following section. Overall, the laboratory scale studies and preliminary plant scale trials gave a confidence in the potential application of this process in small mills.

Silica constitutes a major undesirable non-process element in the spent liquor from most of the agricultural residue pulps and the presence of silica in spent liquors is considered to be a major problem in Chemical recovery operation. In order to find out the course of silica in the ferrite recovery loop extensive studies were conducted at the Institute. Studies confirm that in ferrite process the silica build-up is in the ferric oxide ore and not in the white liquor generated. Thus the ferrite system has an added advantage by way of inhibiting the silica build-up in pulping cycle. The results of findings are discussed in detail in following sections.

Thus looking into the advancement of this technology in last decade and the studies in India confirming the suitability of the ferrite (DARS) process for the treatment of agricultural residues spent liquors, it can be stressed that the process has a great promise and should be a potential alternative recovery scheme for small mills based on soda process.

Results and Discussions

In earlier studies optimum process conditions for combustion and hydrolysis in ferrite process were studied in detail. The present studies include role of non-process elements like silica and iron in particular, effect of particle size, build-up of silica in ferrite reco-

very loop and findings of the preliminary trials on mill scale operation.

1. Studies on Non-Process Elements (NPE) in Ferrite Recovery Loop :

Non-process elements are those which are not involved directly in chemical reactions and are usually undesirable elements. Sources of NPE are raw material, process water, chemicals, equipment corrosion products and haematite ore in case of ferrite process. Silica carried by spent liquor and soluble iron are the major NPE in ferrite recovery loop.

- a) **Silica Loop in Ferrite Process :** Spent pulping liquors from most of the agricultural residues contain appreciable high amounts of dissolved silica and amount varies from 3-8% on black liquor solids. For a typical 30 tpd mill based on rice straw it is expected that about 1500 to 3000 kg. of silica will be carried by spent liquors. In conventional chemical recovery most of the silica carried by black liquor is going with the lime mud during causticization. It was decided to see the course of silica during ferrite process. Experiments were conducted with model compounds containing silica and spent liquor. The results are given in Table-1

Black liquor and ferric oxide were pyrolysed and resulting product sodium ferrite was hydrolysed. Silica was determined in regenerated ferric oxide and white liquor concentration was varied from 32 to 218 g/l of NaOH. The results clearly indicate that very small proportion of silica passed

into white liquor and remaining portion was retained with regenerated Fe_2O_3 . Even at 218 g/l alkali concentration the carry-over of silica to the white liquor was as low as 1.47% of the total silica in black liquor. It is evident that the silica carried by the black liquor is retained with Fe_2O_3 presumably in a physically bound state. Build-up of silica during recycling Fe_2O_3 was calculated and is given in Appendix-1. The silica balance indicate that about 12.9% of the dead load was resulted due to build-up of silica, after six cycles. After tenth cycle the silica build-up dead load was around 22%. It will not be practicable to recycle the ore with high silica contents. From the activity of regenerated Fe_2O_3 it is felt that ore should not be recycled more than six times and the reduced activity of silica rich ore was attributed to brittleness.

These studies clearly indicate that retention of silica by Fe_2O_3 is advantageous as any silica passing into white liquor which will be carried over to pulping loop and subsequently to black liquor is not desirable. Fresh black liquor will contain only silica from raw material and it may not be necessary to incorporate additional step of desilication before evaporation. Thus for the first time it has been shown that build-up of silica in pulping cycle can be prevented by ferrite auto-causticization.

- b) **Iron in White Liquor :** Substantial quantity of natural haematite ore as a source of Fe_2O_3 for auto-causticizing will be used in ferrite process.

Table-1
SOLUBILITY OF SILICA IN REGENERATED ALKALI

Sl. No.	Concentration of regenerated alkali as NaOH, g/l (a)	Causticity %	Silica in white liquor, ppm	Silica,%* passed to white liquor
1.	36	83.7	Nil	Nil
2.	132	93.9	433	0.83
3.	218	92.1	1634	1.47

Sodium ferrite was produced with bagasse spent liquor at 850°C, 15 min.

*Percentage of the total silica in black liquor (6168 ppm).

There is a likelihood of presence of some soluble iron compounds in ore which are subsequently carried to white liquor regenerated in ferrite process. Kiiskila, et al⁶ have reported that concentration of iron in white liquor produced by hydrolysing sodium ferrite was in the range of 0.0–2.2 ppm. They also observed that concentration increased slightly with increasing alkali concentration. It has been well established that presence of iron in white liquor and subsequently carry-over of iron by the pulps has adverse effect on the bleachability of pulps. In this context, it was decided to collect data on extent of solubility of iron in regenerated white liquor.

The mixture of black liquor and haematite ore was pyrolysed and resulting sodium ferrite was hydrolysed in such a way that the concentration of NaOH in resulting white liquor was around 100 g/l. The quantity of iron was estimated in the white liquor. It was observed that maximum solubility of iron was around 3 ppm as Fe. Unbleached pulps obtained by cooking with white liquor containing 3 ppm Fe were bleached and the yellowing tendency as post colour number was determined. The results indicated that the carry-over of iron by the pulp was very negligible and traces of it did not affect the bleachability.

Studies on solubility of iron reveal that when high purity haematite ore is used the solubility of iron is negligible and it did not have any adverse effect.

2. **Leaching of Sodium Ferrite :** Leaching is a key step of ferrite process and conditions maintained should allow maximum causticity and soda recovery. It

is necessary to ensure that sodium ferrite is completely hydrolysed and maximum extraction of sodium hydroxide in the form of concentrated solution is achieved. Sodium ferrite is relatively soft and susceptible to mechanical breakdown to produce fines⁷. Increased proportion of fines is not desirable. Most efficient leaching configuration will be pure counter-current contacting. In previous studies Kulkarni, et al⁸ have shown that efficient hydrolysis occurs at temperature around 90°C. Keeping the counter-current system in mind it was decided to see the extent of leaching at each stage. The results are given in Table-2.

The results show that during first extraction about 50% sodium was recovered with the resulting causticity as high as 94%. The causticity decreased in subsequent stages due to increased extraction of less soluble Na₂CO₃ fraction. Covey, et al⁸ have reported that the cold water leaching prior to hot water leaching removes the carbonate fraction. However, in our studies on leaching conducted at 20°C and 80°C it was observed that hot water extraction even after cold water leaching, the causticity was not enhanced, indicating that cold water leaching was not effective in removing Na₂CO₃ fraction. Results in Table-2 show that minimum of 4 stages of extraction would be required for a sodium recovery over 90%. Covey, et al have observed that for maximum concentration of recovered sodium hydroxide about three stages should be adequate.

3. **Effect of Particle Size :** It has been a subject of extensive studies as to what should be the optimum particle size of the haematite ore particle for maxi-

Table-2
LEACHING OF SODIUM FERRITE

Leaching stage	Causticity, %	Sodium recovered, % as Na ₂ O	NaOH recovered, % as Na ₂ O	Na ₂ CO ₃ recovered, % as Na ₂ O
1	94.30	50.67	47.77	2.90
2	28.40	16.68	4.75	11.95
3	20.80	8.00	1.67	6.33
4	11.56	12.49	1.43	11.09
5	Nil	4.44	Nil	4.75

mum causticity and quick filtration of the white liquor⁹.

As Na_2CO_3 and Fe_2O_3 react in solid phase, it is necessary that both the reactants be in intimate contact. However too fine particle of Fe_2O_3 may lead excessive loss of ore through flue gases without reacting with Na_2CO_3 . In the present studies Fe_2O_3 with particle size of 500 μm and 250 μm were used. Each of this fraction was made to react with sodium carbonate with varying ratio of Fe to Na from 1.0 to 2.0. The results are recorded in Table-3.

The results indicate clearly that when 500 μm particle size was used, there was an appreciable

When 250 μm particle size was used due to smaller size more number of particles are available to sodium carbonate for reaction and less cavities are developed on each particle. This results in a large number of particles retaining their sizes. The effect is enhanced when Fe : Na ratio increased. It was observed that the sodium ferrite formed with 500 μm particle size ore was hard and resulting causticity was on lower side. When ore with 250 μm size ore was used the resulting ferrite was soft and higher causticity was obtained.

4. **Thermodynamics of black liquor and Fe_2O_3 Combustion :** Thermo gravimetric (TGA) and Differential Thermal Analysis (DTA) is useful tool

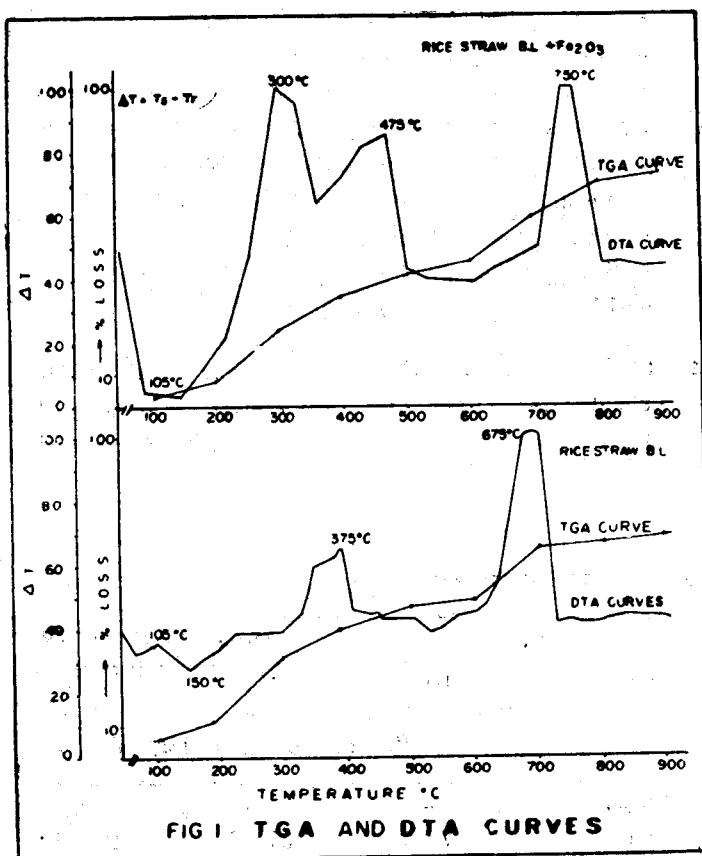
Table-3
STUDIES ON INFLUENCE OF PARTICLE SIZE OF Fe_2O_3

Initial Particle size	500 μm			250 μm			
	Fe to Na Ratio	1.0	1.5	2.0	1.0	1.5	2.0
Particle size distribution after hydrolysis		Percentage of original size			Percentage of original size		
+ 500 μm		66.21	77.19	86.36	—	—	—
— 500 + 250 μm		14.20	5.00	3.13	77.08	87.87	92.45
— 250 + 125 μm		5.94	3.75	3.53	11.67	5.42	2.59
— 125 + 63 μm		8.42	8.62	3.89	8.47	4.66	2.59
— 63 μm		5.23	5.44	3.09	2.78	2.05	2.37
Causticity, %		55.6	78.9	80.0	59.1	84.2	88.4
Sodium recovery, %		83.6	78.3	84.0	94.0	79.3	79.4

reduction in particle size after hydrolysis. With Fe:Na ratio at 1.0 only 66.2% fraction retained the original size and with increasing ratio Fe:Na more fraction retained the original size. The reason for this can be explained on the basis that Na_2CO_3 forms a cavity on the ferric oxide particle forming $\text{Na}_2\text{Fe}_2\text{O}_4$. On hydrolysis NaOH is released, leaving a cavity. When Fe:Na ratio is less, then more than one cavity can be formed on one Fe_2O_3 particle making it weak and by vigorous stirring during leaching the particle collapses to smaller fragments. In the other case, when Fe:Na ratio is higher, more particles are available for Na_2CO_3 reaction thereby causing less cavities per particle and hence the original size is retained by the particles.

in understanding the rate of decomposition of material during pyrolysis. Further DTA studies held in predicting whether the reaction is endothermic or exothermic. Fig. 1 shows the TGA and DTA curves for combustion of black liquor in presence and absence of Fe_2O_3 .

Using the simultaneous thermal analyser STA-781 Differential Thermal Analyses & Thermo gravimetric analyses were carried out for rice straw black liquor with and without Fe_2O_3 mixed in stoichiometric ratio. The furnace was programmed to heat at the ratio of 20°C/min upto 1000°C. The differential thermal analyser curve indicate that in the case of black liquor alone a less pronounced exothermic peak appeared at 375°C followed by another strong exothermic peak at



675°C. At these temperatures weight loss was more prominent as indicated by thermogravimetric curve. In the presence of Fe_2O_3 , under the same furnace conditions the black liquor gave two strong peaks at 300°C and 475°C followed by another strong peak at 750°C. The results indicate that in the presence of ferric oxide there is a catalysed thermal decomposition of black liquor at a reasonably lower temperature. These findings support the work of Nakura⁹. The thermal analysis studies gave a strong evidence that in ferrite process even with high inorganic load, the combustion of spent liquor is not impaired but on the contrary, a catalysed and exothermic reaction occurs at a considerably lower temperature than the black liquor alone.

5. **Studies on Ores from Different Regions in various States :** Abundantly available natural Haematite ore constitutes the main source of Fe_2O_3 used in Ferrite Process. The chemical conversion efficiency and magnitude of non-process elements in the white liquor regenerated in the ferrite process, to a large extent, are influenced by the quality and purity of the ore. A typical analysis of some of the ores collected for ferrite auto-causticization is given in Table-4.

Table-4
CHEMICAL COMPOSITION OF HAEMATITE ORES

Particulars	Origin of Ore			
	Karnataka (A)	(B)	Rajasthan (C)	Orissa (Cuttak) (D)
Loss on ignition, % (950-1000°C)	14.20	0.55	12.50	11.60
Hot water solubles, %	—	0.50	—	0.46
Alkali solubility, % (2.5 N NaOH)	—	1.50	—	3.05
Acid Insolubles, % (SiO_2)	6.10	—	0.15	1.5
Fe, %	50.0	65.9	65.4	12.6
Fe_2O_3 , %	72.0	94.4	93.5	18.1
Chlorides, %	—	0.80	1.8	—
Sulphates, %	—	0.66	0.37	—

(A) Sample used for plant scale trial at Mandya National Paper Mills.

(B) New consignment of ore obtained by Mandya National Paper Mills.

The ores were collected from different regions in Karnataka, Rajasthan and Orissa states. The analyses show wide variation in the quality of the ore. Ores 'B' and 'C' showed higher amount of Fe_2O_3 contents and significantly low proportion of impurities like acid insolubles and alkali solubles. The chemical conversion efficiency of ores 'B' and 'C' was on very much higher side compared to the other two ores. Ores 'A' and 'D' showed very poor chemical conversion efficiency and also the resulting white liquor contained significant quantities of impurities like silica, sulphates and chlorides. It is important to use high quality ore which would facilitate in reducing the dead load due to impurities and at the same time higher chemical conversion efficiencies are achieved.

6. Experience of Plant scale trial of Ferrite Process :-

Encouraged by the laboratory investigations, it was decided to study the application of ferrite process on pilot plant scale and to identify related problems. Bagasse based mill at Mandya National Paper Mills (MNPM) was chosen for these studies. The mill is using 100% bagasse and soda pulping process is followed. The present Chemical Recovery System at MNPM involves a Rotary incinerator into which thick black liquor is fired and semi burnt black liquor in the form of black ash is dissolved to get green liquor. The green liquor is causticized using lime to get sodium hydroxide.

Arrangements for ferrite studies is illustrated in Fig.-2. The capacity of roaster was about 1.65 tonnes of black liquor solids/hour at 50% concen-

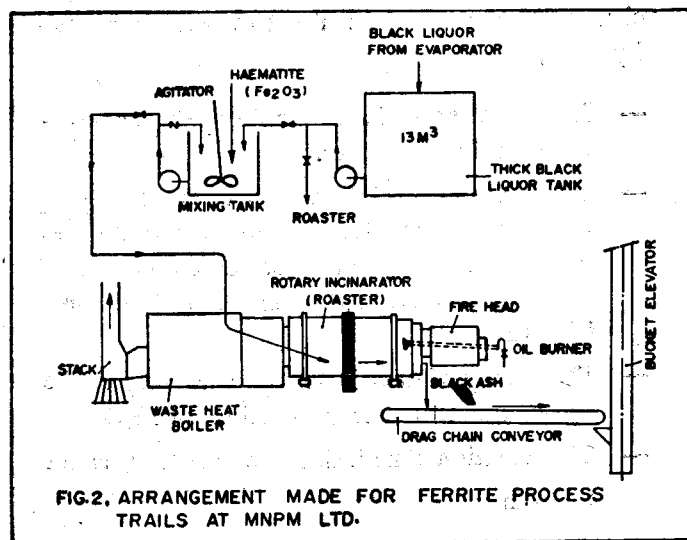


FIG-2. ARRANGEMENT MADE FOR FERRITE PROCESS TRAILS AT MNPM LTD.

tration. At 40% the capacity was about 1 ton/hour. The retention time of black liquor in the roaster was about 15-20 minutes. The thick black liquor had specific gravity of about 45° Tw. About 0.5 M³ of this thick black liquor was drawn into mixing tank to which haematite ore was added and mixing was effected using an agitator. After mixing, the specific gravity was around 70° Tw. The resulting mixture was pumped into one end of the roaster and furnace oil was fired from the other end of the roaster. During burning flow of the furnace oil is maintained to get the desired temperature in the roaster. About three batches of trials were conducted. Ore 'A' whose analysis is given in Table-4 was used for these trials. The chemical conversion efficiency is given in Table-5.

Table-5
ANALYSIS OF SODIUM FERRITE GENERATED ON MILL SCALE TRIALS

S. No.	NaOH, %	Na ₂ CO ₃ , %	Causticity, %	Carbon, %
1.	1.70	81.14	2.80	12.04
2.	5.40	75.00	9.09	13.67
3.	9.90	81.05	16.60	13.95
4.	17.03	63.76	27.20	13.22
5.	41.74	24.73	73.84	17.86

The causticity varied from 2-73%. It was observed that the reasons for low level of causticity were,

- It was not possible to monitor the temperature within the roaster.
- There was not sufficient draft to expel the CO₂ from the roaster. The increased partial pressure of CO₂ resulted in poor decomposition of sodium carbonate and subsequently low causticity values.
- The quality of the ore used was very coarse and contained lower proportion of Fe₂O₃.
- The retention time inside the roaster was not uniform.

Nevertheless these trials were highly successful in the sense, as they helped in identifying the problem relating to various process conditions and necessary modifications which may be required.

Perspectives of Application of "DARS" Process to small mills

a) **Conventional Technology** : Capital intensiveness of chemical recovery system is one of the main reasons why the small pulp mills cannot afford to have conventional recovery process. Other factors which limit the scope of conventional recovery system are :

- Low solids concentration of initial black liquor requiring high energy input during evaporation.
- Considerably higher proportion of silica.
- Very high viscosities at solids concentration over 35% solids.

Looking into the technical factors limiting the scope of application and high capital investments it may not be possible to have conventional recovery system under the conditions prevailing today.

b) **Alternative Technologies** : Number of chemical recovery technologies alternate to conventional smelting furnace such as Fluidized Bed Combustion, Wet Air Oxidation, Toras-xucla process, etc. have been developed. These technologies were primarily aimed as a replacement for conventional smelting furnace to overcome the hazards in smelt

handling operations. Due to sophisticated equipments and complexity of operations, none of these processes can be offered to small mills.

c) **Need of the Small Mills** : Small pulp mills, today are, looking for a recovery system which is simple, safe, flexible in operation, feasible technically and viable economically. Looking from these different angles DARS process should be a potential alternative chemical recovery system. From the studies conducted in India (at CPPRI) greater degree of confidence has been recorded in the technical feasibility of this process.

d) **Economics of DARS Process** : When observing the advantage of elimination of silica with Fe₂O₃ and subsequently reduction in build-up of silica in pulping cycle, this process becomes more attractive. While considering technical feasibility, we cannot overlook the economics of the scale of operation. Covey, et al¹¹ have worked out the cost per unit of production as follows :

Assuming that the capital cost of DARS recovery is two thirds of that of a kraft recovery of the same size and that the cost exponent of capacity for chemical recovery units is 0.7 then capital cost per unit of production falls in proportion to a capacity to the power^{0.3}. i.e. Total capital cost \propto (Capacity)^{0.7}.

$$\text{Capital cost per unit of Capacity} \propto \frac{1}{(\text{Capacity})^{0.3}}$$

Therefore, based on above calculation, the capital cost per tonne of pulp for kraft recovery to equal that by DARS—the kraft recovery must be about four times as large. Considering the fact that kraft recovery is feasible for a 100 tpd capacity then DARS should be feasible for a capacity four times less than that of kraft i.e. 25 tpd.

CONCLUSION

- 1) Studies on laboratory scale and plant scale experiments reveal that the DARS process is technically more attractive for small pulp mills using soda process and based on agricultural residues, compared to other alternative technologies available today.
- 2) Calculation of the scale of operation, assuming that DARS requires two third less capital compared to kraft (conventional) recovery system, reveal that

DARS will be economically viable even for 25 tpd scale of operation.

- 3) Considering the advantage DARS process has over the conventional recovery with a specific advantage of elimination of silica problems associated with non-woody spent liquors, DARS process seems to be a potential alternative recovery system for small mills.

APPENDIX-1

SILICA BUILT-UP IN FERRITE RECOVERY LOOP

These results are based on the laboratory experiments on Ferrite Process. Black Liquor from a bagasse based small mill was used for the experimental work.

Mill Capacity, tpd	= 30.00
Pulp yield, unbleached, %	= 45.00
Black liquor solids, tpd	= 36.60
Silica, in black liquor, % w/w	= 1.52
Total silica in black liquor, kg/day	= 556.3
Sodium in black Liquor, as Na ₂ O, %	= 24.26
Total sodium in black liquor as Na ₂ O, tons/day	= 8.87
Sodium oxide to Fe ₂ O ₃ ratio	= 1:2.6
Ferric oxide required, t/day	= 23
Total ferric oxide required, t/day after 10% additional Fe ₂ O ₃	= 25.37
Organic to inorganic ratio in the first cycle	= 50.2:49.8

II CYCLE :

Total black liquor solids, t/d	= 36.6
Total silica in black liquor, kg/day	= 556.3
Ferric oxide, tonnes/day	= 25.37
Silica in Ferric oxide, carried over, kg/day	= 544.5
Organic to inorganic ratio in II cycle	= 49.7:50.3
Dead load, due to silica, %	= 2.16

SUBSEQUENT CYCLES :

After 6 cycles, silica in ferric oxide, kg	= 3267
Dead load after Six cycles, %	= 12.86
Dead load after Tenth cycle, %	= 21.6

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