Closing The Pulp Mill Chemical Cycle Using Fluidized Bed Technology

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ABSTRACT

Fluidized Bed Technology has been successfully implemented in recovering soda ash from black liquor for a number of pulp mills in India. Agro Pulping Machinery (Agro) has extended this technology to produce steam and power for medium size pulp mills as well as close the chemical recovery loop to produce white liquor and reburn lime mud. With increasing cost of caustic (INR 32/kg), it becomes more cost effective to produce green liquor from the output of the Fluidized Bed Incinerator for black liquor. This green liquor can be converted by conventional means of causticizers and slakers, into white liquor to be reused in pulp cooking process. However, the resulting lime mud is a pollutant and the new process proposed here is to tackle it by using a calciner based on fluidized bed (FB) technology. Since the major cost of the calciner is fuel, Agro's design includes a closed coupled biomass gasifier that supplies the fuel for burning the lime. The FB calciner produces lime at high purity and efficiency that can be reused in the recausticizing process of the green liquor. In this fashion, we can close the chemical recovery loop by installing a complete soda and lime cycle using fluidized bed technology fueled by biomass gasifier.

Introduction

In this era of increasing energy and chemical costs, closing the pulp mill loop is no longer just an environmental necessity but economic one. For large pulp mills the deployment of conventional recovery system has been successful as it requires the mills to close the pulp mill loop in order to operate. On the other hand, fluidized bed technology employed in low temperature incinerators (LTI) have been quite successful in producing soda ash for resale at small and medium pulp mills processing 50-330 TPD of black liquor solids. This approach only recovers the chemicals but its reuse is not addressed. This paper explores the closing of the pulp mill loop that employs fluidized bed technology or LTI for processing black liquor. In addition, the medium size pulp mills can also generate steam and power from this process.

Literature Review

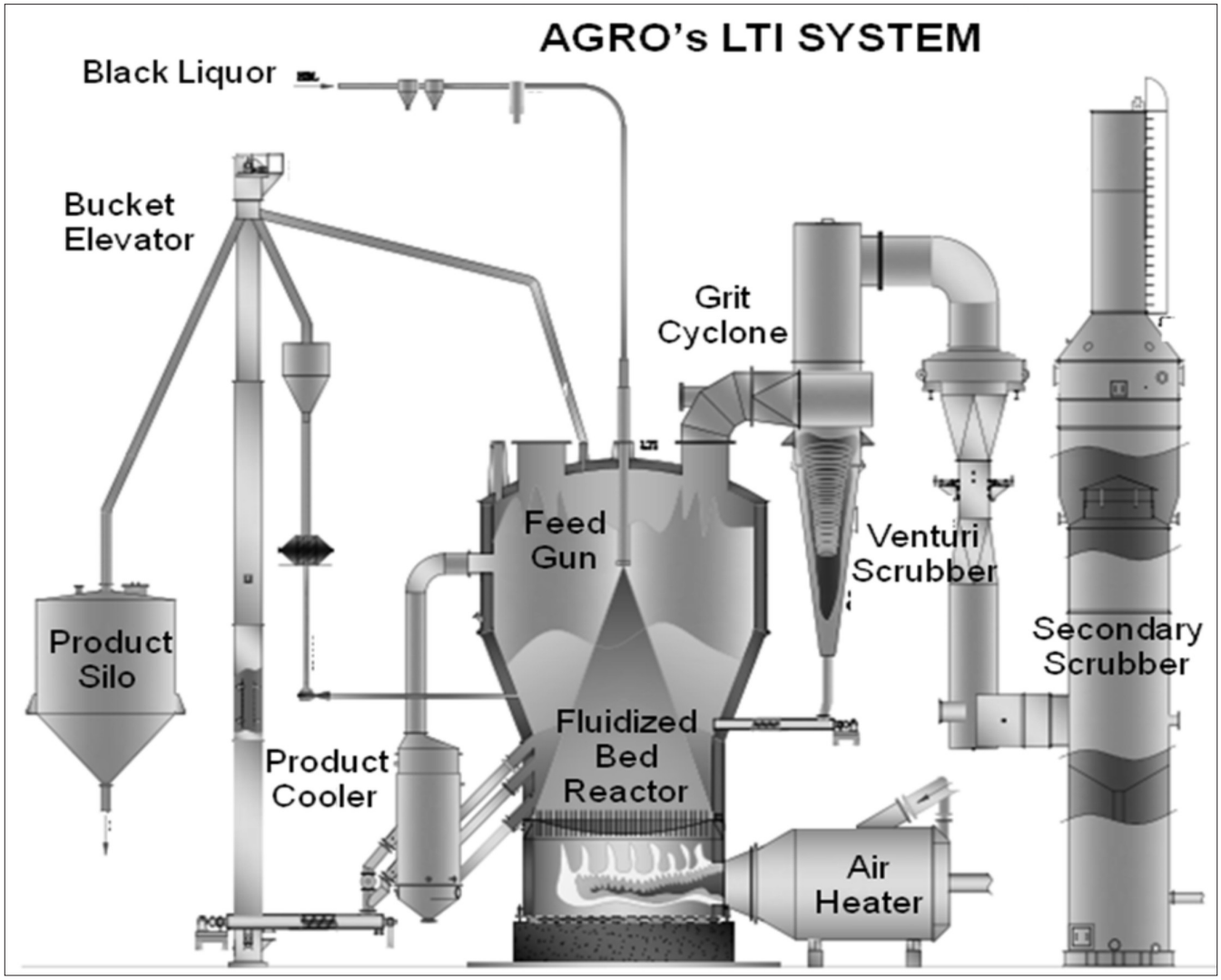
Chemical recovery system from black liquor solids have been researched over decades as its impact on the profitability of the pulp mill is paramount [1, 2, 3]. Recent developments in gasification [4,5] and high pressure recovery boilers attempt at squeezing more out of the same conditions. However, these systems are only economical for large pulp mills of around 800-1000 tonnes per day. On the other hand, fluidized bed technology that is employed in the Low Temperature Incinerator or LTI system, has filled the gap between small and large pulp mills. Although this process was introduced in 1960's in US, only in 1995-96, this technology was introduced by Agro Pulping Machinery who modified and added wet washing systems to address the chlorides in the black liquor that is an anathema for fluidized bed technology. The steam and power generation in this technology was not economical as the volume and temperature conditions were not ideal.

Closing of the pulp mill loop in conventional recovery system requires a recausticizing unit to convert the green liquor to white liquor as well as reburn the lime mud produced in the process. The recausticizing systems have been supplied by various vendors and the efficacy of the process is greatly dependent on the quality of green liquor and lime added. There have been marginal design improvements in this area but it has been largely accepted that causticizers and slakers do a fairly good job of conversion if the temperature and other parameters are maintained correctly. The lime mud reburning, on the other hand, has been a sore spot in the chemical recovery process because it is energy intensive. The predominant process in the paper and pulp industry is reburning of lime mud using a lime kiln. This process suffers a great deal of inefficiencies due to the high thermal conditions needed for the lime conversion as well as the rotating parts of the system that have to be mechanically maintained. In this paper we explore the reburning of lime mud using fluidized bed technology that may address some of these issues.

Results and Discussion

This paper is divided into three sections. The first one examines how fluidized bed technology for black liquor incineration has been established since it was introduced by Agro Pulping Machinery at Shreyans Industries in 1996. This is followed by the need or economics of closing the pulp mill loop and how the fluidized bed technology can assist in it. Finally, we examine the process and economics of closing the pulp mill using fluidized bed technology.

FIGURE 1
Schematic representation of the Low Temperature Incinerator System

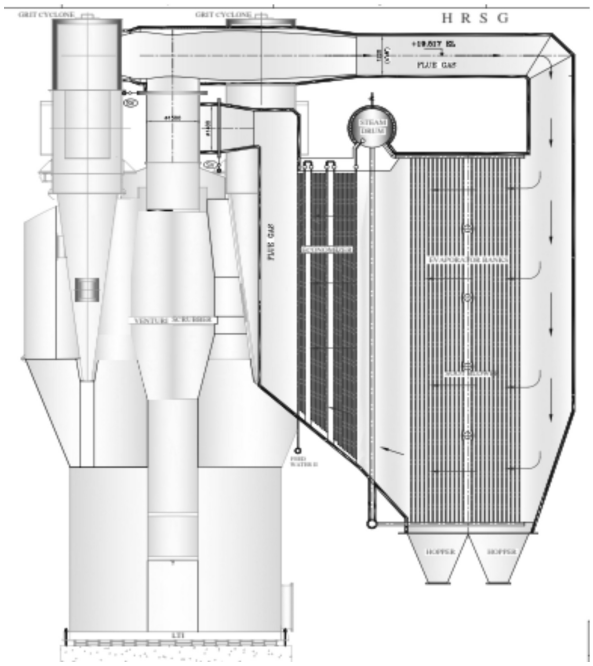


Fluidized Bed Technology for Black Liquor Incineration

This process was introduced in 1996 in India by Agro Pulping Machinery, and has been very successful in operation at several small and medium pulp mills. Figure 1 shows the main equipment that is used in the Low Temperature Incinerator (LTI). The main area that this technology has addressed is the zero discharge of black liquor at a total installed cost that is affordable to the small and medium pulp mills (50-400 tpd BLS). The return on investment is further boosted as the soda ash produced by this system capable of being sold in the marketplace for glass, soap and other industries. Soda ash from these LTI systems, accounts for 800-1000 tonnes per day.

The dearth of heat recovery or steam generation in the first set of installed LTI units, have been addressed by utilization of the heat of the flue gases. Recent developments in this technology has addressed the steam and power generation from the flue gases. Agro has introduced a Heat Recovery and Steam Generation or HRSG unit for LTI systems processing at least 200

Figure 2
LTI System equipped with Heat Recovery and Steam Generation Equipment



Heat **R**ecovery for **S**team **G**eneration

tpd of black liquor solids. HRSG units are closed coupled systems with LTI to maximize the heat recovery and steam generation. Figure 2 shows an illustration of one such system. Typically the steam generated in this unit is sufficient for the requirement of steam in the continuous digester at pressure of 10 bar. The availability of 10 bar steam from the LTI unit allows the steam boilers to produce power with high pressure steam which otherwise would have been diverted to the continuous digesters. Figure 3 shows how process① can be replaced with process ② and high pressure steam production can be used in the turbines to produce power. HRSG units can be used to produce higher pressure steam 40 – 65 bar if needed. These units are typically used for LTI systems processing 300 tpd of BLS or higher. The employment of HRSG units with LTI systems would accompany a corresponding change in the multiple effect evaporators as they would need to produce black liquor at 42-45% solids as opposed to 22-25% in a typical LTI system. However, the high steam economy of the evaporators reduces the amount of steam required and hence there is a positive contribution of steam by these units.

Closing the Pulp mill Loop

With the increasing cost of caustic that is used for pulp cooking, the economics of closing the pulp mill loop to recover the chemicals makes more sense even for small and medium pulp mills. The sodium carbonate produced in the LTI system can be dissolved to produce Green Liquor. The green liquor after clarification is converted into white liquor reacting with lime in the slakers and causticiziers. In this paper we are not addressing the equipment for the recausticizing as these are the same ones that are employed in large pulp mills. The causticizing reaction yields caustic in the form of white liquor as well as lime mud or calcium carbonate. The lime mud is then clarified and incinerated in the calcining process to reproduce lime that can be reused in the slaking and causticizers. The typical reactions that happen in the recausticizing and calcining processes are shown below.

Slaking

$$CaO\ (Lime) + 2H_2O \rightarrow Ca(OH)_2$$

Causticizing

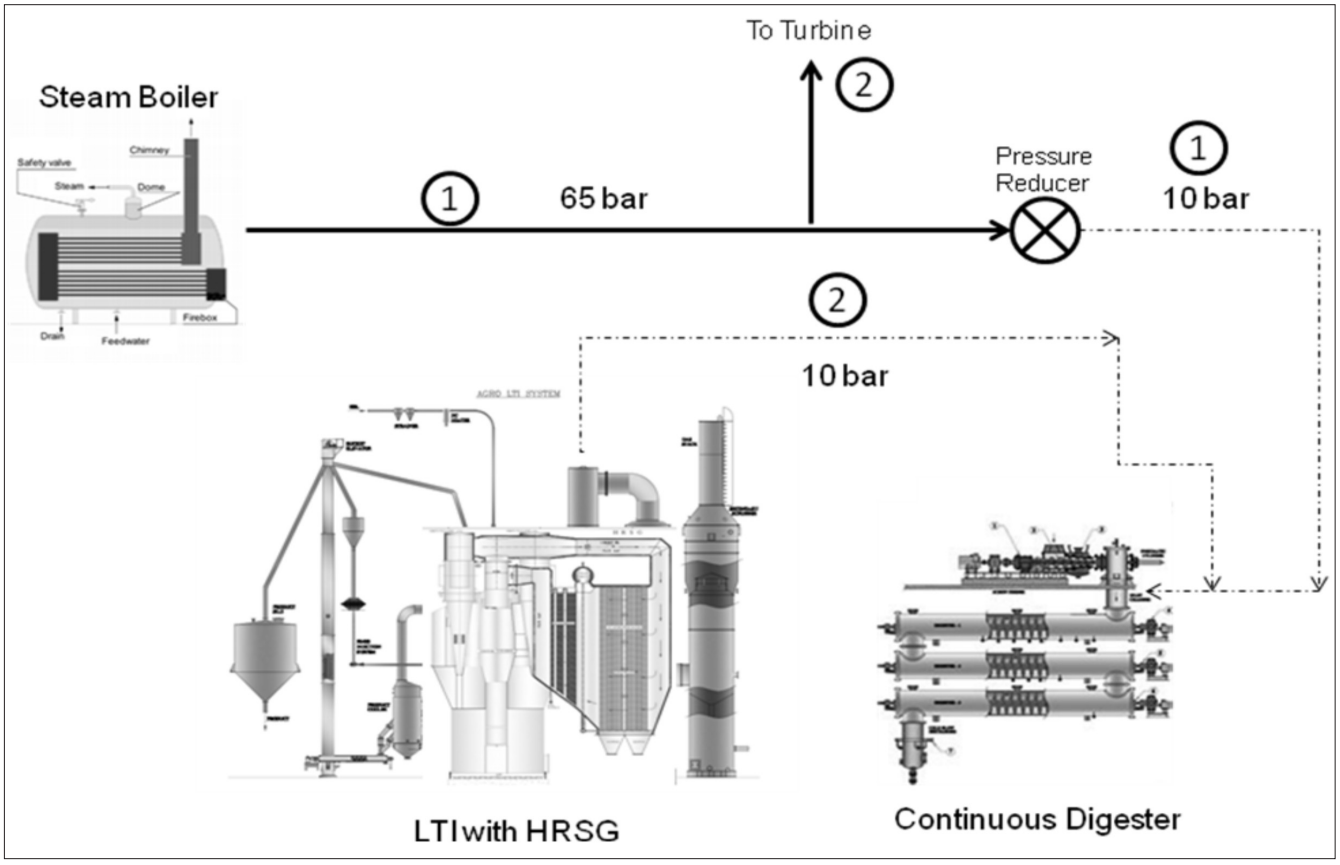
$$Ca(OH)_2 + Na_2CO_3 \rightarrow CaCO_3\ (Lime\ mud) + 2NaOH\ (caustic)$$

Calcining

$$CaCO_3\ (Lime\ mud) \xrightarrow{Heat} CaO\ (reburned\ lime) + CO_2$$

Figure 3 illustrates a typical Soda and Lime cycle described in the previous paragraph. The focus of this paper is the use of fluidized bed technology for the calcining process. For large pulp mills lime kiln technology [6] has been employed. One of the biggest drawbacks to the lime kiln technology is the high fixed, operating and maintenance costs. This paper examines the fluidized bed calciner that has the potential to address each of these areas in the sections

Figure 3
Steam Generated from HRSG allows extra power production by replacing the supply of steam to the continuous digester



Fluidized Bed Calciner

In Figure 4, the typical layout of the equipment is shown for a fluidized bed calciner that is quite similar to the LTI system that is used for black liquor incineration. Here the lime mud is introduced into the fluidized reactor zone along with fuel. The reaction converts lime mud or $CaCO_3$ to lime CaO. The lime dust escaping with the fuel gases are captured through a grit

Figure 4: A typical soda and lime cycle

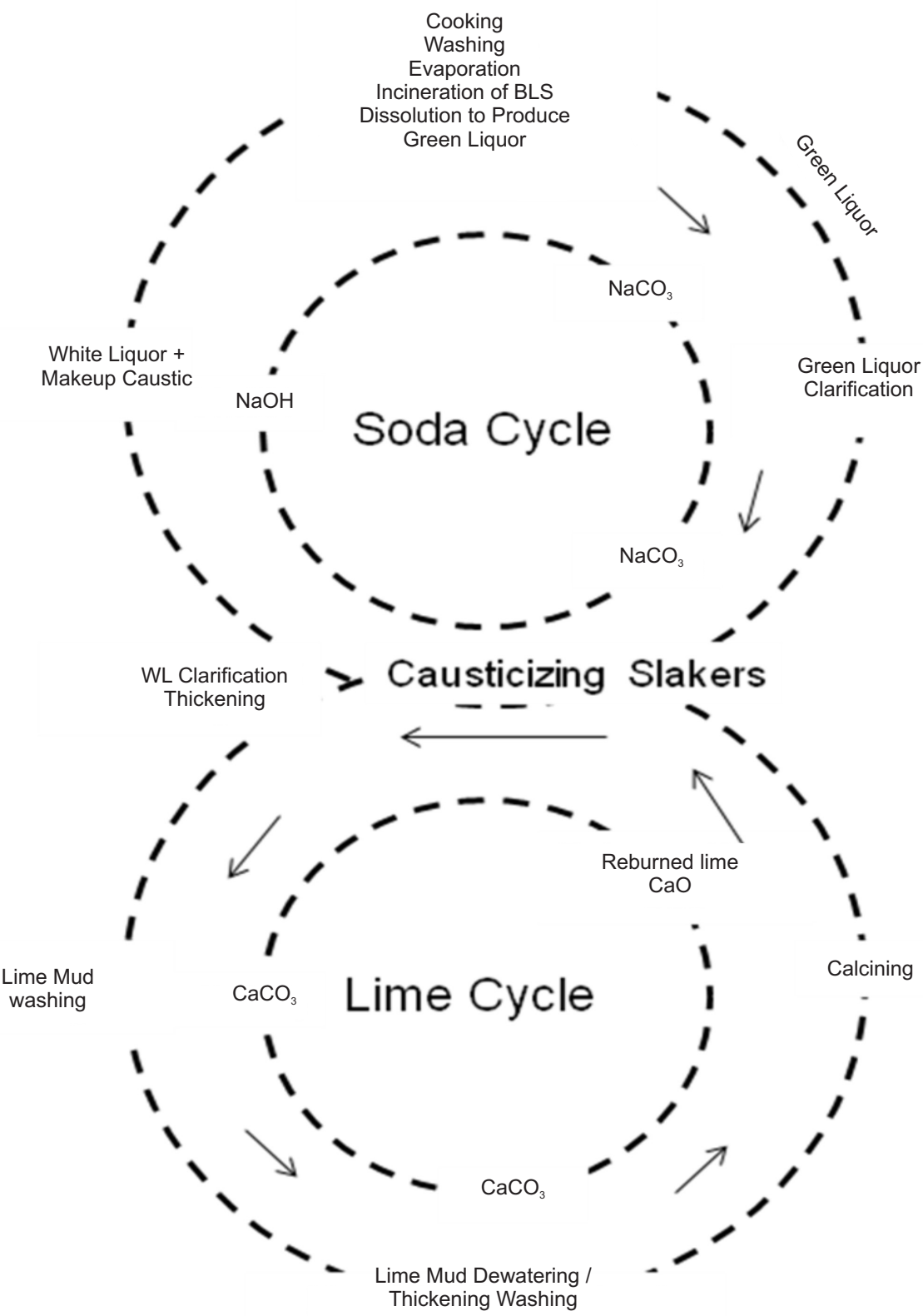
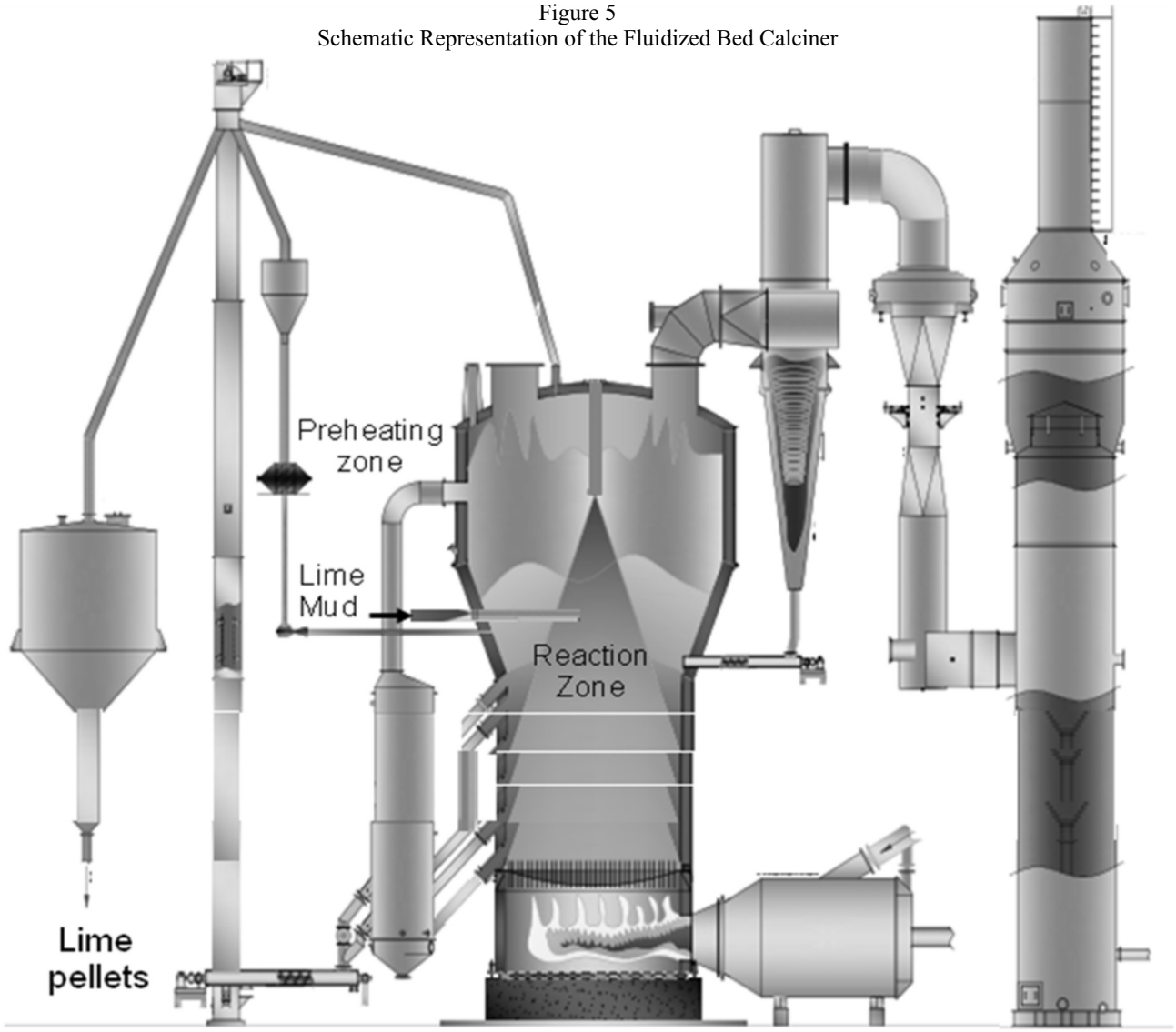


Figure 5
Schematic Representation of the Fluidized Bed Calciner



cyclone and other particulate matter is scrubbed by the venture and secondary scrubbers. This system can be enhanced to capture green house gases like CO_2 by scrubbing the flue gases with weak caustic to get sodium carbonate which can be introduced back at the recausticizing system.

In a typical fluidized bed calciner there are at least two zones preheating and reaction zone. The preheating zone uses the hot gases from the product cooler to maintain the temperature of the lime dust and mud introduced into the system. The lime mud is introduced at 60-65% solids. This means the lime mud from the white liquor clarifiers must be thickened using a lime mud filter. This is widely used in the paper industry and can be employed for this system. The introduction of lime mud into the calciner is typically done from the sides of the Fluidized zone with multiple feed guns in a concentric circle. Fuels are also introduced in the same fashion.

Due to high cost of fossil fuels in India, this fluidized bed system is equipped with on-site syn-gas production from pyrolysis of biomass material that the mills already have. The syn-gas is relatively inexpensive fuel compared to fuel oil or natural gas. Despite the choice of the fuel, the economics of using a fluidized bed calciner shows that it has positive contribution as the cost of caustic has risen to a point that an open loop pulp mill loses a ton of money.

Economics of Fluidized Bed LTI and Calciner

In this section we examine the economics of fluidized bed technology for black liquor incineration with HRSG technology as well as the ROI on closing the pulp mill loop using fluidized bed. For purposes of model case study, Mill A producing 250 tons per day of bleached pulp is taken to examine the economics. At this pulp capacity, Mill A would be deemed to be at low end of medium sized pulp mill. However, the mill produces enough black liquor solids to employ all of the above technologies and close the pulp mill loop.

LTI and HRSG Economics

Tables 1 detail the assumptions, costs and net contribution from soda ash production. The typical cost for the LTI implementation for Mill A is around Rs 14 crores, and the annual salaries are around Rs 150 lakhs. The payback period

Figure 6
CHITEC SYSTEM Biomass Gasifier that produces Syngas that will be used as fuel for Fluidized Bed Caliciner.

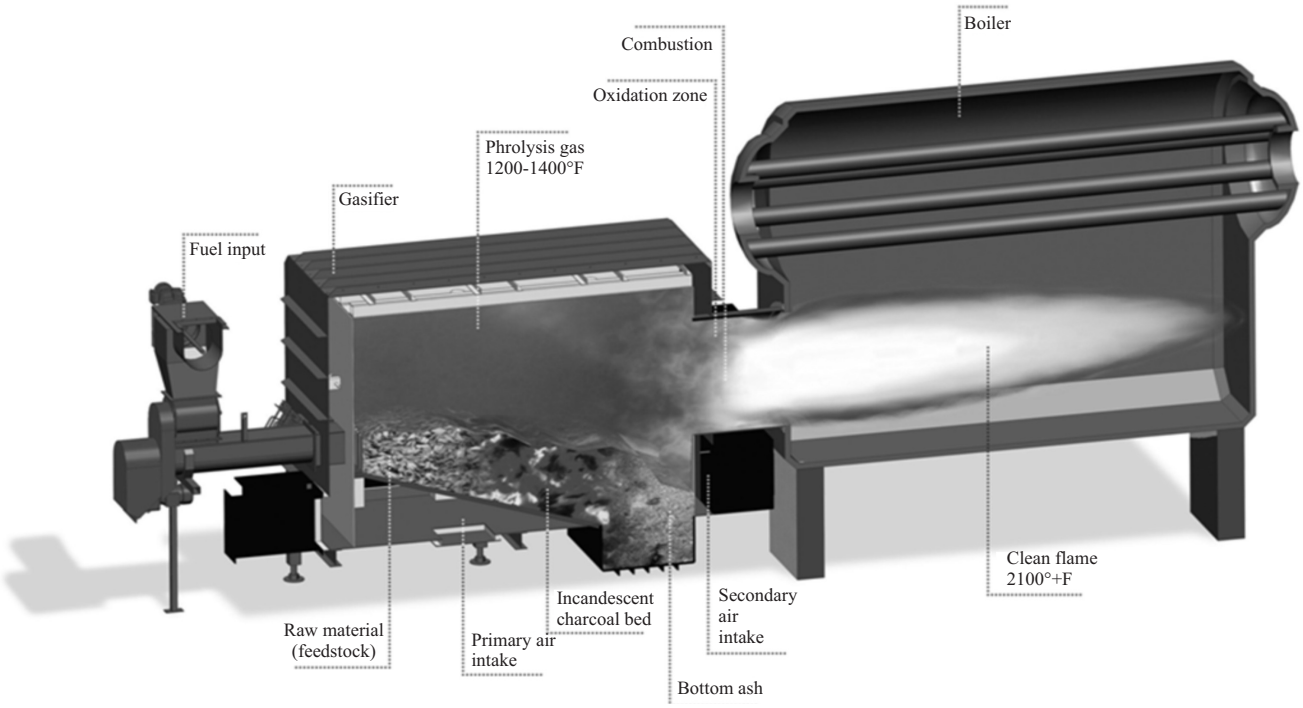


Table 1
ECONOMICS OF LTI SYSTEM FOR PROCESSING 250 TPD BLS

I.	**Assumptions**			
	1	Total Black Liquor Solids	250	TPD
	2	Cost of Steam	1100	Rs. / ton
	3	Cost of Power	8	Rs. / ton
	4	Cost of Charcoal	12	Rs. / ton
	5	Fuel Oil	75	Rs. / ltr.
	6	Salaries & Wages per annum	150	Lakhs
	7	Soda Ash Production	79	tons / day
	8	Cost of Selling Soda Ash	13000	Rs. / ton
	9	Working Days / Annum	330	days
	10	Total Estimated Project Cost	1400	Rs. lakhs
	11	Concentration of Black Liquor	8%	
	12	Volume of Black Liquor Produced	3125	m^3
	13	Concentration of Strong Black Liquor from Evaporator Plant	25%	
	14	Volume of Strong Black Liquor from Evaporator	1000	m^3
II.	**Variable Cost**			
	Steam	Water Evaporated in Evaporators	2125	m^3
		Steam Economy	5	
		Steam Consumed in Evaporators	425	tons
		Steam Consumed in Ejectors	11	tons
		Total Steam Consumed in Evaporators	436	tons
		Variable Steam Consumed Cost / Day	479600	Rs.
	Power	Power Consumed / ton of Soda Ash Produced	360	kwh
		Soda Ash Produced / Day	78.51	tons
		Total Power Consumed / Day	28263.6	
		Total Variable Power Cost	84790.8	Rs.
	Charcoal	Charcoal Consumption / ton of Soda Ash Produced	5.4	kgs
		Soda Ash Produced	78.51	tons
		Total Charcoal Consumption / Day	423.93	kgs
		Total Variable Charcoal Cost / Day	2120	Rs.

Fuel Oil	Fuel Oil Consumption / ton of Soda Ash	7.5	ltrs / ton
	Total Fuel Oil Consumption	588	ltrs
	Total Variable Fuel Oil Cost / Day	17640	Rs.
	Total Variable Cost / Day	584150.8	Rs.
	Total Variable Cost / Annum	**1927.7**	Lakhs
III Fixed Cost			
	Salaries & Wages / Annum	150	Rs. Lakhs
	Total Fixed Cost	**150**	Rs. Lakhs
IV. Cost of Soda Ash			
	BD raw material to be used	500	BDT PD
	Alkali Used	13%	
	Alkali Used / Day	65	tons
	Soda Loss in Brown Stock Washing @ 5%	3.25	tons
	Total Alkali	61.75	tons
	Losses in Evaporator and LTI @ 4%	2.5	tons
	Alkali for Recovery	59.25	tons
	Soda Ash Produced / Day	78.51	tons
	Annual Production of Soda Ash	25900	tons
	Sales Turnover	**3367**	Lakhs
V. Net Contribution			
	Sales Turnover - (Fixed Cost + Variable Cost)	**1289.3**	Lakhs
VI. Payback Period			
	Total Project Cost ÷ Net Profit	**1.09**	**Years**
	Less Then	2	Years

for the LTI system alone is less than 1 year. If you include the contribution of steam by adding HRSG unit, the project cost will increase by Rs 6-7 crores. However, the contribution of steam from the system is roughly Rs 3 lakhs per day and it reduces the payback for this additional expenditure to around 6 months. The details of the steam production used in the arriving at the economics of using the HRSG technology along with LTI are shown in Table 2.

Table 2
Process Details for Heat Recovery and Steam Generating System for LTI

Black Liquor Solids at grit cycolone / LTI Outlet	250 TPD	
DRY Gas	65100 kg / hr	50780 nm^3 /hr
Moisture	17500 kg / hr	21870 nm^3/ hr
Dry Gas Analysis		
CO2	13.5% (Avg)	
O2	6.6% Max	
CO	0.30%	
N2	80.8% Max	
Fluid Gas Inlet to HRGS Temperature	655°C	
Fluid Gas Outlet to HRGS Temperature	140°C	typical
Feed Water Temp (From Deaerator)	105°C	
Max. Working pressure (Design Pressure)	14 Kg/Cm^2	
Saturation Temp, Operating Press At	10.5 Kg/Cm	181°C
Heat Load		
Economizer	$1.33X10^6$ kcal/hr	Typical
HRGS	$8.18X10^6$ kcal/hr	Typical
Net Steam Generation		
Gas Inlet Temp	655°C	WHRB
gas Outlet Temp	205°C	WHRB
Feed Water / Steam at Economizers	105°C	170°C
ECO GAS TEMP	205°C	140°C
Gas Flow	50670 nm^3hr	14500 kg / hr
Economizers gas flow	65100 kg/hr	Dry gas Boiler 75 mm
Pressure drop, Entrance & Exit losses	ECO 95 mm wc	wc
Mass Velocity BOILER	10.11 kg/Sec/m^2	(gas side)

Table 3
ECONOMICS OF CLOSED SYSTEM FOR PROCESSING 250 TPD BLS

I.Assumptions

1	**Green Liquor Solids Produced**	**74.58**	**TPD**
2	Lime Required	39.40	TPD
3	Cost of Lime	5000	Rs. / ton
4	Cost of Power	6	Rs. / ton
5	Causticizing Efficiency	0.9	
6	Fuel Oil	75	Rs. / hr
7	Salaries & Wages	150	Rs Lakha / Annum
8	Caustic Production	50.66	tons / day
9	Market price of Caustic / White Liquor	32000	Rs. / ton
10	Working Days / Annum	330	days
11	Total Estimated Project Cost (LTI + Recaust + FB Lime Calciner)	3400	Rs. Lakhs

II. Variable Cost

Steam	For heating in the recausticizing system	1	Per ton of caustic
	Cost of Steam per day	55724.6	Rs.
Lime	Makeup	7.88	TPD
	Availability	80%	
	Cost of Makeup Lime / Day	39,401	Rs.
Power	Power Consumption / ton of Lime Produced	400	kwh
	Lime Produced	31.52	tons
	Total Power Consumption / Day	12608	
	Total Variable Power Cost / Day	37824	Rs.
Fuel Oil	Fuel / ton of Lime	190	ltrs / ton
	Total Fuel Oil Consumption	9625	ltrs
	Total Variable Fuel Oil Cost / Day	288750	Rs.
	Total Variable Cost / Day	421,700	Rs.
	Total Variable Cost / Annum	**1391.61**	Lakhs

III Fixed Cost

	Salaries & Wages / Annum	100.00	Rs. Lakhs
	Total Fixed Cost	**100.00**	Rs. Lakhs

IV. Cost of Caustic Produced

BD raw material to be used	500	BDT PD
Alkali Used	13.00	%
Alkali Used / Day	65.00	tons
Soda Loss in Brown Stock Washing @ 5%	3.25	tons
Total Alkali	61.75	tons
Losses in Evaporator and LTI @ 4%	2.50	tons
Alkali for Recovery	59.25	tons
White Liquor produced	50.66	tons
Annual Production of White Liquor	16710.00	tons
Market price of White Liquor	**5347.20**	Rs. Lakhs

V. Net Contribution

Market price of WL - (Fixed Cost + Variable Cost)	**1777.89**	Rs. Lakhs

VI. Payback Period based on Contribution

Total Project Cost ÷ Net contribution	**1.91**	**Years**

Economics of Closing the Pulp mill

If Mill A chooses to close the pulp mill loop instead of selling the soda ash, the economics is even better. In the previous scenario, the cost of caustic to be purchased for the daily cooking was not taken into account as that was part of the cost of doing business. If this cost is offset by closing the pulp mill loop, the contribution is more significant as caustic prices are rising.

Mill A would have to install a recausticizing plant that involves slakers and causticiziers along with lime mud filter and dregs filter. This system typically costs around Rs 6-8 crores. This would allow the mill to produce white liquor that can be reused

in the cooking process. The white liquor produced from the reaction of sodium carbonate and lime ends up with 85-90% $CaCO_3$ and other inerts. The lime mud from the white liquor clarifier is then sent to lime mud filter to dewater the lime mud before it enters the fluidized bed calciner.

The fluidized bed calciner would typically cost around Rs 14-16 crores for Mill A. So the total investment for recausticizing system and calciner estimated to be Rs 20 crores. The return on investment or ROI for this part of the investment is based on the amount of caustic recovered for reuse in the pulp mill. The payback period calculated for the total investment including the MEE, LTI, Recausticizing system and FB Calciner, is estimated at 2 years for Mill A.

The major cost of the FB Calciner is the fuel cost. To offset this cost, the use of syn gas from biomass can be employed. The cost of equipment is estimated to be around Rs 6 crores and the payback period is less than 1 year. It reduces the operating cost by nearly 60-70% assuming that the collection and processing of biomass is feasible and cost effective.

Conclusions

The closing of the pulp mill loop has long been beneficial for large pulp mills. The small and medium ones have deferred this due to the high installed cost of conventional recovery boilers and lime kilns. The fluidized bed technology employed in the chemical recovery cycle has shown how the economics can be improved for small and medium pulp mills. The LTI system has been successfully installed at several mills. With the increasing cost of caustic, the authors contend that using fluidized bed calciner along with a recausticizing system, the pulp mill can be closed to provide measureable benefit to small and medium pulp mills. The intangible benefit of closing the loop will be felt when the mills do not have to be subject to the vagaries of caustic and lime pricing. This would allow precious capital to be used in other parts of the company to add value to the product they are producing.

Literature Cited

[1] S. Stultz S., J. Kitto (1992, 40th edition). *Steam its generation and use*. Babcock & Wilcox. ISBN 0-9634570-0-4.

[2] Chambers, M., Grieco, G.J., Caine, J. C., "Customized Rigid Discharge Electrodes Show Superior Performance in Pulp & Paper Applications," paper presented at the 8th International Conference on Electrostatic Precipitation, Birmingham, AL, May 14-17, 2001

[3] Adams, T.N., "Kraft Recovery Boilers", Tappi Press, P.3, 1997.

[4] Dorris, G.M. and Allen, L.H., , "Operating Variables Affecting the Causticizing of Green Liquors with Reburned Limes", Journal of Pulp and Paper Science, 13:3, P.J99, 1987.

[5] Gebart, B. R. et al., "Recent advances in the understanding of pressurized black liquor gasification", Cellulose Chemistry and Technology, April 12, 2011.

[6] Venkatesh. V, "Lime Reburning: Rotary Lime Kiln", Chemical Recovery in Alkaline Pulping Process, edited by R. P. Green and G. Hough, TAPPI Press, Altanta, GA, 1992.