Advantages of Fluidized Bed Calciner Over Lime Kiln in Indian Pulp Mill Context

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ABSTRACT

With increasing demand for paper and paperboard, paper mills have embarked on expansion plans. As per pollution control norms the expansion plans need to include increase in capacity in Chemical Recovery area for processing the black liquor and lime mud. In this paper the focus is on the lime mud re-burning system that is currently employed in the Indian pulp mills, namely lime kilns. This technology has high installed and operating costs even for large pulp mills. The authors are proposing a Fluidized Bed Calciner as a cost effective and viable alternative for lime kiln. The major advantage of this technology is that even small and medium pulp mills can avail of this system as the installed and operating costs are significantly lower than that of lime kiln. The technology does not suffer from the disadvantages of silica in the lime mud that plagues lime kiln operation. With fewer moving and rotating parts this system reduces the downtime significantly. Along with comparison of this technology with lime kiln, the paper addresses the mass and energy balances for a typical system, its economics and the impact of 100% alternative fuel for its operation.

Introduction

Paper and pulp industry has been always a capital intensive one with strict environmental constraints. Although over 90% of the chemicals used in the pulping process can and should be recovered, these processes have long been a subject of research and development to improve the efficacy and operating cost. In this paper we are examining the impact of fluidized bed technology that can be employed in the lime reburning area of the lime sludge generated in the recaustizing area. This system is an alternative to lime kiln to regenerate lime from lime mud sludge. Currently, the available technology for lime mud sludge reburning in the pulp and paper industry in India is rotary lime kiln. Agro Pulping Machinery (Agro) is introducing a Fluidized Bed Calciner that has distinct advantages over lime kiln technology:

a) Lower capital cost by 30-50% over lime kiln
b) Eliminates issues of scaling / rings that plague lime kiln due to presence of silica
c) Reduces operating costs by drastically reducing downtime for maintenance and breakdowns
d) Allows for better Energy usage through multi-fuel facility with capability of 100% alternative fuel substitution.

By far the biggest advantage of this technology is that it can be cost effectively employed for a range of capacities from 30 TPD to 400 TPD of lime mud sludge. This flexibility of lower installed and operating cost is attractive to small and medium pulp mills who are looking to produce caustic in the Chemical Recovery process. Typically lime kiln installations for these mills tend to be cost prohibitive to install and operate. For larger pulp mills this FBC technology provides an alternative for lime kiln green field expansion, and in cases where they are limited by current capacity of lime, low capacity installation of FBC allows for moderate expansion of the pulp mill in a cost effective manner.

Literature Review

First Experimental Lime Kiln was started in Sweden in 1905 by F.L. Smith [1] and the development took place in North America after 1935 and in Europe after 1950. Earlier Kilns tended to consume more fuel (20GJ/Ton) and more space than modern versions. Modern Lime Kilns were modified along with coolers to reduce the fuel consumption (7.0GJ/Ton) [4] but it increased the capital cost. Though the modern lime Kiln are more energy efficient it is not suitable or economical for small capacity (< 100 TPD of lime mud, or 300-350 TPD unbleached pulp). Furthermore, lime kiln operation in Indian pulp mills suffer from the issue of silica in the lime sludge as well as issues with regard to scaling and fuel substitution. Producer gas has been used to substitute fuel oil but it produces tar that impacts the burner operation in the lime kiln.

Fluid Bed Calciner (FBC) technology introduced by Agro addresses several of these issues with fuel consumption approximately (7.0GJ/Ton) in par with modern kiln but with a lower capital and operating cost. Fluid Bed Calciner is suitable for low capacity operation that occupies less space and it tolerate the disadvantages caused by the silica present in the lime mud sludge [5]. Fluidized Bed Calciner was tested in Glatfelter pulpmill [6]. However, this technology did not take hold in pulpmills and instead gravitated to mining industry mainly due to the energy efficiency of the initial designs. Agro has improved this aspect to make it at par with modern lime kilns and this technology should serve as a viable alternative for lime kilns in the Indian pulp mills.

Result and Discussion

This paper examines how Fluid Bed Calciner is viable alternative for Lime Kiln for the Indian Pulp and Paper industry. This technology provides solutions for operating issues like scaling rings, mechanical breakdown, burner / flame length, fuel consumption, temperature profile maintenance that plague a typical lime kiln operation. In the paper the economics and efficacy of a typical FBC is addressed along with the Mass and Energy Balance of a typical system.

Fluid Bed Calciner for lime recovery

Calcination is the process of converting lime mud sludge in to lime, this reaction takes place at higher temperature starting at 850^0C.

Calcining

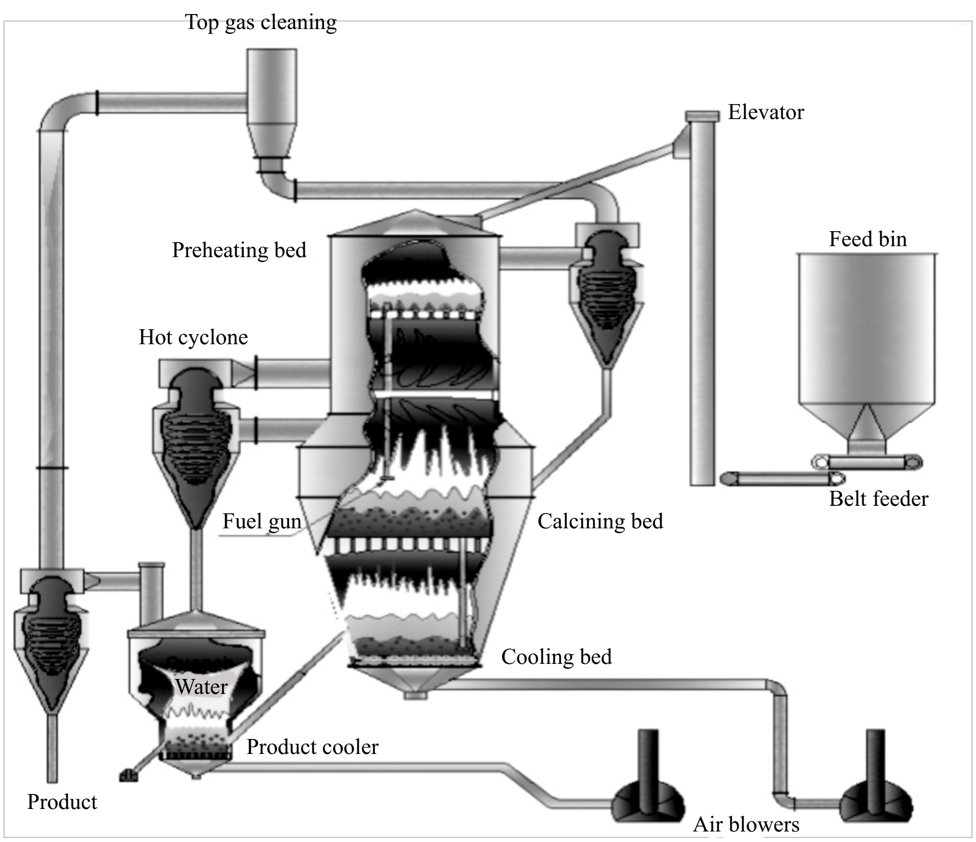
$$\boldsymbol{CaCO_3}\ \textit{(lime mud)} \underset{\text{Heat}}{\leftrightarrow} \boldsymbol{CaO}\ \textit{(reburned lime)} + \boldsymbol{CO_2}$$

Fluid Bed Calciner (FBC) employs the fluidized bed technology that has been popularized by Agro in India for black liquor low temperature incineration (LTI) for small and medium pulp mills [7]. FBC is similar to LTI construction and operates with the same concept of fluidize bed. However, there are key differences in operating conditions and auxiliary equipment. A schematic representation of Fluid Bed Calciner is shown in *Figure 1* shows how the construction is quite similar to that of LTI [5]. The LTI system used for black liquor incineration, the burning is done autogenously, but in a FBC or lime kiln, external fuel is needed to provide to reach the calcination temperature in the fluidized reactor zone. The lime dust escaping the FBC reactor zone along with the fuel gases is captured through a grit cyclone system while the other particulate matter is scrubbed by the venturi and secondary scrubbers.

The resulting effluent gases meet all pollution norms as defined by Central Pollution Control Board of India [8] [9] & [10]. This system may 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 re-causticizing system.

In a typical FBC 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 piece of equipment is widely used in the paper industry and can be employed for this system. Lower lime mud solids would mean higher fuel consumption. The introduction of lime mud into the FBC 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.

Figure 1 SCHEMATIC DIAGRAM OF LIME MUD CALCINER



The reaction starts at 850^0C the temperature of the reaction is maintained to avoid the reverse reaction to occur. The lime formed by the calcinations forms around 2mm pellets in the fluidized bed and is discharged to a product cooler. The cooling of the product is critical so that the pellets do not agglomerate. At the product cooler discharge, a lime crusher or cage mill can be employed before sending the product to the recaustizing area. The cooling of the product also flashes steam and vapors that are reintroduced in the preheating zone of the FBC.

Economics of A Fluidized Bed Calciner

To understand the economics of FBC, this technology is being compared with a typical system of lime kiln that processes 100 tons per day of lime sludge. The FBC requires roughly 12m x 12 m area for its equipment where as a lime kiln requires approximately 3.2m shell diameter and the length is 82 to 85m. A more detailed economics and payback period based on net contribution to the caustic production for FBC is shown in the *Table 1*. A comparable lime kiln system would be 30-50% or more, in installed cost in comparison to a Fluidized Bed Calciner. The fuel cost for both systems are at par but the power requirement for FBC is 25-30% lower and operationally more convenient.

Operation Conditions

Operation of a lime kiln involves several critical aspects, namely, maintenance of a thermal profile along length of the kiln, an optimal rotary motion to allow proper calcination, a cooling zone to cool the product, maintenance of flame length and clean burner operation to avoid thermal induced ball formation. The power consumption for 200 TPD of lime to produce is approximately 220KWh for lime kiln. For the same capacity FBC consumes 150KWh and this is shown along with fuel consumption in *Table 2*. By design the FBC technology has few moving parts compared to a lime kiln. This alone helps a FBC to have a longer sustained operation without incurring downtime to breakdown of moving parts such as chains in a lime kiln. The FBC technology lends itself to continuous operation and the operating controls to maintain air fluidization and temperature is simple compared to the tight control parameters in the case of the lime kiln. Unlike the case of the lime kiln where the temperature profile along the length of kiln needs to be maintained diligently so that rings or scaling does not take place, maintaining temperature

TABLE 1 Economics of Chemical Recovery System with a LTI and FBC systems

300	**TPD Unbleached Pulp**			
2500	**FBC Project Cost Lakhs**			(P1)
1800	**Low Temperature Incinerator for Black Liquor**			(P2)
100	**Salaries & Wages Lakhs / Annum**			
Assumptions				
	Green Liquor Solids Produced	**90**		
1	Lime Required	47	TPD	
2	Cost of Lime	4000	Rs. / Ton	
3	Cost of Power	6	Rs. / Ton	
4	Causticity	0.8		
5	Fuel Oil	75	Rs / Ltr.	
6	Salaries & Wages	150	Rs Lakhs/ yr	
7	White Liquor Production	54	Tons / Day	
8	Cost of Makeup Caustic	36000	Rs / Ton	
9	Working Days / Annum	330	Days	
10	Total Project Cost	2000	Rs Lakhs	
Variable Cost				
Lime	Makeup	9.5	TPD	
	Availability	80%		
	Cost of Makeup Lime /Day	37,825	Rs	(A)
Power	Power Consumption / Ton of Lime Produced	150	Kwh	
	Lime Produced	37.83	Tons	
	Total Power Consumption / Day	15132		
	Total Variable Power Cost /Day	45396	Rs.	(B)
Fuel Oil	Fuel / Ton of Lime	178.5	Ltrs / Ton	
	Total Fuel Oil Consumption	10,266	Ltrs	
	Total Variable Fuel Oil Cost / Day	3,07,980	Rs.	(D)
	Total Variable Cost / Day			
	(A+B+C+D)	3,91,201	Rs.	
	Total Variable Cost / Annum	**1,291**	Lakhs	(E)
Fixed Cost				
	Salaries & Wages / Annum	100	Rs. Lakhs	(F)
	Total Fixed Cost	**100**	Rs. Lakhs	(J)
Contribution from WL Produced				
	BD raw material to be used	600	BDT PD	
	Alkali Used	13	%	
	Alkali Used / Day	78	Tons	
	Soda Loss in Brown Stock Washing @ 5%	4	Tons	
	Total Alkali	74	Tons	
	Losses in Evaporator and LTI @ 4%	3	Tons	
	Alkali for Recovery	71	Tons	
	White Liquor produced	54	Tons	
	Annual Production of White Liquor	17,830	Tons	
	Contribution from White Liquor production	**6419**	Lakhs	(K)
Net Contribution				
	Contribution from White Liquor production - (Fixed Cost + Variable Cost)			
	K - (E + J)	**2745**	Lakhs	(L)
Payback Period				
	Total Project Cost ÷ Net contribution (P1+P2) - L	**1.6**	**Years**	
	Less Then	2	Years	

TABLE 2: Fuel and Power Consumption and Comparison

	Lime Kiln	**FBC**
Reburnt Lime Production	180 to 200 TPD	180 to 200 TPD
Availability in the lime	81.00%	82 – 84%
Particulate Emission	50.00mg/Nm^3 (Dry Basis)	25-50.00mg/Nm^3(Dry Basis)
Power Consumption		
Lime Kiln System	220.00KWH	150.00 KWH
Producer Gas Plant	90.00KWH	
Specific Furnace Oil Consumption @65% Dryness	177 Kg/Ton of lime	178.5 Kg/Ton of lime
Substitution of FO with Producer Gas/ Bio Mass		Fossil fuel substitution
Fuel Oil		
Producer Gas / BioMass	30% - 54 KG/ Ton of lime 70% -70 TPD of coal	70% 300 TPD Biomass 100% ~500 TPD Biomass

Table 3: Requirements for Lime Sludge Feed Composition and Efficiency of Calcining

Basis: 300Tons of pulp = 96 Tons of NaOH
Expected Product output: 62 Tons of lime
Causticizing
$Ca(OH)_2 + Na_2CO_3 \rightarrow CaCO_3$ *(lime mud)* $+ 2NaOH$ *(Caustic)*
From the above equation:
Soda Ash = 121 Tons
Lime Required = 60 Tons including inerts
Lime Mud Formed =100 Tons including inerts
Calcining:
$CaCO_3$ *(lime mud)* $\leftrightarrow CaO$ *(reburned lime)* $+ CO_2$
Re-burned Lime Produced = 52 Tons

1.	TYPICAL LIME MUD SLUDGE ANALYSIS	FBC	LIME KILN
a.	Dryness	60-65%	**60-65%**
b.	Calcium Carbonate	86 – 90%	**92-95%**
c.	Sodium Oxide	0.3 – 0.7%	**<0.2%**
d.	Silica	5.7 – 8.0%	**<0.2%**
e.	Mixed Oxide	1.0 – 2.0%	**<1.01%**
f.	Free Lime	0.4 - 0.8%	**<0.5%**
2.	**EXPECTED PRODUCT OUTPUT (BURNT LIME)**		
a.	Calcium Oxide (CaO)	2.14 TPH	**2.08 TPH**
b.	Magnesium Oxide & (Na_2O)	0.08 TPH	**0.07 TPH**
c.	Silica & Inserts	0.22 TPH	**0.17 TPH**
d.	Un-burnt $CaCO_3$	0.14 TPH	**0.25 TPH**
	Total	2.58 TPH	**2.56 TPH**
	CaO Purity / Availability	**82 -84 %**	**81 - 82%**

TABLE 4: Energy Balance and Fuel Requirement for Lime Kiln vs. FBC

Description	Older Lime kilns GJ/Ton	Modern lime kiln GJ/Ton	Fluid Bed Calciner GJ/Ton
Drying & Evaporation Feed moisture	2.51	2.30	2.74
Energy Kiln Product	1.08	0.19	0.166
Enthalpy of Calcination	3.18	3.18	2.626
Enthalpy of CO_2 from Calcination	0.2	0.1	0.12
Energy in dust	0.06	0.04	-
Enthalpy of Combustion Product	1.23	0.45	1.082
Radiation & Un Accountable Losses	1.40	0.9	0.725
Total Energy	**9.66**	**7.16**	**7.45**
Fuel oil consumption (Kg / Ton of Lime)	**241**	**177**	**178.5**

TABLE 5 :Analysis of various fuels that are employed in kiln or FBC
Calcination Capacity (Burnt Lime TPD)-
300 TPD @ 30% F.Oil & 70% Producer Gas

Fuels: - Heavy furnace oil			
Viscosity (50°C)	Sec	410	
Gross calorific value	Kcal/Kg	9990	
Carbon	%	84	
sulphur content (Max.)	%	4.0	
Ash (Max)	%	0.1	
Producer Gas:		From Coal	From Bio Mass*
Calorific Value	$Kcal/Nm^3$	1050	1446
Temperature	^0C	75	200
CO	%	18 – 20	16.18
H_2	%	11.50	9.13
O_2	%	0.3	0.45
N_2	%	55.95	64.24
C_nH_m	%	2.25	1.75
CO_2	%	6.0	8.25

* 100% Fuel oil substitution is not possible in a Lime kiln since the tar in producer gas impacts the burner operation where as in FBC 100% substitution is feasible.

in FBC is straightforward and controlled by fuel-to air ratios. Furthermore, coolers in the lime kiln tend to reduce the life time of refractory bricks and the thermal efficiency which impacts the product quality as time wears on. For these reasons, lime kiln operation typically experiences higher scheduled and unscheduled downtime. In the case of FBC, the product cooling is done outside the reactor zone. The external cooling system for product cooling also is used to recover the heat and the temperature of the flue gases is effectively utilized in the preheating zone of the FBC.

Maintenance and Operating Issues

The major technical problems faced during lime kiln operation are due to presence of silica, sodium oxide, sulphur and phosphorus. These impurities are associated with the common calcining problems such as balling and ringing [3]. Ball formation typically occurs just ahead of the kiln burning zone, soda and sulfur compounds have lower melting point consequently tend to coat the lime pellets and large balls (several feet in diameter) that form and roll down the kiln. The ring formation has been attributed to high level of sulphur and silica or sodium in mud the feed results overheating of the refractory surface. Due to the above problems the quality of the lime is reduced. This FBC technology addresses these issues by its design and operation.

Fluid Bed Calciner technology can tolerate higher silica (2-3%) and sodium oxide beyond 0.8% in the lime mud sludge without facing major technical problems in its operation. If the temperature of the bed is maintained over 900^0C and the fluidizing air to fuel ratio is maintained, $CaCO_3$ undergoes complete calcination due to the continuous agitation provided by the bed fluidization. Hence, FBC tends to produce superior quality of lime as the agitation in the fluidized reactor zone ensures higher efficacy of calcinations. Furthermore, the fluidization also ensures that pellets are formed instead of sticky dust that is usually the primary cause for scaling or rings. Additionally, the silica in the lime mud is removed continuously as it becomes a part of the product pellets. A typical analysis of the lime mud sludge and reburnt lime are shown in *Table 3*.

Energy Efficiency Through Use of Alternative or Renewable Fuel

The fuel oil consumption plays vital role in production of lime. Energy requirement and fuel consumption per ton of lime to produce is shown in *Table 4*. In the case of FBC there is a possibility of radical cost reduction by alternate fuel such as biogass / producer gas. Gross Calorific value of Fuel oil is 10,000 Kcal/Kg is requiring for 300TPD of lime sludge to burn. Indian pulp mills have been successful in replacing up to 70%

TABLE 6: Overall Comparison of Fluidized Bed Calciner with Lime Kiln

	Lime Kiln	Fluid Bed Calciner
Capital Cost (Rs. Lakhs) for 100 -150 TPD lime sluge	4000 – 4500	2200 - 2500
Area Requirement (150TPD)	Dia 3.8m and 38m length	20m length and 20m Breadth.
Power Requirement (KW h)	220 KWh	150 KWh
Fuel Oil (kg/Ton of lime)	177	178.5
Operating conditions	• Need for maintaining temperature profile • Frequent maintenance of the moving parts like chains • Flame length control is vital for calcination. • Coolers operation is critical to avoid down time.	• Need to maintain temperature above calcination (850^{0}C). No requirement for temperature profile. • With few moving parts the system can operate for long periods without down time. • No flame length control is required. • Product is cooled outside reactor zone.
Operating Issues	Balling and Ring Formation Due to Presence of silica, Sulphur, Sodium Oxide.	Feasible to operate with the presence of silica beyond 2 - 3% and sodium oxide beyond 0.8%.
Capacity	Typically for 150 Tons / Day to be economical. Low capacity tends to the cost prohibitory.	Suitable for all sizes small (30-50 TPD), medium (100-150 TPD) and large size mils (> 300 TPD). Economical even for small and medium mills.

fuel oil with producer gas that is generated from coal [2]. However, this approach substitutes one fossil fuel, namely fuel oil with another, coal. Furthermore, the quality of producer gas is greatly impacted by the quality of coal available. The producer gas system produces tar along with the gas that tends to impact the burners and flame length in the kilns.

The alternate methodology is to produce the synthesis gas from biomass which can substitute 100% fuel oil as shown in *Table 5.* Current technologies of producing syn-gas greatly reduce the tar production. Although this fuel alternative is viable for both lime kiln and FBC, the presence of tar does not impact the FBC as it does to lime kiln operation. Thus high levels energy optimization can be achieved in FBC with the use of 100% renewable fuels without impacting the quality and quantity of lime production.

Conclusions

The authors have discussed how Fluid Bed Calciner is viable and economical technology for lime reburning. For small and medium pulp mills, the FBC allows them to close their pulp mill loop in a cost effective manner. A comparison of lime kiln and FBC is shown in *Table 6.* With increasing cost of caustic, and the pollution norms requiring reuse of lime much, FBC technology is an excellent choice for these mills. For larger mills who are looking for green field expansion, or just marginal enhancement of their pulp production, the FBC technology allows for economical way to do so. In all of these cases, the operation ease and the capability of FBC to handle the silica and scaling issues, proves that FBC may be a better alternative than lime kiln for Indian conditions. Furthermore, FBC is easier to operate and it requires less power than lime kiln. These economic considerations along with the lower installed cost of FBC (30-50% lower) in comparison to a lime kiln, is an added incentive for pulp mills to seriously consider this technology for their lime reburning systems.

In conclusion, the authors point out that fluidized bed technology introduced in 1996 by Agro through low temperature incineration for black liquor has been successfully deployed in over 15 locations for small and medium pulp mills. Its economical and worry-free operation bodes well for FBC that employs similar approach for lime mud reburning. The cherry-on-the-cake is that FBC systems allows for 100% fuel oil substitution along with 100% alternative renewable fuel like biomass. For Indian pulp mills the Fluidized Bed Calciner technology may be better alternative in terms of both function and cost.

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