

**Title : UTILIZATION OF LIME SLUDGE FOR VALUE
ADDED PRODUCTS AND PRODUCTIVITY
ENHANCEMENT OF LIME KILNS**

**Sub Title : REBURNING OF LIME SLUDGE FOR LIME
MANUFACTURE IN VERTICAL SHAFT LIME KILN**

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SUMMARY AND CONCLUSIONS

1. M/s Central Paper and Pulp Research Institute, (CPPRI) Sharanpur have approached National Council for Cement and Building Materials (NCB) to prepare a joint report on utilization of lime sludge generated by paper industry. The project was divided into four sub projects. Among these four sub projects one is, "Reburning of Lime Sludge for Lime manufacture in captive Lime Kiln".
2. A joint team of NCB and CPPRI experts visited paper plants for collection of data and samples so as to have a upto date knowledge about the paper industry regarding various aspects such as technology, sludge generation characteristic of sludge etc. The average quality of lime sludge is as follows :

MC%	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO%	MgO%	LOI%	SO ₃ %	Na ₂ O%
40-60	2-8	0.8-1.2	0.8-1.2	48-53	0.2-0.3	37-42	0.1-0.3	0.8-2.0

3. Presently two types of calciners are being used in paper industry for calcination of lime, i.e. rotary kiln technology and fluidized bed technology.
4. Technology used for manufacture of lime in India are based on vertical shaft kiln technology and Rotary kiln.
5. In vertical shaft kiln technology various types of shaft kiln as well as long and short rotary lime kilns are in operation. Comparative evaluation of various parameters in different kiln systems have been dealt with.
6. Lime kilns are based on solid/liquid/gases fuels. Their efficiency, heat of dissociation, heat balance, factors effecting thermal efficiency of lime kiln as well as combustion efficiency is described in details.
7. Widely used technologies for lime calcination are both Rotary and Vertical Shaft Kilns. It is well established that rotary kiln technology is capital

(ii)

intensive and economically viable for higher capacity plants. Where as vertical shaft kilns have preheating, calcining and cooling zones in a single shaft, hence making the process less capital intensive as compared to rotary kilns.

8. Since the generation of lime sludge in paper mills is only 0.6 metric tonnes with respect to its production capacity of one tonne of paper. This makes the manufacture of quick lime by vertical shaft kiln an attractive proportion.
9. Since paper sludge is a very fine powder having high moisture content it cannot be fed directly into a vertical shaft kiln. To use such a material in vertical shaft kilns drying and briquetting techniques were studied in details. Using drying techniques the moisture content was brought down to < 10% and the briquettes were made. Static and dynamic load of these briquettes were also studied for its performance in Vertical Shaft Lime Kiln. Attention was also paid to the shape, size and strength of the briquette.
10. Calcination studies were undertaken using briquettes as well as nodules. Its calcination temperature, retention time as well as available CaO was measured and optimised.
11. Site selection, layout, flow sheet and specifications of plant and machinery have been worked out.
12. Infrastructure facilities such as power, water, transport, communication, human resources, climate and rainfall, seismicity working facilities, construction materials etc. have been identified.
13. Requirements and classifications of Building lime/Quick lime and hydrated lime for chemical industries as well as use of lime in various sectors have been compiled.

(iii)

14. Manufacture of hydrated lime, its chemical reaction and mechanism, types of lime hydrates, manufacturing process have been described.
15. Equipments used in lime hydrated plant have been compiled alongwith flow sheet of the process.
16. The project cost of 50 tpd hydrated lime has been estimated as Rs. 461 lakhs.
17. The production cost Per Tonne of quick lime & hydrated lime works out to be Rs. 1335/- & Rs. 1186/- respectively.

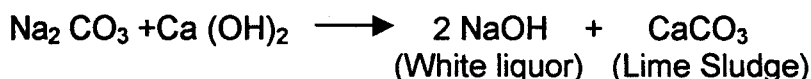
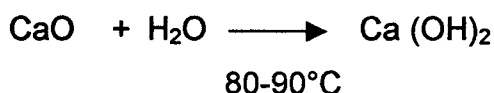
REBURNING OF LIME SLUDGE FOR LIME MANUFACTURE IN CAPTIVE LIME KILN

1.0 INTRODUCTION

These days there is an increasing emphasis on a cleaner environment and maintaining the balance of the eco-system of the biosphere. It is generally believed that environmental protection with zero risk and economic growth do not go hand in hand, but at the same time it is also true that sustainable growth with environmental quality is not an unattainable goal. The problem is multi dimensional and multifaceted and calls for integrated efforts by the industry, Govt. policy makers, environmental managers and development agencies to look into generation, disposal and utilization aspects.

Paper and pulp industry in India is generating nearly 0.8 million tonnes of lime sludge that too only in organized sector. The beginning of the Modern paper Industry in India dates back to 1832 when the first paper machine was established, but actual production were taken up in the end of century. Currently installed capacity for paper manufacture in India is about 4.6 MT out of its 380 paper mills scattered throughout the country. Out of 380 plants 32 plants are in the large scale sector and the rest in medium and small scale sector. The production capacity of large scale sector ranges above 100 tpd of paper production and of medium and small scale sector is below 100 tpd. The raw material base for these plants are wood, bamboo, straw and agricultural waste. Most of the large paper mills are based on wood and bamboo. However, in the last couple of years 5 – 6 number of agro based mills have increased their production capacity more than 100 tpd and have installed a chemical recovery system. The type of paper manufactured depends upon the raw material and pulping process adopted.

All the large scale plants are equipped with chemical recovery system i.e. conversion of green liquor to white liquor by causticizing process. In this process calcined lime is used for regeneration of caustic soda by conversion of soda ash generating calcium carbonate sludge as a waste :



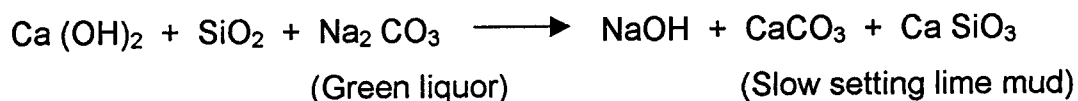
The recausticizing reaction occurs at a solid-liquid interface within the solid particle (1,3). The green liquor containing dissolved Na_2CO_3 reacts with solid Ca(OH)_2 , forming solid CaCO_3 and NaOH . The solid CaCO_3 remains at the interface and NaOH leaves in the dissolved form. Principally CaCO_3 , which is generated as a by-product during recausticizing process of green liquor to white liquor is commonly known as Lime Sludge which is a solid waste generated from paper industry. Calcium carbonate thus produced is washed with water and filtered to recover alkalies and disposed off either as cake or mixed with water and flown out in settling tanks or disposed off by dumping in low lying areas, open fields thus make them unfertile. Many a times it is spread in a mill yard which has taken a shape of a big mountains due to accumulation of so many years. The rough estimate of this solid waste as mountain is about 7-10 million tonnes.

1.1 CHARACTERISTICS OF LIME SLUDGE

Lime sludge is a very fine precipitated CaCO_3 particles along with unsettled dregs carried over from green liquor clarifier. The average Physico-Chemical properties of Lime Sludge waste is as follows :

MC%	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO%	MgO%	LOI%	SO ₃ %	Na ₂ O%
40-60	2-8	0.8-1.2	0.8-1.2	48-53	0.2-3.0	37-42	0.1-0.3	0.8-2.0
Mineralogy = Calcite, Quartz, Hemihydrate, hydroxyl								

Major impurities associated with lime mud (sludge) are Silica and Magnesium. Silica enters mainly via raw materials or through purchased lime and goes to chemical recovery loop. During the causticizing operation SiO_2 forms CaSiO_3 which is gelatinous in nature. This gelatinous nature hinders the setting property of lime mud (sludge). It has been observed that high percentage of silica in lime mud entraps higher moisture content (4-5).



Particle Size distribution

Size range in micron

+90	Nil
-90 to +50	8
-50 to +30	11
-30 to +10	78
-10	3

Attention is required to use this solid waste either as recycling product to be used for the paper manufacturing process or in some other value added products.

Some Paper Industries are already recycling Lime Sludge and converting it to quick lime which can be further reused in paper manufacturing process. Out of 32 large paper mills only 5 mills are having lime reburning calciner to convert Lime Sludge to quick lime for reuse in the causticizing process. The high temperature process which drives the CO₂ out of CaCO₃ to produce CaO is called Calcination. The unit that reburns the lime are called calciners or Lime Kilns.

In view of above , the proposed project envisages to convert this solid waste into value added products. One such area is looking into the aspect of reburning of lime sludge to reclaim lime by using appropriate technology which could be economical and cost effective as well as electrical and thermal energy efficient. At the same time it is able to handle different impurities associated with lime sludge which are introduced by using different types of raw materials.

2.0 PRESENT STATUS OF LIME REBURNING IN PAPER INDUSTRIES

At present there are 32 large scale paper mills having chemical recovery system and among them five paper mills where lime reburning calciner are in operation to convert Lime Sludge to quick lime.

The type of calciner reported (6-12) to be used world wide for lime reburning are:

- Rotary kilns
- Fluidized bed

2.1 ROTARY LIME KILN

For burning Lime Sludge, rotary kiln is a type of calciner where either furnace oil or pulverized coal is used as fuel. Rotary kiln is basically a large steel tube lined inside with refractory bricks and with properly designed heat transfer chain system, rotary cooler and firing equipment. The kiln is slightly inclined from the horizontal and slowly rotates on a set of riding rings. Lime Sludge is introduced on uphill end along with high grade lime stone. The sludge slowly makes its way to the discharge as a result of the inclination and rotation of the kiln. A burner is installed at the downhill or discharge end of the kiln where the fuel is burned to form a roughly cylindrical flame. Heat transfer from this flame and the hot combustion gases that flow up the kiln dries, heats and calcines the counter-flowing lime sludge. Schematic diagrams of the outside and inside of the rotary lime kiln are shown in Fig. 1 & 2. The rotary kiln used in paper and pulp industry are long lime kiln in the range of Dia 2.1 M x 53 M long to 4 m x 122 m long. Steel shell thickness is about 2.5 cm to 6.4 cm and refractory lining is from 15.2 cm to 25.4 cm thick. Production capacity ranges from 50 tpd CaO to 450 tpd CaO. Long rotary kilns are favoured in paper industry because it can process finer material like 3/8" x 10 mesh.

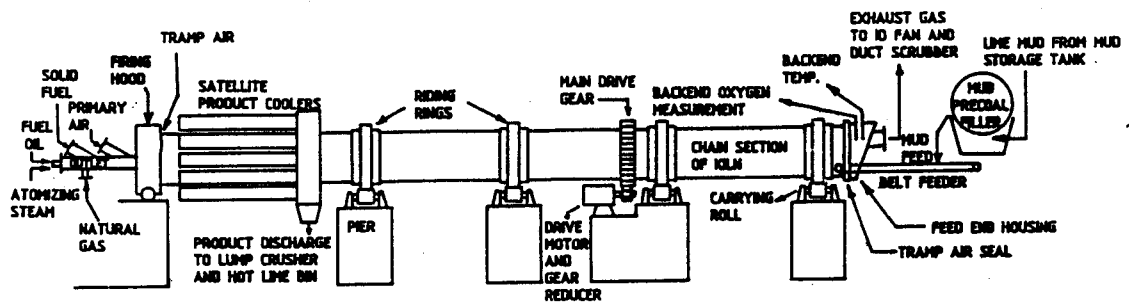


Fig. 1 : Schematic diagram of a modern rotary lime kiln

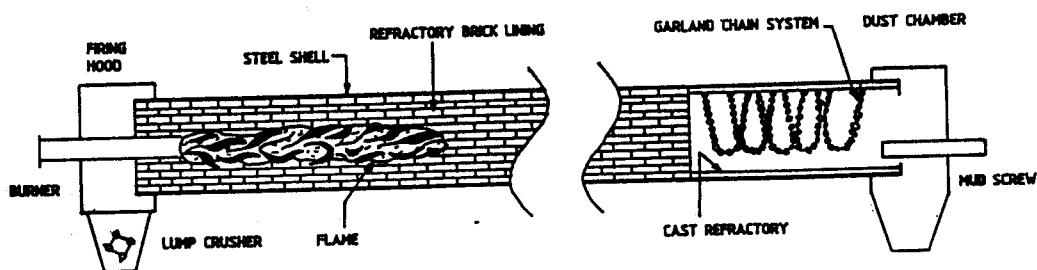


Fig. 2 : Internal features of a rotary lime reburning kiln

All modern rotary lime kilns are fitted with coolers. These are tubes attached to the kiln shell and rotating with the kiln and shown in Fig 3. The hot reburned lime product drops through the holes in the shell just uphill from the tip of the kiln into the tube coolers. Internal structures move the lime back uphill in these tubes as they orbit with the kiln rotation. They also bring hot lime into contact with air which preheats the combustion air.

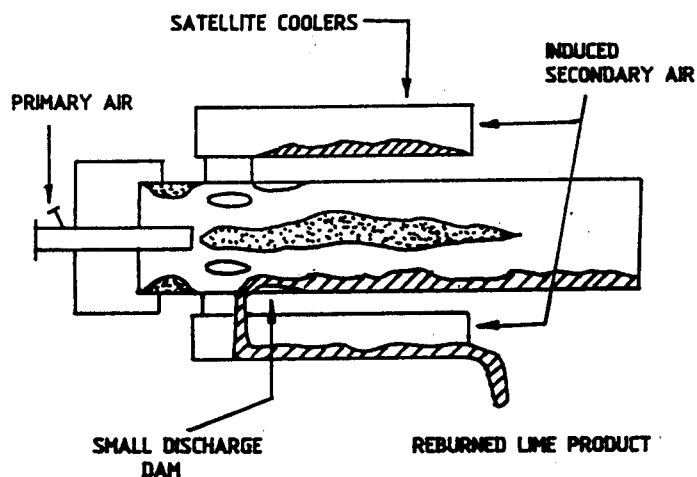


Fig. 3 : Schematic diagram of a rotary lime kiln with satellite product coolers

2.2 FLUDIZED BED CALCINER

The fluidized bed calciner is a two compartment vessel in which the top bed is for higher temperature calcination of calcium carbonate and pelletization of the calcium oxide, and the bottom bed is for heat recovery. A positive displacement blower is used to supply air to the reactor for fluidization which is also used as combustion air for fuel burning. Within the reactor, solid and gas flows are counter current the solid flows downwards and the gases flow upwards. The dry carbonate powder feed is metered to an air swept pipeline and is blown into the bottom part of the calcination bed through a series of feed guns located around the periphery of the reactor. Heat to the calciner is obtained by direct bed burning of fuel which is distributed through fuel guns also located around the periphery of the reactor. Complete combustion of the fuel is obtained by maintaining an excess of preheated air rising from the chamber below. It is important to note that, in case of heavy fuel oil, the oil is not atomized in the conventional manner. Fuel burns in the fluid bed without visible flame. Combustion being accomplished as a result of a turbulent mixing of air, fuel and solids at the elevated temperature in the bed. At a calcination temperature $>815^{\circ}\text{C}$ immediate calcination of the fine carbonate feed takes place. The space above the fluid bed, called the free board is expanded in area to decrease the velocity of the uprising gases. This will allow fine solids to

disengage from the gas stream and fall back into the fluid bed, where they act as nuclei for the pellet growth. If fine solids are not generated for pellet nuclei, a portion of calcined pellets is recycled through a roller crusher for reentry to reactor. Calcined lime pellets, which are $\frac{1}{4}$ " to 20 mesh in diameter flow through an internal underflow pipe to a cooling compartment. The hot pellets are cooled and incoming air is heated to a temperature of 150-200°C. Cooled pellets flow from this chamber to cooling bed which can be lifted by bucket elevator for reuse. A general flow sheet for a fluid bed calciner is shown in Fig. 4. For past two decades fluid bed calciner are available and more than 80 units in the field with nearly 20 application to lime reburning in the paper and pulp industry are functioning in USA & Japan.

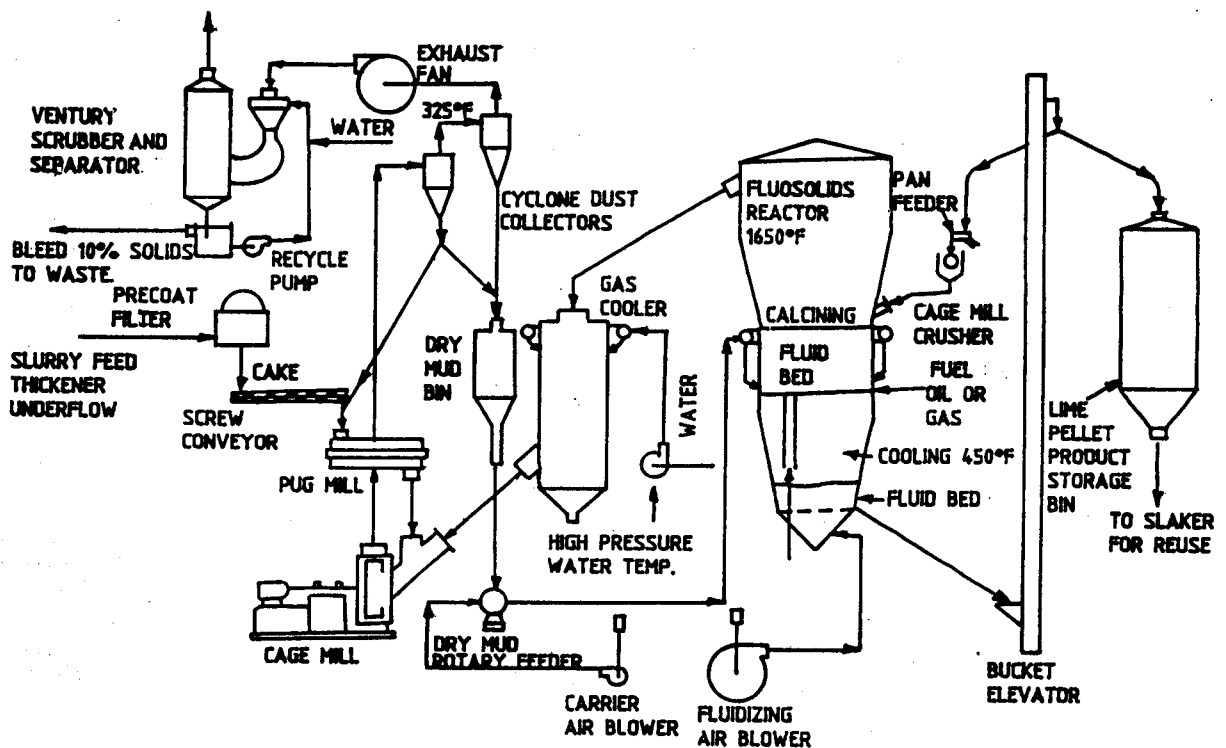


Fig. 4 : Schematic diagram of a fluid-bed calciner

3.0 PRESENT STATUS OF LIME KILNS TECHNOLOGY

Technology of lime manufacture basically involves thermal dissociation of limestone containing predominantly calcite mineral under certain conditions of temperature and pressure, in one or the other type of kilns. For centuries lime was produced by burning limestone in simple masonry kilns of various shapes and sizes, till the time lime came under heavy demands for major industries like steel, sugar, paper, chemicals, agriculture, health and lime based building materials and it could no longer be produced by conventional methods in desired quantity and quality. Large scale manufacture of lime conforming to rigid quality standards for different usage, brought in not only better technologies to produce it, but also led to significant research and development efforts to understand the physico-chemical, mineralogical, mechanical, thermal and thermodynamic behaviour of limestones and the process and operational parameters in burning it. This understanding is today an integral part of lime manufacturing technologies.

Lime manufacture in India can be conveniently grouped under the following :

- 1) Organised large scale lime manufacture, and
- 2) Un-organised small scale lime manufacture.

Most of the lime produced in India in the organised sector is for captive use of the industries like steel, sugar, paper, chemicals etc. The lime manufacturing plant capacities range from 60-400 tpd of lime. The largest size mixed-feed coal fired vertical kiln used in the country is 60 tpd and a battery of such kilns is being used to produce upto 400 tpd of lime. Most of the vertical mixed feed kilns are having mechanical charging and manual discharging systems. Some of the sugar and paper manufacturing units in the country are using energy efficient oil fired vertical kilns. Rotary kilns are also in use for producing metallurgical grade lime by some of the steel plants and are oil/tar fired.

No authentic data is available on the average fuel consumption for either vertical or rotary kilns. However, values ranging from 1000-1400 Kcal/kg of lime

have been reported for the vertical kilns for average quality limestone (~85% CaCO_3) and 1300-1400 Kcal/kg of lime for rotary kilns.

Lime in unorganised sector is mostly produced in mixed feed vertical kilns with capacities ranging from 2-60 tpd using coke/coal/cinder as fuels. The kilns of small capacity upto 10 tpd are operated manually and produce variable quality of lime with moderate reactivity. The percentage of contaminants is also high. However the quality of lime produced in large capacity mixed feed kilns using large size feed has been reported to be much better, although no instrumentation is generally used even for monitoring temperature, pressure, oxygen and CO content in the exit gases of these kilns.(13)

3.1 TECHNOLOGIES FOR THE MANUFACTURE OF LIME

Although a large number of technologies are available for the manufacture of lime, the two most developed and widely used technologies in India are – (1) Vertical Shaft Kiln (VSK) Technology; and (2) Rotary Kiln Technology.

Over the years a large number of developments have taken place which have resulted in enhanced capacities of the plants, lower fuel and energy consumption, reduction in quantity of quarry wastes, utilization of solid fuels, higher capacity utilisation and better quality of products etc. Some of these developments have been discussed here.

3.1.1 VERTICAL SHAFT KILN TECHNOLOGY

Manufacture of lime by Vertical Shaft Kiln technology is centuries old. Basically the vertical kilns incorporate the preheating, calcinating and cooling functions in a single shaft. Newer developments have essentially been directed towards improving kilns for more efficient operations, increasing their versatility to accept varying feed sizes, utilization of solid, liquid and gaseous fuels in the same kiln and the waste heat recovery. A brief description of different VSK kilns are given here.

3.1.2 MIXED FEED KILN

Mixed feed kilns are the conventional and most widely used kilns in the world and are both continuous and semi-continuous types. Hundreds of refinements and improvements in the basic design are practised the world over despite the fact that the quality of lime produced is highly variable and relatively inferior. These kilns however, are considered to be energy efficient with a heat consumption of as low as 900 Kcal/kg of lime and if the quality requirements are not stringent, these types of kilns are the most logical to operate. These kilns are available in sizes ranging from 20 to 200 tonnes/day. However, large capacity mixed feed kilns are today not favoured because of the developments of new innovative vertical kilns in the 1960's.

3.1.3 MODERN VERTICAL KILNS

Modern Vertical Kilns are basically of three types – (i) Double Inclined; (ii) Annular Shaft, and (iii) Parallel Flow Regenerative.

3.1.3.1 DOUBLE INCLINED SHAFT KILN

Double Inclined Shaft Kiln was first installed in Germany in 1960. The kiln is a rectangular shaft with two combustion chambers opposite to each other at different heights (Fig.5) The kilns can be fired with oil/gas or a mixture of coke and oil/gas. The kiln recuperates the heat internally and operates on a fuel consumption range of 1000-1100 Kcal/kg lime for a 98% CaCO_3 stone with product CO_2 of < 1.5%.

Japan has reported developments of a new energy efficient double inclined vertical shaft kiln (New DSO) of 200 tonnes/day capacity which can be fired with coke and coal in the ratio of 30 to 70. The salient features of the kiln are given below :

Capacity	200 TPD
Heat Consumption	900 Kcal/kg of lime
Lime quality	Less than 1% CO_2
Stone size	10-30 mm
Fuel	Coke : coal (30:70)

This new development successfully enables the use of smaller stone than any other vertical kiln with a fuel consumption comparable to other modern vertical kilns and considerably better than the Rotary Kiln for almost the same feed size.

3.1.3.2 ANNULAR SHAFT KILN

Annular Shaft Kiln was first introduced by Bechenbach of Germany in 1961 with kiln capacities of 100-600 tpd with multiple units of higher capacities. The kiln is a symmetrical shaft having a hollow cylinder inside forming an annular section (Fig. 6). The kiln auxiliary equipment features multiple combustion chambers located at two levels of the calcining zone. The kiln is fitted with an air to air heat recuperator. The highly instrumented kiln is capable for accepting a very wide range of feed sizes of 20 to 200 mm with a maximum feed size ratio of 4:1. The kilns till 1980 were fired by gaseous fuels and oil but recent breakthrough in use of solid fuels has been reported with fuel consumption of 870 to 900 Kcal/kg of lime having good reactivity with a core content of 1 to 1.5% CO₂. The dust loading factor in the exhaust gases has been reported to vary from 4.5 to 11.5 gm/m³.

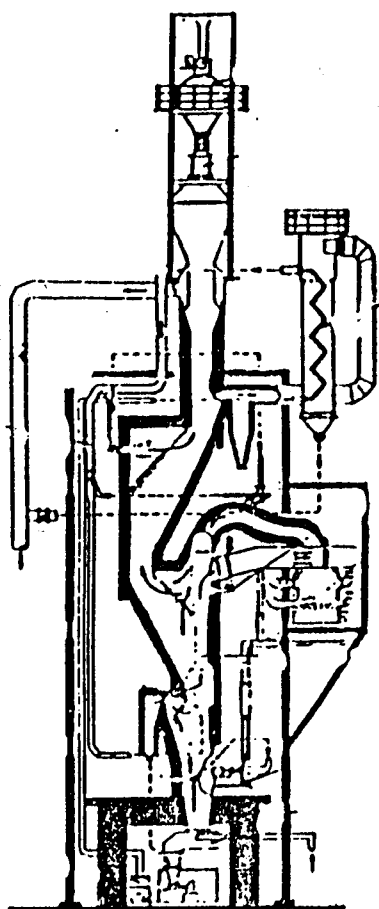


Fig. 5 : Double Inclined Shaft Kiln

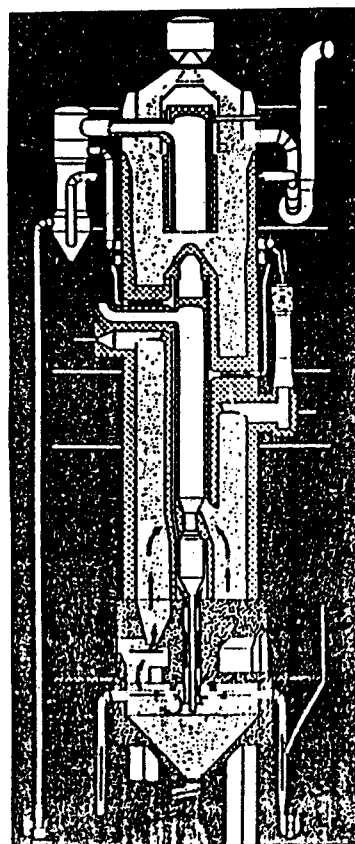


Fig. 6 : Annular Shaft Kiln

3.1.3.3 Parallel Flow Regenerative Kiln

Parallel Flow Regenerative kilns have been claimed to be the most efficient system with a proven capacities from 100 to 700 tpd. These operate with either two or three independent shafts within one large vertical shell. While one is operating in parallel flow, the others operate in counter flow as heat exchangers and regenerator sections. After short recuperating periods of 10 to 15 minutes, the gas flow is reversed and the shaft previously used in parallel flow now operates in counterflow. Thus upper part of the shaft acts as heat regenerator by alternately heating primary air or cooling exit gases (Fig 7). The stone feed size acceptable to the kiln varies from 25x150 mm with a maximum feed size ratio 1:3. The feed size has been reported to be higher for greater diameter of the shaft in higher capacity units.

Gaseous fuels and oils are generally used for burning of limestone but recently pulverized coal fired parallel flow regenerative kilns have been reported with fuel consumption of ~850 Kcal/kg of lime. Since parallel flow calcining is used the hard burning of lime is minimised and soft burnt limes with CO₂ content of nearly 1% are obtained.

A new vertical shaft parallel flow kiln has been reported from USA. The kiln is rated at a peak capacity of 600 tonnes/day and burns coal or gas with a fuel consumption of 880 Kcal/kg compared to 1700-1900 Kcal/kg used by their rotary kiln unit.

The kiln is coupled with a programmable controller which controls the entire unit operations from central control room. The installation has the advantage of utilizing maximum quarried and crushed stone as the larger size fractions are fed to the vertical kiln and smaller to the rotary kiln.

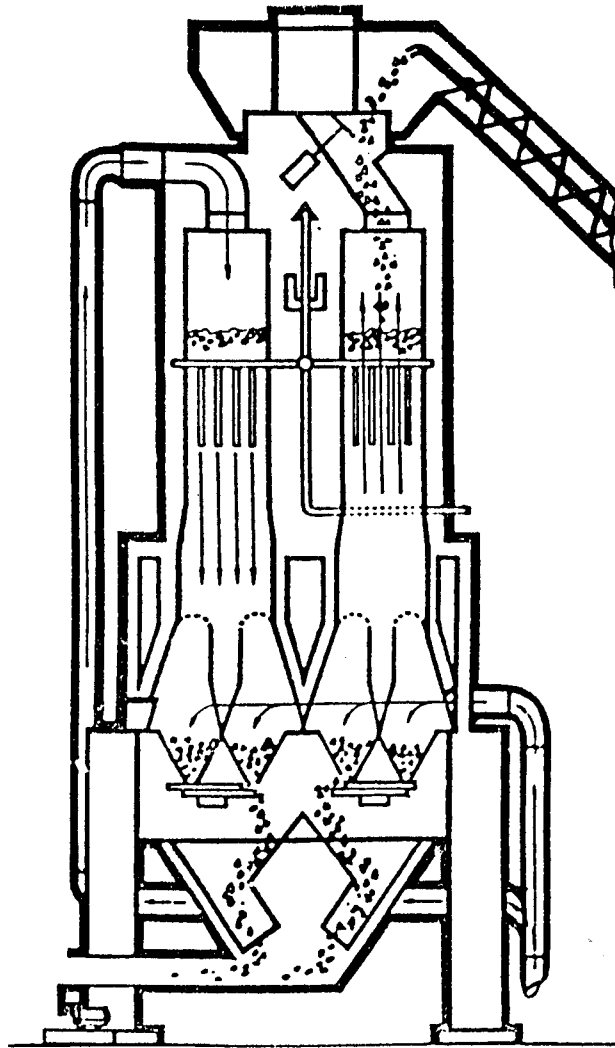


Fig. 7 : Parallel Flow Regenerative Kiln

3.1.4 ROTARY KILN TECHNOLOGY

Rotary kiln technology for the manufacture of lime is very well established. The biggest advantage in use of rotary kiln technology has been the capacity of a single rotary line upto 1000 tpd or more and the facility of use of pulverized coal as fuel. The technology received an impetus in early seventies following international oil crisis when use of alternative energy sources became imperative.

Conventional rotary kilns for the manufacture of lime had D/L ratio of 1:30-40 with a length of 30 to 150 meters and diameter of 1.2 to 3.3 meters. The stone size fed to the kiln was -20 mm and heat consumption of 3000-4000 Kcal/kg of lime.

The first preheater introduced in 1960 reduced the fuel consumption to less than half. In view of this there was a consistent effort in modernising the long rotary kiln to less energy intensive high output kilns by conversions to shorter kilns incorporating preheaters and coolers. The retro-fitted kilns increased the capacities by more than 40 percent while reducing the fuel consumption to 1100-1600 Kcal/kg. Modern rotary kiln technology for manufacture of lime incorporates various types and designs of stone preheaters (travelling grate, shaft preheater, suspension preheater) and coolers (Contact Cooler, Planetary Cooler, Rotary Cooler and Grate Cooler). The kiln internals have also become increasingly complicated and use of intricate chains assemblies, tumblers, lifters and dams to improve heat transfer have become more common. The type and capacity, feed size, fuel and energy consumption and quality of lime production in rotary kilns is presented in Table 1. A flow sheet of rotary lime manufacturing technology using small size crushed stones as kiln feed is shown in Fig. 8.

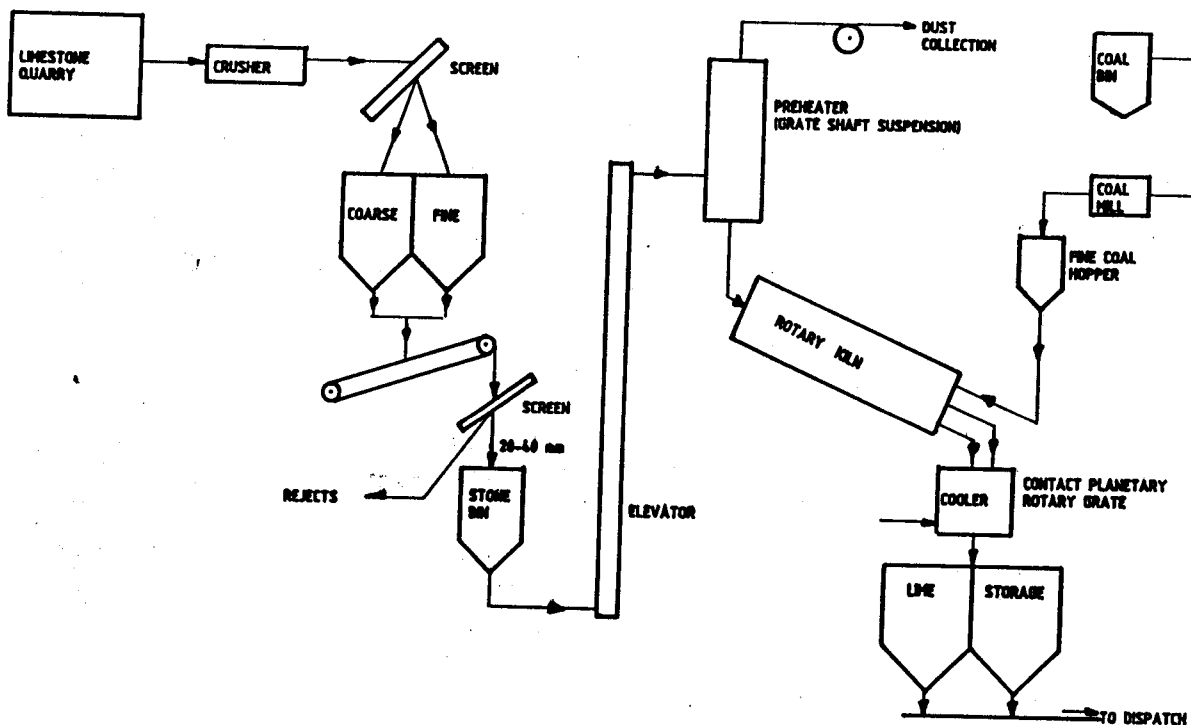


Fig. 8 : Flow Diagram of Rotary Kiln Lime Plan

TABLE 1**COMPARATIVE EVALUATION OF ROTARY LIME KILNS**

System	Long Rotary Kiln	Short Rotary Kiln
Capacity (tpd)	100-1100	150-1000
Fuel	Gas/oil/coal	Gas/oil/coal
Feed size (mm)	6-50	10-40
Fuel Consumption (Kcal/kg)	1600-2200	1100-1250
Power Consumption (Kwh/ton)	24-32	32-36
Preheaters	-	Shaft/grate/shaft round, Rectangular, polygone
Internals	Trefoil/dams/lifters/chains	Trefoil/dams/lifters
Coolers	Contact/grate/planetary	Contact/grate/planetary
Product Quality	0.2-0.8	0.2-0.8

3.1.5 COMPARATIVE EVALUATION OF VARIOUS KILN SYSTEMS

It is evident from the foregoing discussions on the vertical lime kilns that each of the VSK technologies has its strengths and weaknesses. Data regarding more important parameters of the vertical kilns is presented in Table 2. It is evident from the table that the kilns differ widely in their capacities. Vertical mixed feed and double inclined vertical kilns can be used only for capacities up to 250 TPD and are more suitable for smaller capacity units. Parallel flow kilns have the largest capacity for single unit 700 tpd. The feed size variations are also very large for the various kilns for a meaningful comparison. However, soft stones which on quarrying and crushing yield a high percentage of lower sized fractions (<40 mm) can be used only in double inclined shaft kilns. The annular shaft kiln accepts the largest variation in the feed size (20x200 mm) with a feed size ratio of 1:4 followed by 1:3 for parallel flow kiln and 1:2 for the other categories. All the kilns today can be fired with coke coal/coke combination but the present fuel for the annular and parallel flow shaft kilns are oil/gas or a combination of coke and oil/gas to maintain an acceptable purity of the product. The product quality in terms of CO₂ content is almost the same for the modern vertical kilns however, a relatively poor quality of product is obtained in case of vertical mixed feed kiln.

Investigations on studies relating to the effect of stone quality and size of kiln on fuel consumption have been reported for shaft kilns. Studies have also been carried out on contamination of the product in coal fired kilns and their relation with feed size.

Stone quality has been found to materially affect the heat consumption. Data obtained on an annular shaft kiln on heat consumption as a function of CaCO₃ content in limestone has been plotted in Fig. 9 which indicates that heat consumption per kg of limestone increases from 750 Kcal to 950 kcal with increase in CaCO₃ content from 85 to 98%. It has also been observed that the fuel efficiency for lower grade limestone is better compared to high grade lime-stone.

Heat consumption has also been found to be related with the capacities of the kiln and a relatively lower fuel consumption of 865-880 for 600 tonnes/day kiln has been observed compared to 900-950 Kcal/kg for 300 tonnes/day kiln (Fig 10).

TABLE 2
COMPARATIVE EVALUATION OF VERTICAL LIME KILNS

Kiln Type	Vertical Mixed Feed	Double Inclined	Annular	Parallel Flow
Capacity (tpd)	20-230	100-250	100-600	100-700
Fuel	Coal/coke	Oil/gas/ coke/coal	Oil/gas/ coke	Oil/gas/ coke
Feed size (mm)	40x180	20x40	20x200	25-*50
Fuel Consumption (Kcal/kg)	900-1400	900-1100	870-900	850-900
Power Consumption (Kwh/ton)	10-25	22-30	18-30	22-35
Dust Collection type	-	Bag house	Gravel bed/ Bag house	Gravel bed
Product CO ₂ (%)	1-3	1.5	1-1.5	1-1.5

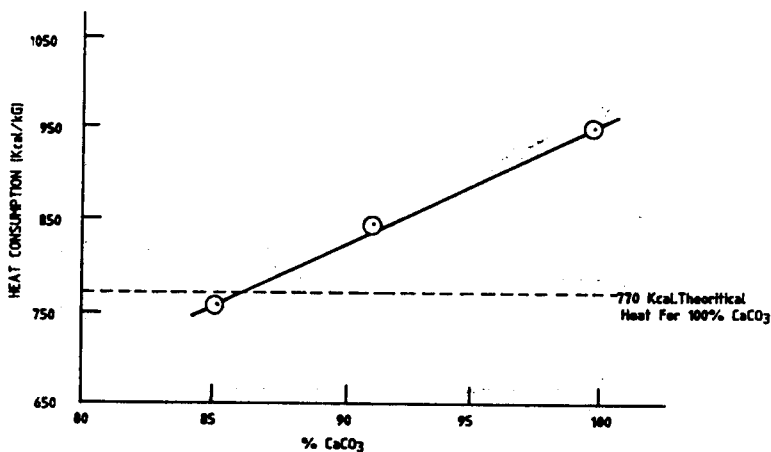


Fig. 9 : Heat Consumption as a Function of CaCO₃ in Limestone

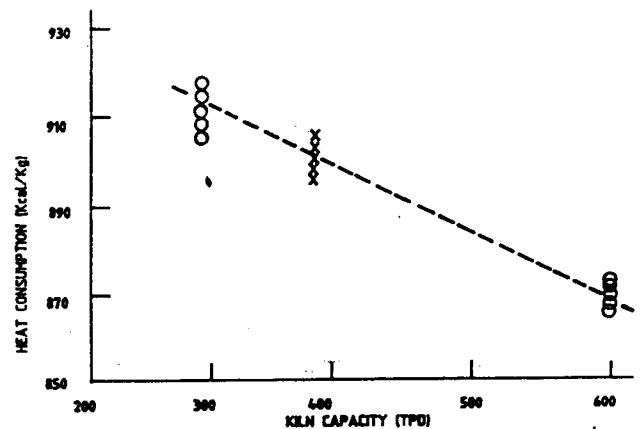


Fig. 10 : Heat Consumption as a Function of capacity of kiln

Contamination of the product by fuel ash and gases has been a major constraints in use of various fuels in different technologies. Use of pulverized solid fuel in vertical kilns has been restricted to maintain a high purity and better reactivity of the product. Recent researches have however indicated that such a constraint can be overcome by judicious selection of feed sizes. A relationship between the product size and sulphur and silica contamination in a double inclined kiln at different levels of coke percentages (Fig 11 & 12) indicate that most of the contaminants concentrate in products fractions below 5 mm.

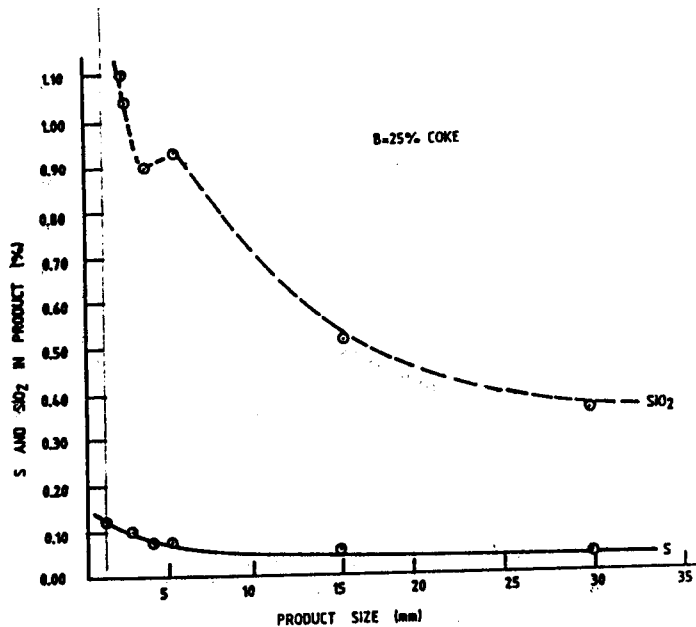


Fig. 11 : SiO₂ and S contamination as a function of product size

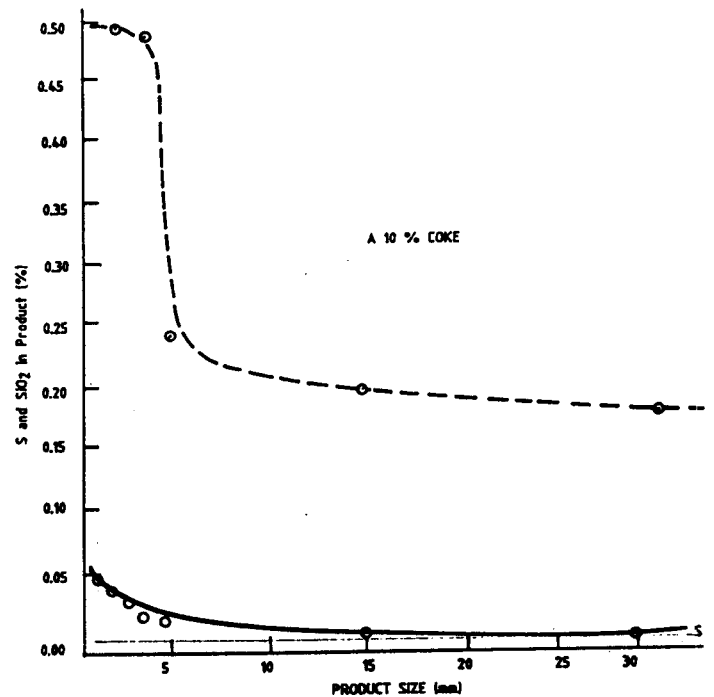


Fig. 12 : SiO₂ and S contamination as a Function of product size

A comparison of the vertical and rotary kiln lime manufacturing technologies indicate that the former have capacities upto 700 tpd only whereas the latter have unit plant capacities of 1000 tpd or more. Another important difference in the two technologies is an almost exclusive use of pulverised coal in the rotary kilns and a low degree of contamination caused to the product despite the fact that feed size to the rotary kiln is comparatively much smaller. This is primarily due to the fact that most of the fines are carried away by the gases and get lodged in the dust collectors. Most of the vertical kilns are preferably fired with oil/gas or a mixture of coke and oil/gas and the newer developments of using pulverized solid fuels is yet to catch up. However, the VSK technology for lime manufacture is decidedly more fuel and energy efficient compared to the rotary kiln technology.

The above discussions lead to an inevitable conclusion that because of the VSK technology having advantages of lower capital investment, better heat efficiency and lower power consumption factors, it is likely to find more extensive usage. For larger capacity VSK plants, a battery of kilns can be installed side by side on a small area and operated from a single control room.

3.1.6 FUTURE OUTLOOK

There is general need to modernise the existing large size lime plants in the country to accept solid fuels to substitute oil, wide range of feed sizes to reduce rejects, better burning and heat recovery system to lower fuel consumption and efficient operation by introducing a higher degree of instrumentation and control, improved quality and production. Retrofitting of rotary kilns can be considered as a step towards modernization.

All future lime manufacture units of the capacity larger than 200 tpd should be based on the latest modern VSK technologies suitable for specific needs.

In this context, a coal fired, energy efficient, continuous vertical mixed feed shaft kiln of the capacities ranging from 50-100 tpd to cater to the requirements of building lime and industry in the country is developed.

Kiln is the heart of lime manufacturing process and considerable efforts have gone into the development of newer and better kilns of various types and capacities. Modern lime manufacturing technologies incorporate a much higher degree of sophistication necessitated by stringent quality requirements, higher output rates, larger capacities to take advantage of the scale of operations, higher and better fuels and kiln efficiencies, use of cheaper and/more readily available fuels, lowering of energy consumption and stringent pollution control regulations.

A comparative evaluation of various lime kilns in operation in India and abroad with regard to capacities, types of fuels, fuel consumption, energy requirements, feed-size acceptance and quality of lime produced has also been presented. Status of lime industry in India both in the organised and unorganised sectors has been discussed, particularly with respect to innovations which can be incorporated in the Indian context keeping in view the fuel, energy, capital and manpower requirements.

4.0 FUELS AND EFFICIENCIES IN LIME KILN

Lime manufacture uses wide variety of fuels i.e. coal, coke, furnace oil, light diesel oil, producer gas, natural gas and bio-gas (14). The choice depends upon availability, transportation, overall economic and end use of lime. Most common among them is coal followed by coke & furnace oil. At present there is no lime kiln operating on natural gas or bio-gas in India due to its poor availability. Few lime kilns are reported to operate on producer gas, produced from coke where coal as raw material is still to find place due to the problem of recovery and disposal of by-product i.e. volatiles and tar. In the manufacture of high purity lime, furnace oil is being used. Sewage gas or bio-gas is reported to have been used in kilns installed near sewage and bio-gas plants. Major fuels can be classified as :

4.1 SOLID FUELS

Coal can either be used directly for burning limestone or is converted into coke and producer gas for use in lime kilns. A coal with low volatile matter such as anthracite or smokeless steam coal is best when burned in intimate contact with limestone in mixed feed lime kilns, as the high volatile matter of coals would either escape as unburned or is burned under conditions where it is of no use. Moreover coals with large proportion of volatile matter create irregular heating and sticking in lime kilns, but such coals can be advantageously used in external fire boxes and as a source of producer gas, as this gas will burn with a longer and hotter flame. Unburned volatile matter is likely to condense in cooler areas, in the form of soot or tarry deposit thus creating cleaning problems.

Powdered coal is not desirable where high grade lime is required as the ash from the fuel is blown into the lime, otherwise it would be an excellent fuel.

Objectionable impurities in coal used for lime burning are volatile sulphur (which should never exceed 1 percent) ash and water. Sulphur and ash may spoil lime chemically whereas water will consume heat for its vaporisation.

The chief disadvantage of using coal is the great tendency to produce too short and too hot a flame which tend to deposit finely divided carbon in the lime resulting in discolourisation, as well as tending to over burn the lime. If uniform distribution of the fuel

the stone bed is not ensured, hot spots are likely to develop in areas where a fuel is in abundance and this may also cause over burning and sticking due to fusion of ash.

4.2 LIQUID FUELS

Various petroleum fractions are available for burning limestone but the most popular of these is furnace oil, being cheaper and comparatively easily available.

Furnace oil is the cheapest of the petroleum fractions, but still it is costly fuel as compared to coal. Where lime of high purity is required, and mixed feed cannot be used, furnace oil and producer gas are the alternatives. Producer gas obtained from coke is as costly a fuel as furnace oil, taking into account the high cost of coke and the capital investment in the producer gas plant. However, the comparative costs work out favourably when coal is used as a fuel in the producer gas plant, and the volatile matter along with the gas is burned in the lime kiln. Removal of tar and volatile matter by cooling the gases results in the loss of sensible heat, making the costs higher.

The other advantages of using oil are :

1. Ease of handling and transportation.
2. Better control over the combustion.
3. Cleaner operations.
4. Lesser Capital investment than in the case of producer gas.
5. Purer product.

4.3 GASEOUS FUELS

Natural gas and producer gas are the two gaseous fuels which are extensively used for burning lime. In India piped natural gas is still not available, hence there are no lime kilns fired by this gas. Producer gas is an ideal fuel for lime burning as it produces condition similar to those of wood. By suitable regulation of the primary and secondary air, a long and comparatively cool flame can be maintained with the elimination of all chances of contaminating the lime with ash. Further-more, the control of temperature within narrow limits when using gas is perfectly simple and for this reason the gas fired kiln can produce purer and better lime than any other type.

4.4 THERMAL EFFICIENCY OF LIME KILN

Thermal efficiency of lime kiln is defined as the ratio of the total heat supplied by the fuel to that required theoretically to decompose the stone completely under ideal conditions. It is usually expressed as a fractions or percentage, as follows :

$$\% \text{ Thermal efficiency} = \frac{\text{Theoretical heat of Dissociation to produce a unit of CaO} \times \% \text{ available CaO in product}}{\text{Total Heat Input}}$$

4.5 HEAT OF DISSOCIATION

Values reported for heat required to decompose limestone to produce lime vary between 695-835 Kcal/kg. for high calcium quick lime but 770-723 Kcal/kg for high calcium and dolomitic quick limes respectively appear to be average values. For magnesium lime the value is close to high calcium values.

4.6. HEAT BALANCE OF LIME KILNS

The fuel costs are the most critical cost factor in lime production costs, it warrants meticulous analysis, particularly since reduction in thermal efficiency are usually tangible. As a prerequisite to a fuel conservation program an accurate detailed heat balance must be ascertained on all lime kilns. Generally the heat balance of a lime kiln can be represented by the following diagram (Fig 13).

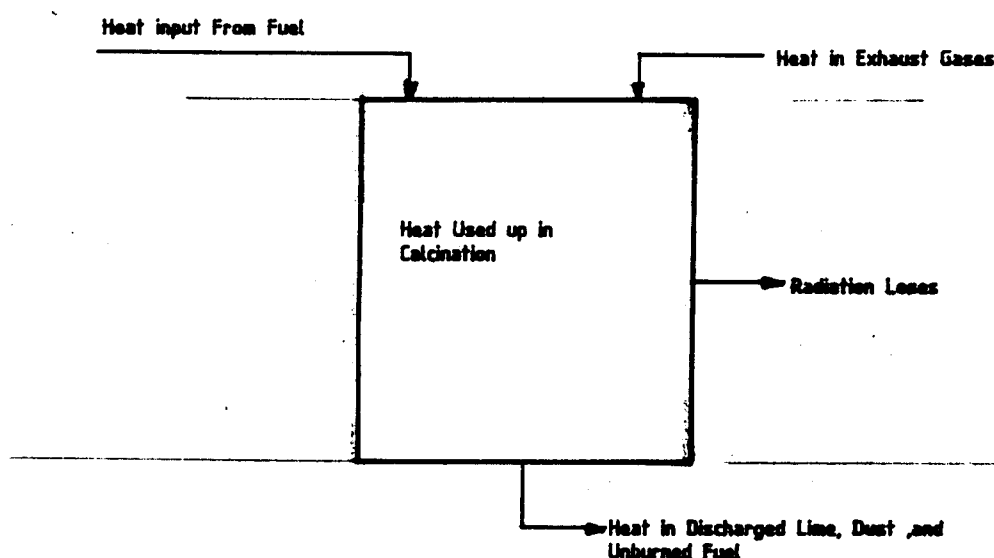


Fig. 13 : Diagram of Heat Balance of Lime Kiln

4.7 HEAT INPUT

Heat for dissociation is supplied by burning fuel. The net calorific value is the total heat available from a fuel. However, heat available per unit of fuel will depend upon the combustion efficiency which is governed by various factors discussed elsewhere for the purpose of calculating the thermal efficiency of the kiln, total heat input available from the fuel will have to be taken into account.

4.8 HEAT GOING OUT OR HEAT LOSSES

The heat losses in the lime kiln are :

1. Heat in exhaust gases : This will include the unburnt carbon and the products of incomplete combustion.
2. Heat in the discharged lime at higher than ambient temperature ash, dust and unburnt carbon in the ash in the case of solid fuels.
3. Radiation losses from the walls of the kiln.

4.9 HEAT USED UP IN THE PROCESS

The difference between the total best heat input available from the fuel or fed and the heat losses computed as above will represent the heat utilised in the lime kiln for burning process under ideal conditions. This heat should not exceed the heat of dissociation of limestone, but in actual practice complete heat recovery from the two outgoing streams and the minimising the heat loss through radiation are not practical.

4.10 FACTORS AFFECTING THERMAL EFFICIENCY OF LIME KILNS

The efforts of the scientists and engineers have been directed towards the new designs of lime kilns and making improvements in the existing ones to minimise the losses. Better heat transfer quicker calcination, improved insulation and maximum heat recovery from the outgoing streams of burnt lime and exhaust gases are of primary importance for improved performance and better efficiencies. A comparison of heat consumptions in various types of kilns is given in Table 3, and heat balance is shown in Table 4.

Table 3
HEAT CONSUMPTIONS IN VARIOUS TYPES OF KILNS

Types of Kiln	Heat Consumption Kcal/kg. of lime
Mixed feed Cylindrical kiln	1750-2000
Separate Heating Cylindrical Kiln	1300-1500
Separate Heating recirculation type	1100-1200
Parallel flow regenerative type	830-850
Rotary Kilns	1530-1830

Table 4
HEAT BALANCE OF LIME KILNS

	ROTARY		VERTICAL SHAFT
	(Powdered Coal Fired)		(Producer Gas Fired)
	No. 1 (%)	No.2 (%)	(%)
INPUT			
Heat in Coal	100.0	100.0	95.9
Heat in Steam	-	-	<u>4.1</u>
OUTPUT			<u>100.0</u>
Heat in product	11.2	12.3	12.0
Stack Loss	43.7	41.2	30.6
Decomposition of stone (CaCO ₃)	25.0	28.4	35.0
Radiation & Convection (measured)	8.7	7.9	12.4
Unaccounted for losses	11.4	10.2	10.0
	-----	-----	-----
Total :	100.0	100.0	100.0
	-----	-----	-----

4.11 COMBUSTION EFFICIENCY

To ensure thorough combustion of the fuel, it is necessary to control the furnace atmosphere, proper atomisation of the liquid fuels and mixing of the combustion air with the fuel. These parameters are usually taken care of, during the furnace design. However, improper operation may result in poor combustion efficiencies.

To control the combustion, the following parameters are required to be measured and controlled.

1. Quantity of fuel being fed.
2. Quantity of combustion air (both primary and secondary).
3. Pressure of fuel and air.
4. Temperature of fuel and air.
5. Exhaust gas temperature.
6. Flue gas analysis for excess air and full combustion.

The analysis of flue gases from the combustion chamber is the most important parameter, which should be monitored frequently to regulate the quantity of excess air to bare minimum for good and full combustion. The flue gases should not contain any unburnt carbon in any form and this can be ensured only by analysing the flue gases.

5.0 IDENTIFIED MANUFACTURING PROCESS FOR QUICK LIME

The two most developed and widely used technologies for calcining limestone world over are :

- Rotary Kiln Technology
- Vertical Shaft Kiln Technology

Rotary Kiln Technology is capital intensive and economically viable for higher capacity plants.

Manufacture of lime in Vertical Shaft Kiln technology is centuries old. Basically these vertical shaft kilns incorporate preheating, calcining and coolong zones in a single shaft, hence making the process less capital intensive as compared to rotary kiln.

Vertical shaft kilns are conventional and most widely used kilns in the world. They are both continuous and semi-continuous types. Such kilns are most popular in India and are particularly used in various chemical and process industries, where lime is one of the raw materials. Several improvements on mechanical handling, process controls as well as improvement in quality of lime has been seen in the last two decades resulting in economical production of lime in small capacity (20 – 100 tpd.) mixed feed lime kilns.

Since the generation of lime sludge in paper mill is only 0.6 MT with respect to its production capacity. This makes the manufacture of quick lime by vertical shaft kiln an attractive proposition.

Vertical shaft kilns are widely used through out the world. All modern vertical kilns are divided into three distinct zones i.e.

- * Pre heating zone - designed to heat to its disassociation temperature
- * Calcining zone - combustion zone
- * Cooling /discharge zone – at the base where lime is discharged.

The quality of lime is most influenced by the conditions in the calcining zone. Here, heat must be supplied where the limestone is already above its dissociation temperature. Consequently for most kilns, there is sufficient heat in the products of combustion (and carbon dioxide from the dissociation of the limestone) to fulfil the heat requirements of the pre heating zone. To provide optimum quality product, it is important to ensure that the temperature in the calcining zone is uniform, with no hot or cold spots, and that it can be controlled within quite fine limits. This type of operation requires a considerable amount of operator experience, since the conditions in the calcining zone are set by the feed which has been charged many hours previously.

The cooling zone is necessary to cool the lime product so that it can be handled easily and to recuperate as much heat as possible into the feed combustion air. The relative size and positions of the preheating, calcining and cooling zone can also be adjusted by changes to the feeding and discharge rates of the kiln. In any well run kiln, ample voidage within the charge is necessary to ensure an even circulation of the combustion gases. The results in consistent heat and mass transfer (removal of CO_2) at any particular kiln cross-section and is one reason why feed size of less than 50mm diameter (or with wide size distributions) can not be processed in this type of kilns. If there is insufficient void space (or a large variation in this void space) inefficient mixing and gas channelling can occur. The recommended ideal void space in calcining zone is 45%. It is known that calcination rate are a function of feed size and therefore it is important to balance the larger feed sizes required to active optimum voidage with the smaller feed size for faster calcination.

Depending upon the nature of fuel used vertical shaft lime kilns can be divided into:

- Mixed feed vertical shaft lime kilns.
- Oil fired vertical shaft lime kilns.

5.1 MIXED FEED VERTICAL SHAFT LIME KILNS

They are most widely used lime kilns where coal is used as fuel. These kilns can be continuous or semi continuous type. These kilns are divided into four distinct zones by imaginary horizontal planes. From top to bottom in sequence are (fig. 14)

- * Feed storage - a vertical or often a modified hopper –shaped zone
- * Preheating zone - designed to heat the feed near dissociation temperature.
- * Calcining zone - where combustion occurs
- * Cooling and discharge zone- usually shaped like inverted, truncated cone, at the bottom of which lime is discharged.

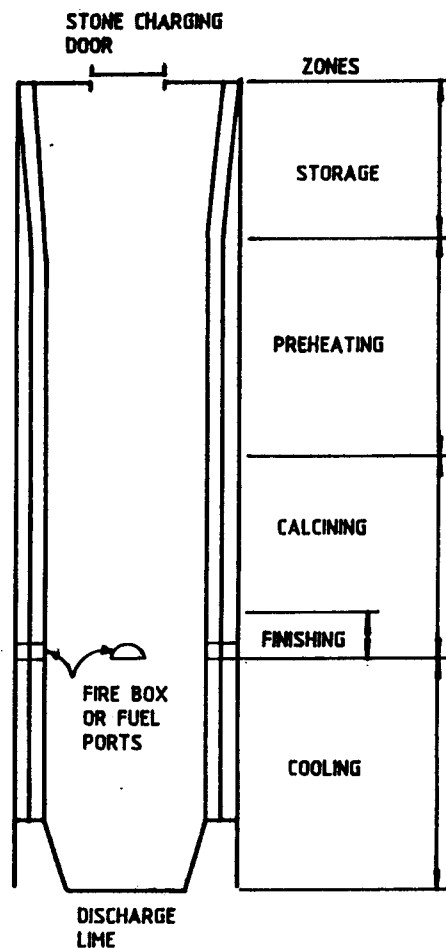


Fig. 14 : Zonal section of vertical mixed feed lime kiln

The design of these kilns demand slow firing before the hot lime could be safely discharged. This is achieved by introducing excess air into the kiln. For maximum thermal efficiency, a dense metallurgical grade of coke of low reactivity or anthracite coal, both of which are low in ash and volatile matter can be used. The fuel is admixed intimately with the kiln feed at a predetermined proportion. The fuel and feed should be of comparable size gradation. This method is superior to traditional mixed – feed charging of alternate beds of fuel and feed, since it obviates excessive localized temperatures with resultant over burning and promotes more even heat distribution through out the whole kiln cross-section.

5.2 OIL FIRED VERTICAL SHAFT LIME KILN

In Oil / gas fired vertical shaft lime kiln, natural gas, liquid fuels, produces gas from a gasifier or pulverised fuel is introduced together with a proportion of primary air (or re circulating of the gas) into the calcining zone. (Fig. 15). The balance of the air required for combustion (usually much lesser) enters the kiln via the cooling section usually by forced draft through flue gas suction.

The extent of calcining zone is dependent upon:

- Type of fuel
- Fuel firing rate
- Fuel / Oxygen ratio.

Each of these effect the flame length and heat distribution pattern (16)

Mostly “C” grade oil is utilised as fuel. Unless combustion is carefully controlled, over burning can result from excessive kiln temperature. Oil has a potentially greater magnitude of heat generation power than coke and anthracite. Invariably it is gasified before introduction in the kiln. It is reported that (17) gasification of oil is effected in the following sequence:

- Oil is pumped and preheated to about 93°C
- It is injected under 1.3 – 1.7 MPa pressure into a vaporization chamber where it is atomized into minute oil globules.
- Hot recirculating gases vaporize the atomized oil.
- The hot oil vapours are oxidized to fuel gases.
- Rising temperature decomposes or “cracks” the remaining heavier hydrocarbons.
- Petroleum gas is then introduced into the calcining zone of the kiln through side ports and / or center burners, or a single large burner.

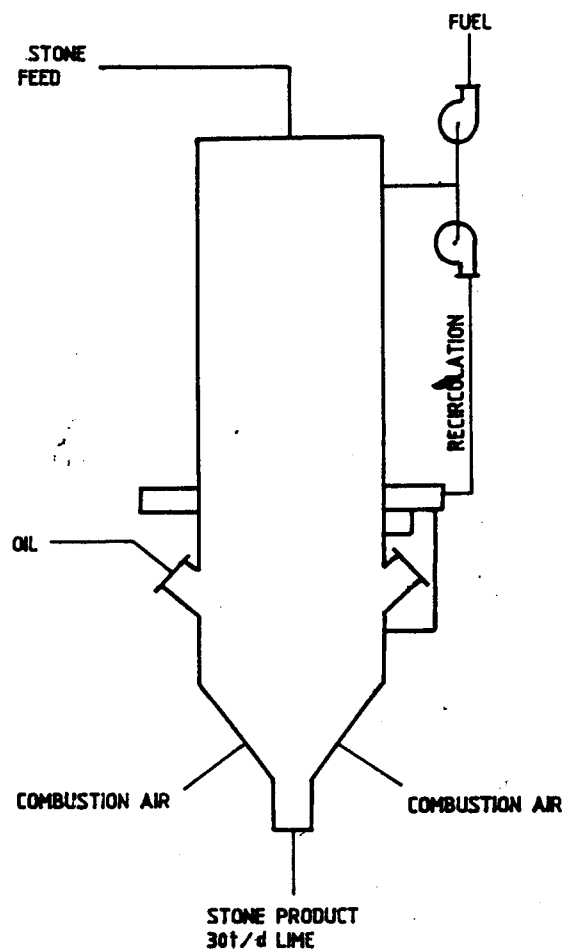


Fig. 15 : Schematic of typical side fired vertical shaft lime kiln

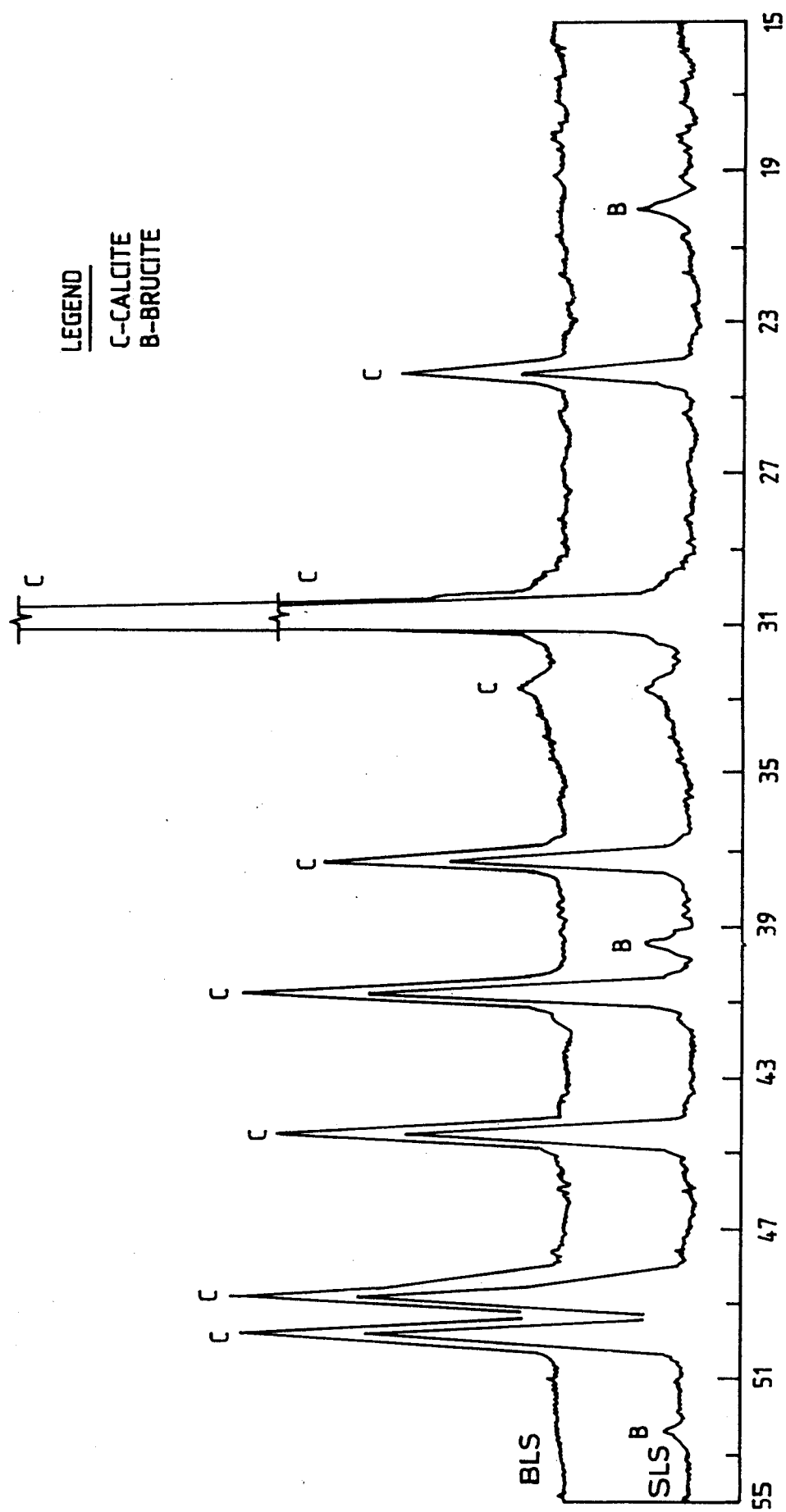


FIG. 16 X-RAY DIFFRACTOGRAM OF COMPOSITE LIME SLUDGE SAMPLE

6.0 PHYSICO-CHEMICAL AND MINERALOGICAL CHARACTERISATION OF THE REPRESENTATIVE SAMPLES OF LIME SLUDGE

Physico-chemical and mineralogical characterisation of the representative samples of lime sludge brought from various paper mills was carried out in NCB laboratories for its major and minor constituents. The details are presented in Table-5.

TABLE – 5
CHEMICAL ANALYSIS OF LIME SLUDGE

Sample No.	CONSTITUENTS PRESENT (%)										
	LOI	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	Cl	MC
BLS	40.63	3.52	0.21	0.76	51.49	2.37	0.15	1.03	0.08	0.021	41.20
SLS	41.85	1.62	0.19	0.24	52.80	2.29	0.00	0.83	0.07	0.005	32.17

6.1 MINERALOGICAL STUDIES

Mineral analysis of representative Limes Sludges was carried out using X-ray diffraction analysis technique. The results indicated the presence of only calcite as major and brucite as minor mineral in the sample. The diffractogram of lime sludge sample is shown in Fig. 16.

Evaluation of results prime facie indicated the suitability of limes sludge sample for the manufacture of Quick lime.

7.0 DRYING AND BRIQUETTING TECHNIQUES FOR LIME SLUDGE

Physical condition of lime sludge generated by paper mill is in powder form having very high moisture content ($> 50\%$). The high moisture content prevents the use of lime sludge directly. It is well known that in vertical shaft kiln powdered material cannot be used since combustion air has to pass through the entire shaft without any resistance to get good combustion. Hence the powdered limesludge has to be filtered dried and briquetted.

7.1 FILTERING TECHNIQUES

In order to make the briquette out of lime sludge the moisture in lime sludge has to be brought down upto less than 5%. This is possible only by using filtration and drying techniques in combination. Filtration techniques used are (18):

- Vacuum filters
- Press filters
- Centrifugal filters

Most commonly used filtration technique in paper mills in India is Rotary Vacuum drum filter.

7.1.2 ROTARY VACUUM DRUM FILTERS

This is still the most popular vacuum filter today. There are many versions available and they all incorporate a drum which rotates slowly (1 to 10 minutes per revolution typically) about its horizontal axis and is partially sub-merged in a shiny reservoir.

The perforated surface of the drum is divided into a number of longitudinal sections of about 20 mm in thickness. Each section is an individual vacuum chamber, connected through piping to a central outlet valve at one end of the drum. The drum surface is covered with a cloth filter medium and the filtration takes place as each section is submerged in the feed slurry. A rake type, slowly moving agitator is used to keep the solids in suspension in the slurry reservoir, without disturbing the

cake formation. The agitator usually has a variable speed drive. Materials of construction of rotary drum filters include mild steel (sometimes rubber covered) stainless steel, nickel, tantalum or plastics.

Filtration can be followed by dewatering, washing and drying. In some applications, compression rolls or belts are used to close possible cracks in the cake before washing or to further dewater the cake by mechanical compression. Final dryness of the cake can also be enhanced by fitting a steam hood. Several different systems of cake discharge are used, all of which can be assisted by air blow back they include simple knife discharge, and roller discharge. The type of discharge selected depends upon the nature of the material being filtered. Filtration can reduce the moisture content to about 15% in lime sludge.

7.2 ROTARY DRUM DRYER

Generally the moisture content in the limesludge requires drying before briquetting. Drying is normally performed in drum dryers. They are constructed as (1) Counter-flow dryers (2) Parallel flow dryers.

The drying efficiency of a counter-flow dryer is lower than parallel flow dryer. Due to the high temperature and moisture gradient, the largest amount of water is removed in the first part of the drum dryer; the evaporation of water in the remaining part of the drum dryer is therefore relatively low.

Convection heat exchange i.e. where the (lime sludge) material particles are brought into direct contact with the heat, is the dominant factor in direct heat rotary dryers. Conduction and radiation play only a small role in conveying heat to the material and can be neglected. To secure maximum utilisation of convection heat transfer principle, the interior dryer cylinder is fitted with lifting flights or shelves for cascading the material insuring long and intimate contact with heat.

The Rotary Dryers can reduce the moisture of lime sludge to below 5%.

7.3 BRIQUETTING TECHNIQUES

In this technique powders are densified and compacted by application of external force in a confined space (19). Forces involved to produce a stable agglomerate includes :

- Solid bridges
- Immobile liquid bonds
- Surface forces
- Mechanical interlocking

The success of the operation depends on the effective utilization and transmission of the applied external force and on the physical properties of the particulate material.

Pressure compaction methods can be broadly classified according to the physical system used to apply the compression force. At one end of the spectrum are punch and die assemblies and molding presses in which particulates are contained in a closed mold and are acted upon by a reciprocating punch or ram. Internal motion and shear of the particles are incidental to consolidation by unidirectional pressing forces. At the opposite end of the spectrum are extrusion systems in which material undergoes definite shear and mixing as it is consolidated while being pressed through an open die or orifice by the action of a screw or a roller.

With most materials the necessary condition to produce a strong compact is to reduce the porosity to a minimum and increase the density to maximum. Lubricants are often employed to facilitate the uniform transmission of forces and reduce undesirable friction effects during compaction. Lubricants may be classified as internal or external types. Internal lubricants are materials which are added to the particular feed not only to improve its flow properties (flow into the mould or die and rearranged during compaction) but also to assist in the release of the final agglomerate from the mould or dye. External lubricants are materials used to prevent friction and usear at the dye or mould surface and are applied directly to it.

7.3.1 BRIQUETTING EQUIPMENT

Piston or ram type briquetting presses are operated as follows. The material to be briquetted (lime sludge) is placed into a forming die which is closed on all but one side face. A close fitting ram or piston then enters into the die's open side and exerts the force required to produce the briquet. The briquet is then ejected or "stripped" out of the die. The ram or piston (which is also sometimes referred to as the stamp or punch) which enters into the die can be actuated either mechanically or hydraulically.

Although dye compaction is used most widely in application (such as tableting in the pharmaceutical industry) requiring strict specification for the agglomerate, there are a few applications in which piston type machines are used simply to compress particulates into a larger size suitable for further processing without regard to fine detail.

7.4 LABORATORY TRIALS ON BRIQUETTING

Weighed quantity of 2.50 kg lime sludge having moisture less than 5.0% was taken and briquetted in the form of bricks (size 230 x 115 x 75 mm) in the hydraulic press with a load of 25 tonnes. Compressive strength of these bricks was measured which is :-

1 day	-	3.78 kg/cm ²
3 days	-	8.70 kg/cm ²

The static & dynamic load on 20 & 50 TPD VSLK are :

TPD	Static load (Kg/cm ²)	Dynamic load * (Kg/cm ²)
20	0.72	1.80
50	1.43	3.58

* Assuming dynamic load factor as 2.50.

This shows the compressive strength are well within the limits.

8.0 CALCINATION STUDIES

8.1 THEORY OF CALCINATION

Manufacture of lime involves thermal decomposition of calcium carbonate under certain conditions of temperature and pressure. The dissociation of CaCO_3 , the main chemical compound in lime sludge takes places as per reaction :



which indicates that for one gram molecule of CaCO_3 , it is necessary to spend 42.53 Kcal heat. Accordingly for obtaining one kg of lime (CaO) from CaCO_3 , the heat energy required will be about 750 Kcal which includes energy for dissociation as well as that needed to bring to the threshold state of dissociation.

The mechanism of calcium carbonate (CaCO_3) decomposition is as follows :

- a) When heating a cube of calcium carbonate from room temperature to calcining temperature, it first expands prior to dissociation.
- b) Surface calcination, starts, the pore volume increase, the sample volume remains constant.
- c) When calcination is complete, the sample has the maximum pore volume and sample volume is still largely unchanged.
- d) With further temperature increase and longer calcination times, crystals grow and sintering begins, both pore volume and sample volume decrease.

The dissociation temperature of CaCO_3 can vary from 800-1000°C.

8.2 PARAMETERS AFFECTING CALCINATION

The factors affecting calcination are :

- a) Crystal size, pore volume, specific surface and reactivity are closely related lime properties.
- b) At constant retention time higher temperature causes coarsening of the grain, decreases surface and porosity, therefore lower reactivity. Inorganic impurities i.e. SiO_2 , Al_2O_3 have the same effect.

- c) For each temperature and feed size there is an optimum retention time.
- d) Calcination temperature is more important than retention time.
- e) Optimum calcination conditions have to be determined for each type.

Therefore, the three basic requirements for calcination are :

- * The lime sludge briquette is heated to dissociation temperature of carbonate i.e. 1000-1050°C.
- * The temperature of calcination is retained for a certain duration.
- * The CO₂ gas evolved must be removed.

The kinetics of CaCO₃ decomposition depends on the rate of temperature rise of the briquette which will be governed by the source of heat supply and the size of the briquette. Since the decomposition is associated with the removal of CO₂, the size will be an important parameter.

8.3 CALCINATION STUDIES WITH LIME SLUDGE

The Lime sludge (SLS & BLS) from two different paper mills was available in powdered form with moisture content 41-32%. Both the lime sludges were subjected for calcination studies by compacting the sludge into a briquette after drying the sludge to less than 5% moisture content. The size of the briquette was 50 mm cube. and in nodule form (Fig. 17). These cubes were subjected to calcination at 950, 1000 or 1050°C for 60, 90, 120 minutes in an electric furnace. After retention, the samples were cooled in ambient conditions.

Fig. 17 : Laboratory made Cubes and Nodules for calcination studies

The calcined sample were calculated for its purity by measuring available lime by chemical analysis as per ASTM-821. Available lime determined in freshly calcined lime sludge cube is shown in Table 6.

TABLE – 6
Available lime in calcined Lime Sludge

Temp. °C	Retention time (min)	CaO Available (%)	
		SLS-C	BLS-C
950	60	79.97	78.98
	90	82.60	79.55
	120	82.73	80.01
1000	60	81.28	80.11
	90	85.62	80.30
	120	86.96	80.37
1050	60	86.32	80.27
	90	87.60	80.35
	120	87.48	80.36

It is clear from the above table that the sample fired at 950°C for 60 minutes contained substantial amount of CaCO₃ where as other sample where retention time was increased from 90 to 120 minutes indicates reduction in CaCO₃ content. At 1000°C & 1050°C all the samples fired with retention time 60, 90 & 120 minutes showed complete calcination. Though there are reports (21) of Lime Sludge calcination at as lower temperature as 700-750°C under different technology condition where powdered material can directly be calcined.

The complete chemical analysis of calcined Limes Sludge sample at 1000°C with 120 minutes retention time is shown in Table-7, which was carried for its chemical requirement as per IS 712 :1984, and the method followed was as per IS 6932 Part I, 1973.

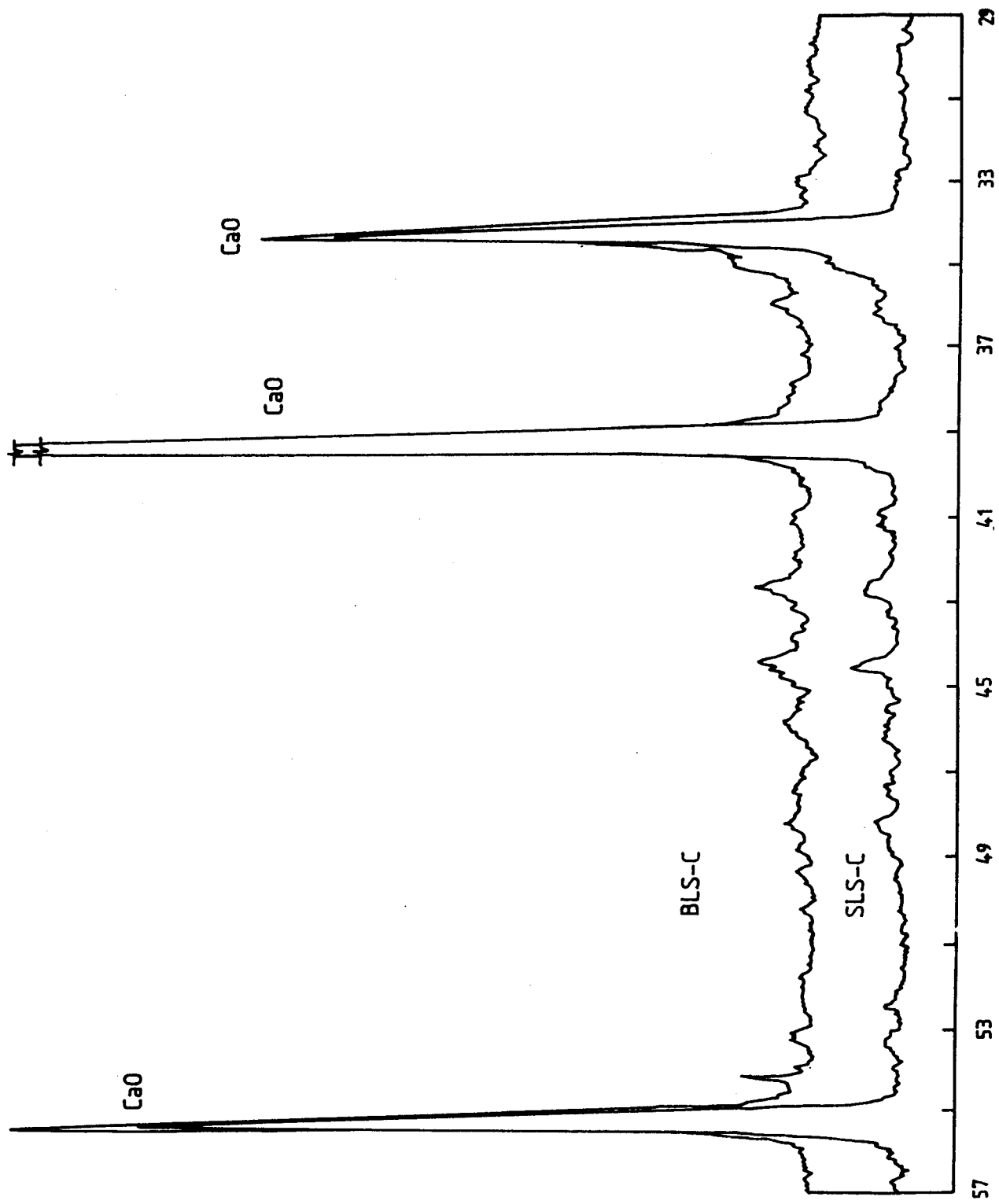


FIG. 18 XRD OF CALCINED LIME MUD

TABLE – 7
Complete Chemical Analysis of Calcined Lime Sludge

Characteristics	SLS-C	BLS-C
CaO	90.30	86.45
MgO	4.28	3.84
SiO ₂	2.98	6.02
Al ₂ O ₃	0.65	1.16
Fe ₂ O ₃	0.20	0.18
IR	3.02	0.08
CO ₂	0.18	0.20
Available CaO	86.96	80.37
Na ₂ O	1.42	1.74
K ₂ O	0.12	0.13

It is seen that total lime and other constituents oxides in both the sample are more or less comparable at 1000 & 1050°C. The chemical analysis of calcination indicates its suitability for building grade lime as per IS : 712-1984.

8.4 MINERALOGICAL STUDIES OF CALCINED SAMPLE

The calcined briquette was powdered completely and a sample was taken for studying mineral phase by X-ray diffraction. Presence of calcite along with CaO in the sample with uncalcined part was seen. No other phase was seen, thus indicating formation of high purity quick lime. However, XRD of completely calcined sample i.e. one calcined at 1000°-1050°C showed presence of only CaO i.e. calcium oxide. (Fig. 18)

The calcined samples were found to be soft and easy to grind. No decrepitation tendency during calcination was observed.

8.5 SIZE, SHAPE AND STRENGTH OF THE FEED

Size, Shape and strength of feed plays an important role in vertical lime kiln calcination. Core content of the feed depends upon the size, larger the size, core content will be more. Optimum size is about 3-4". Where as strength of the briquettes should be able to take the vertical load of the feed. The vertical load of mix feed kiln is about 0.7 kg/cm^2 for a 20 tpd and 1.43 kg/cm^2 for 50 tpd VSLK. Shape of feed plays a role in generating void in the kiln. The kiln should have atleast 45% void so as to have proper combustion. The shape to be used will be a cylinder of 3"-4" dia and 3"-4" height.

9.0 SITE SELECTION, LAYOUT, FLOW SHEET AND SPECIFICATION OF EQUIPMENT

9.1 SITE SELECTION

Since basic raw material for hydrated lime plant is lime sludge. It is desirable to locate the plant near to the source of lime sludge generating Paper Mill provided other important factors do not overweigh this consideration. Some of other factors which require consideration are :

- Nearness to all weather road
- Nearness to power grid
- Availability of labour
- Availability of market
- Communication facilities
- Nearness to railway station
- Nearness to town, hospital, market, school and other facilities.
- Availability of water
- Soil condition
- Availability of suitable land

9.2 PLANT LAYOUT

While working out the details of the plant layout the following main factors are considered :

- The flow of raw materials as well as intermediate product till the last stage of manufacture must be in rational direction and should follow the shortest route.
- The layout should be such that it shall be possible to operate the plant with minimum manpower for operation, maintenance and supervision.

- The plant should have enough space for easy movement of men and materials, maintenance of machinery and yet should be compact. It would have maximum simplicity in installation and operation.
- Centralising plant service facilities into a common service complex.
- The layout should result in economy in construction.

The layout of the proposed 50 tpd hydrated lime plant is shown in exhibit-I (Drawing No. NCB/PCS-CPR/LO/SP-965).

9.3 DESCRIPTION OF THE PLANT

The process flow sheet has been shown in Exhibit-II (Drawing No. NCB/PCS-CPR/LO/SP-965) which clearly indicates the various unit operations involved in the manufacture of hydrated lime at the proposed plant. The following brief description of the plant will help to understand the flow sheet.

Lime sludge transported by means of truck is stored in storage yard. Other material i.e. coal is also transported by trucks and stored in storage yard.

Lime sludge having moisture more than 50% from lime sludge storage yard is sent through lime sludge hopper, rotary screen and belt conveyor to Rotary drum Vacuum filter and the moisture shall be brought down to maximum 35%. Then the lime sludge is fed into rotary drier through belt conveyor and moisture level shall be brought down to maximum 5%. This dried lime sludge is fed into storage silo through screw conveyor, and bucket elevator. From storage silo this lime sludge is fed into briquetting machine through rotary air lock feeder and screw feeder. The lime sludge briquettes were made and stored in the covered yard for further drying.

Two layers of lime sludge briquettes and coal is separately stacked near the bit of skip hoist manually. The layers are put in such a manner that the required proportion of briquetted lime sludge and coal is fed to the kiln manually. The briquetted lime sludge descends from top of the kiln to the bottom by gravity and passes through calcining and cooling zone. Discharge from the kiln is controlled by a rotatable disc placed at the bottom of the kiln and a scraper mounted on the disc.

The combustion air is controlled by the ID fan and damper placed before the ID fan. Exit gases from the kiln is passed through dust settling chamber and goes to the stack through ID fan.

Quick lime from the kiln is conveyed by a Grizzly feeder, troughed belt conveyor and fed to a jaw crusher. After crushing, it is stored in surge hopper through a bucket elevator. A table feeder placed below the surge hopper control the feed to the hydrator and simultaneously controlled amount of water is also sprayed. After the complete hydration, hydrated lime is passed through a single deck screen where the oversize is termed as rejects and dumped separately through a troughed belt conveyor.

Hydrated lime is pulverised in a hammer type pulverizer and stored in a storage bin through a bucket elevator. Vent from the pulverizer and hydrator is connected to suitable bag filter which is mounted on the storage bin.

Hydrated lime is extracted from the storage bin through a rotating disc extractor and then packed in bags by single spout packing machine. These packed bags is either stored in a single shed or directly loaded into trucks.

The specification of major equipment for the proposed 50 tpd hydrated lime plant are given in Table 8.

TABLE – 8

SPECIFICATION OF PLANT AND MACHINERY

1. Lime Sludge hopper

Capacity	:	30 tonnes
Opening	:	500 mm x 500 mm
Construction	:	MS

2. Rotary screen with small quantity of grinding media to break the lumps

Construction	:	MS
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3. Belt Conveyor (Completely covered)
Capacity : 5 tph
Belt width : 500 mm
Conveyor length : 30 m
4. Vacuum Filter with all accessories and feeding system
Type : Rotary Drum
Capacity : 5 tph
Initial Moisture Content : 70 to 80%
Final Moisture Content : 35% (Max.)
5. Belt Conveyor for lime sludge cake
Capacity : 5 tph
Belt width : 500 mm
Conveyor length : 5 m
6. Rotary Drum Dryer with Chain arrangement
Capacity : 5 tph (Dry basis)
Initial Moisture Content : 35%
Final Moisture Content : 5% (Max.)
Complete with fuel storage and pulverisation unit, firing system, feeding and discharge system dust, collection, ID Fan, Variable speed mechanism etc.
7. Screw Conveyor for dry lime sludge
Capacity : 5 tph
Length : 2 m
8. Bucket elevator for dry limes sludge to feed storage silo
Capacity : 5 tph
Height : 8 m
9. Storage silo for dry lime sludge
Capacity : 20 tonnes
Construction : MS

10. Rotary Air Lock Feeder
Capacity : 5 tph
11. Screw conveyor for dry lime sludge
Capacity : 5 tph
Length : 2 m
12. Briquetting Machine
Capacity : 5 tph
13. Skip Hoist
Total lift : 35 m
Capacity : 2 Tonnage
Bucket Volume : 1.8 m³
Motor HP : 7.5
Gear Box size : U-600
Quantity : 1 Unit
14. Lime Kiln (NCB Mixed Feed Vertical Shaft Lime Kiln)
Shell Diameter : 2500 mm (effective)
Shell Height : 27500 mm
Refractory Lining of 150 mm thick, chimney 1500 mm dia with Dust Collector, ID Fan etc.
ID Fan Capacity : 15000 m³ /hr
Pressure : 450 mm WG
Type of feeding system : Cone bell type
Discharge : By Rotating disc
Capacity : 50 tpd quick lime
Duty : 24 Hours Service
Quantity : 1 Unit
15. Grizzling Feeder below lime kiln
Capacity : 5 tph

16. Belt conveyor

Type	:	Troughed type rubber belt Conveyor
Capacity	:	5 tph
Conveyor width	:	500 mm
Length	:	25m approx.
Motor	:	5 HP ; 1440 rpm, with pulley & Gear box
Quantity	:	One unit
17. Jaw Crusher

Type	:	Double toggle bush type
Size	:	400 x 225 mm
Capacity	:	5 tph
Product size	:	- 25 mm
Motor HP	:	15 HP, 1440 rpm, with pulley and gear box
Quantity	:	One unit
18. Bucket Elevator

Type	:	Centrifugal discharge
Conveying height	:	14m approx.
Capacity	:	5 tph
Motor	:	5 HP, 1440 rpm
Quantity	:	One unit
19. Storage Bin with Agitator

Capacity	:	30 t
Construction	:	MS
Size	:	3.0 m x 3.0m x 4.5m
Bottom opening	:	450 x 450 mm
- 19.1 Agitator

Type	:	Paddle type
Motor	:	2 HP, 1440 rpm, with pulley & gear box
Quantity	:	One unit

20.	Dust Collector		
	Type	:	Reverse pulse jet bag house, Complete with standard accessories, ducting etc.
	Fan capacity	:	1500 m ³ /hr, at 250 mmWG
	Fan motor	:	5 HP, 1440 rpm
	Quantity	:	One unit
21.	Table Feeder		
	Capacity	:	5 tph
	Type	:	Rotary disc type
	Size	:	600 mm
	Motor	:	2 HP, 960 rpm
	Quantity	:	One unit
22.	Hydrator (3 Tier)		
	Capacity	:	5 tph
	No. of Screws	:	Three
	Type	:	Screw type
	Motor HP	:	20 HP, 1440 rpm
	Quantity	:	One unit
23.	Vibratory Screen		
	Type	:	Mechanical Vibrating type
	Capacity	:	5 tph
	Motor HP	:	3 HP, 1440 rpm
	Quantity	:	One unit
24.	Belt Conveyor for rejects		
	Capacity	:	2 tph
	Type	:	Troughed type
	Belt Width	:	300 mm
	Length	:	20 m
	Motor	:	3 HP : 1440 rpm
	Quantity	:	One unit

- | | | | |
|------|----------------------------|---|--|
| 25. | Pulveriser | | |
| | Capacity | : | 5 tph |
| | Type | : | Hammer type |
| | Motor | : | 10 HP, 1440 rpm |
| | Quantity | : | One unit |
| 26. | Bucket Elevator | | |
| | Capacity | : | 5 tph |
| | Type | : | Centrifugal discharge |
| | Height | : | 12 m |
| | Chain | : | Pin bush type, 12 t breaking load |
| | Bucket size | : | 150 m |
| | Motor | : | 5 HP, 1440 rpm |
| | Quantity | : | One unit |
| 27. | Storage Silo with Agitator | | |
| | Capacity | : | 100 t |
| | Construction | : | MS |
| | Bottom opening | : | 450 x 450 mm |
| 27.1 | Agitator for Silo | | |
| | Type | : | Paddle type |
| | Motor | : | 3 HP, 1440 rpm |
| | Quantity | : | One unit |
| 28. | Dust Collector | | |
| | Type | : | Reverse pulse jet type bin mounted complete with compressor and associated standard accessories. |
| | Fan capacity | : | 2500 M ³ /hr at 250 mmWG |
| | Fan motor | : | 5 HP, 1440 rpm |
| | Quantity | : | One unit |

29. Packing Machine

Capacity	:	200 bags/hr. (50 kg bag)
Type	:	Single Spout
Motor HP	:	7.5 HP, 1440 rpm (for compressor)

The unit is complete with accessories.

30. Water Pump

Capacity	:	5000 litre/hr.
Type	:	Centrifugal type
Head	:	25m
Motor	:	3 HP
Quantity	:	2 units (One standby)

The unit is complete with piping and valve, water tank capacity of 100 litres.

9.4 INFRASTRUCTURE

The lime sludge collected by M/s. Star Paper Mill & M/s. Ballarpur Paper Mills was found suitable for manufacture of hydrated lime. 50 TPD CRI-VSLK plant can be installed at the plant site. Skilled unskilled labour and other infrastructural facilities should be available close to the factory site.

9.4.1 POWER

The estimated power requirement for the proposed 50 tpd CRI-VSLK plant is about 300 KVA (contract demand).

9.4.2 WATER

About 50 KL/day of water is required for the process alone. Proposed site should have sufficient to cater to the water requirements of the VSLK plant. The water available should be suitable for industrial, domestic as well as construction purposes.

9.4.3 TRANSPORT

The plant site should be adjacent to the State Highway. So that machinery and equipment will be directly received at plant site. The railway station should be nearer to the proposed plant site having all the facilities for loading and unloading of machinery and equipment.

9.4.4 COMMUNICATIONS

Post and Telegraph office, telephone exchange and other general facilities like dispensary/hospital, petrol pump, police station, fire station, guest house, motor servicing centre etc. should be available within a radius of 15 km of the proposed site.

9.4.5 HUMAN RESOURCES

The direct manpower required for operation at the 50 tpd CRI VSLK plant is 69 as in Table No. 9. Plenty of skilled, semi skilled and unskilled personnel should be available at the proposed site. ITI, Polytechnic, Science College and Engineering College should be around the plant site and high schools exist nearby.

9.4.6 CLIMATE AND RAINFALL

The raw materials especially lime sludge and coal should be transported to site and stored so as to meet the requirement of rainy season. However it should be envisaged that the normal rains would not have any adverse effect on the transportation of raw materials to the site.

9.4.7 SEISMICITY

The area should be practically free from any seismic activity.

9.4.8 WORKING FACILITIES

General workshop facilities like welding, grinding, turning, shaping, drilling and milling as required for day-to-day plant operation shall be made available at the plant's own workshop. In addition, the forging and casting should also be available at the proposed plant site. For other major jobs like fabrication, machining etc. should be able to do at the nearest place. Consumables/spares like lubricants, refractories, grinding media etc. must be stored in adequate quantities.

9.4.9 CONSTRUCTION MATERIALS

Various construction materials like sand, aggregates, cement, timber, steel, bricks, tiles, asbestos sheets, GI pipes etc. should be available locally to cater to the construction activities of the proposed plant.

TABLE 9
MANPOWER

Sl. No.	Category of personnel	No.
1.	Plant Manager	1
2.	Shift Supervisor	3
3.	Skilled Burner	6
4.	Assistants	6
5.	Chemist	1
6.	Lab Assistant	3
7.	Unskilled Labour	40
8.	Electrician	1
9.	Maintenance Fitter	1
10.	Admn./Accounts Officer	1
11.	Admn./Accounts/Store Asst.	1
12.	Clerk/Typist	1
13.	Security Officer	1
14.	Time Keeper	3
15.	Total	69

10.0 REQUIREMENT AND CLASSIFICATION OF BUILDING LIME/QUICK AND HYDRATED LIME FOR CHEMICAL INDUSTRIES

In large country like India, the method of lime manufacture and the manner of its use differs from region to region. In addition the quality of limestone fuel and handling processes varies causing variation in quality of lime, therefore to stream lime uses of lime in building sector, standard specification IS:712 was made in 1956. Building lime shall be classified as follows:

- CLASS A - Eminently hydraulic lime used for structural purposes.
- CLASS B - Semi hydraulic lime used for masonry mortars, lime concrete and plaster undercoat.
- CLASS C - Fatlime used for finishing coat in plastering, white washing, composite mortars etc. with the addition of pozzolanic materials for masonry mortar.
- CLASS D - Magnesium/Dolomite lime used for finishing coat in plastering, white washing etc.
- CLASS E - Kunkar lime used for masonry mortars.
- CLASS F - Siliceous dolomite lime use for undercoat and finishing coat of plaster.

10.1 MANUFACTURING OF BUILDING LIME IN INDIA

Chemical and physical specifications for building lime in India are given in Table 10 & 11. It is evident from the table that no limits are specified for the normal contaminants which may come from ash or volatile of fuels. The quality is defined by the gross limits of CaO and MgO, available lime contents, insoluble residue and CO₂ in the product etc. Depending upon the availability of suitable limestone source, building lime of various classes conforming to IS: 712 can therefore be produced by the conventional mixed feed vertical lime kilns using solid fuels. Most of the current building lime is produced on cottage, small and medium scales in kilns having capacities from 2 to 50 tpd.

Current demand of building lime in the country is highly uncertain, variable and the present capacity appears to be adequate.. There are very few manufacturers of eminently hydraulic and semi-hydraulic limes. Most of the advantages of such limes are lost due to inadequate controls during burning and hydration. There is also a general difficulty of small manufacturers for creating facilities for quality control.

In view of the low capital investment and labour intensive character of the small mixed feed kilns, it is desirable to produce building lime upto 50 tpd from these kilns and organised industrial sector should set up VSK plants for producing 50-200 tpd of lime . To ensure quality, the small scale manufacture of lime should be taken up by relatively large consumers like CPWD, Housing Boards and developmental authorities who can create monitoring facilities for quality control. Depending upon the demand, larger capacity VSK kilns using pulverized coal with a relatively lower degree of automation can be considered for manufacture of building lime.

10.2 REQUIREMENTS OF QUICK & HYDRATED LIME FOR CHEMICAL INDUSTRIES

The chemical grade lime depending on their properties and suitable uses have been categorised into five grades as per IS-1540.

- GRADE A - Suitable for varnish manufacture
- GRADE B - Suitable for bleaching powder & bleach liquor for paper & textile industries
- GRADE C - Suitable for calcium carbide
- GRADE D - Suitable for sugar manufacture
- GRADE E - Suitable for soda ash, caustic soda by lime, soda process, Water treatment and tanning industry

Hydrated lime is used in petroleum industry for manufacture of lime based lubricating greases called cup greases. This is used for machinery not subjected to high temperature. Hydrated lime is also used in manufacture of stable bleaching powder. Other application are soda ash, caustic soda, calcium carbide in textile, sugar, varnish and tanning industries. Requirements of quick lime and hydrated lime

TABLE 10

CHEMICAL REQUIREMENTS OF BUILDING LIME (IS 712-1985)

Sl. No.	Type of Test	Requirements of Building Limes											
		Class A		Class B		Class C		Class D		Class E		Class F	
		Hydrated		Quick Hydrated		Quick Hydrated		Quick Hydrated		Hydrated		Quick Hydrated	
		60	70	6	70	85	85	85	85	50	70	70	70
1.	Calcium and Magnesium oxide, percent, Min	60											
2.	Magnesium oxide) Max percent) Min	6	6	6	6	6	6	-	-	6	-	-	-
3.	Silica, alumina and ferric oxide, percent, Min	20	10	10	10	-	-	-	-	20	10	10	10
4.	Unhydrated oxides, percent, Max	-	-	-	-	-	-	8	8	-	8	8	8
5.	Insoluble residue, Max.	15	10	10	10	2	2	2	2	25	10	10	10
6.	Insoluble matter in sodium Carbonate solution, percent Max.	5	5	5	5	5	5	5	5	5	-	-	-
7.	Loss on ignition, percent, Max	-	5 for large lump, 7 for lime other than lump	-	5 for large lump, 7 for lime other than lump	-	5 for large lump, 7 for lime other than lump	5 for large lump, 7 for lime other than lump	-	5	-	-	-
8.	Carbon dioxide, percent Max.	5	5	5	5	5	5	5	5	5	5	5	5
9.	Cementation value Min Max	0.6 -	0.3 0.6	0.3 0.6	- -	- -	- -	- -	- -	- -	- -	- -	- -
10.	Free Moisture Max.	2	-	2	-	2	-	2	-	2	-	-	2
11.	Available Lime, CaO (Min), dry basis	-	-	-	-	75	75	-	-	-	-	-	-

Note 1 - Percentages shall be expressed on ignited basis in respect of items (1) to (6)

TABLE - 11
PHYSICAL REQUIREMENTS OF BUILDING LIME

Characteristics	Class A A (hyd)	Class B Quick Hyd	Class C Quick Hyd	Class D Quick Hyd	Class E Hyd	Class F Quick Hyd
I FINENESS						
a) Residue on 2.36 mm IS sieve % (Max)	Nil	- Nil	- Nil	- Nil	Nil -	Nil
b) Residue on 300 micron IS sieve % (Max)	5	- 5	- Nil	- Nil	5 -	5
c) Residue on 212 micron IS sieve % (Max)	-	- -	- 10	- 10	- -	Nil
II Residue on Slaking						
a) Residue on 850 micron IS sieve % (Max)	-	10 -	5 -	5 -	- 10 -	-
b) Residue on 300 micron IS sieve % (Max)	-	- -	5 -	5 -	- -	-
III Setting Time						
a) Initial, Min, h	2	- -	- -	- -	2 -	-
b) Final, Max, h	48	- -	- -	- -	48 -	-
IV Compressive Strength in Min N/mm²						
a) at 14 days	1.75	1.25 1.25	- -	- -	1.0 1.25	1.25
b) at 28 days	2.8	1.75 1.75	- -	- -	1.75 1.75	1.75
V) Transverse Strength at 28 days N/mm ² , Min	1.0	0.7 0.7	- -	- -	0.7 0.7	0.7
VI) Workability bumps Max.	-	- -	12 10	12 10	- -	-
VII) Volume yield ml/g. Max.	-	- -	1.7 -	1.4 -	- -	-
VIII) Soundness/ Lechatelier Exp. mm, max.	5	- 5	- -	- -	10 -	10
Popping Pitting	free from Pops & pits	- free from Pops & pits	- free from Pops & pits	- free from Pops & pits	- free from Pops & pits	- free from Pops & pits

for use in chemical industry is shown in Table 12 & 13 as per IS 1540 (Part I) and IS 1540 (Part II). The comparison of chemical and physical properties of Building grade and chemical grade is given in Table 14. Use of lime in various sectors is given in Table-15.

TABLE – 12 AS PER IS 1540 (PART I)
REQUIREMENT OF VARIOUS GRADES OF QUICK LIME FOR USE IN
CHEMICAL INDUSTRIES

	Characteristics	GRADE				
		A	B	C	D	E
i)	Available lime CaO (%), Min	94.0	92.0	92.0	90.0	85.0
ii)	Dead burnt lime as CaO (%) by wt (Max.)	-	2.0	-	3.0	4.0
iii)	CO ₂ , % by wt. Max.	3.0	2.0	4.0	3.0	-
iv)	SiO ₂ , Max.	-	1.0	1.5	2.0	-
v)	Fe ₂ O ₃ , Max.	0.4	0.2	0.5	0.3	-
vi)	MgO, Max.	3.0	1.0	1.0	2.0	2.0
vii)	Sulphur (as S) Max.	-	-	0.2	-	-
viii)	Phosphorous (as P) Max.	-	-	0.01	-	-
ix)	Magnesium as Mn ₂ O ₃ , Max.	-	0.03	-	-	-
x)	SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ Max.	3.0	2.0	2.5	4.0	5.0
xi)	Fe ₂ O ₃ + Al ₂ O ₃	-	1.0	1.0	2.0	-

TABLE – 13 IS 1540 (PART II)
REQUIREMENT OF HYDRATED LIME FOR USE IN CHEMICAL INDUSTRIES

	Characteristics	GRADE	
		A	B
i)	Available lime as Ca(OH)_2 (%), by wt. Min.	87.2	86.0
ii)	Dead burnt lime as (CaO) (%) by wt Max.	-	2.0
iii)	CO_2 , Max.	3.5	2.0
iv)	Volatile matter at 105°C , Max	3.0	2.0
v)	Acid insoluble matter as SiO_2 , Max.	1.0	1.0
vi)	$\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$, Max.	0.5	-
vii)	Fe_2O_3 , Max.	-	0.2
viii)	Al_2O_3 , Max.	-	0.3
ix)	MgO , max.	1.5	1.0
x)	Mn_2O_3	-	0.01
xi)	Particle passing from 45 , Min	95	-
xii)	Particle passing through, Min 75 IS sieve Min	100	-

TABLE – 14

CHEMICAL AND PHYSICAL PROPERTIES : A COMPARISON

BUILDING GRADE	CHEMICAL GRADE
o Relatively rich in impurities & lower reactivity	Quick hydrated lime low in impurities & high degree of reactivity
o Commercially obtained by calcination In country kilns in unorganized sector	Commercially obtained by calcination of high grade limestone & under Controlled burning condition
o White solid having crystalline structure	It is white solid having crystalline structure
o Hydraulic grade lime reacts slowly With water & heat generation is Poor due to dissipation of heat	Quick lime highly reactive & liberates heat on reaction with violently
o It also reacts with air temperature	It reacts quickly with air in presence of moisture & form CaCO_3
o Only fat lime forms suspension, Hydraulic lime mostly settles down	Slightly soluble in water & forms suspension easily
o Solution is alkaline & PH is high	Solution is highly alkaline & PH is high
	The solubility of lime in water decreases with the temperature.
	Particle size has considerable influence on solubility. Freshly slaked lime which is of small particle size is about 10% more soluble than the aged slaked lime. This is due to slow growth of dry lime particles on storage.
	Setting rate depends on size.

TABLE – 15

CHEMICAL USES OF LIME IN VARIOUS SECTORS

Metallurgy

Steel Manufacture
Steel Products Manufacture
Magnesium Manufacture
Alumina Manufacture
Ore Flotation
Non-Ferrous metal smelting

Pulp & Paper

Sulfate Process
Sulfate Process
Bleaching
Straw Board Manufacture

Chemicals

Insecticides & Fungicides
Lime Manufacture
Alkalies
Calcium Carbide & Cynimide
Petrochemicals
Bleaches
Dye & Dyestuff Intermedies
Coke by Products

Water Treatment

Softening
Purification
Coagulation
Neutralization of acid water
Silica removal

Sewage Wastes Treatment

Municipal Sewage
Industrial Wastes
Exhaust Stack Gases

Ceramic Products

Glass
Refractories

Building Materials

Calcium Silicate brick
Concrete products
Miscellaneous building units
Insulation material

Protective Coatings

Pigments
Water paints
Varnish

Food & Food by products

Dairy Industry
Sugar Industry
Animal glue & gelatum industries
Baking industry
Godowns

Miscellaneous Uses

Petroleum
Leather
Rubber
Soaps
Fats

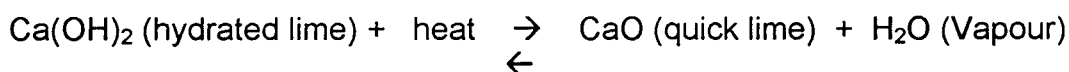
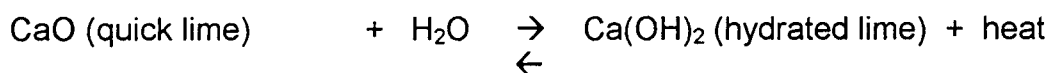
11.0 MANUFACTURE OF HYDRATED LIME

11.1 THEORY OF LIME HYDRATION

The most part of quick lime manufactured is converted into commercial hydrated lime which has an industrial value and is consumed in bulk. Hydrated Lime is produced by mixing water to quick lime and generate dry powdered hydrate which is a strong exothermal reaction. The value of hydrate is determined on the basis of oxide contents (i.e. CaO%), which varies tremendously, depending on the amount of water added (22) .

11.1.1 CHEMICAL REACTION & MECHANISM

The chemical reaction of hydrated lime is a reversible reaction, since dehydration, effected by subsequent heating, recreates quick lime and volatilizes the water of hydration as vapour, as displayed in the following question:



Quick lime exhibits strong affinity for moisture, absorbing it into its pores due to its hygroscopic nature-thus starting the chain reaction. As the water penetrates into the surface pores, heat of hydration is triggered. This inturn, exerts great internal expansive force in the lime particle and causes to fracture, shatter and then disintegrate completely into countless micro particles, either as crystalline "dust" or as a colloidal suspension depending upon the amount of water added. Accompanying this reaction is a steam or evaporated water from the heat of hydration, and a hissing noise owing to the turbulence generated. Invariably the resulting hydrate is whiter than the quick lime from which it is derived. The assimilated water is chemically combined into one distinct hydroxide molecule, a strong base, as compared to other hydrated chemicals.

11.2 WATER CONTENT

From the preceding equation the theoretical water content of hydrated lime can be calculated. Assuming complete hydration of 100% pure quick lime, the water of hydration is 24.3%. The balance 75.7% is the total oxide or lime solid content. This means that there is an increase in weight of the original quick lime to at least the extent of the water of hydration e.g. 55.5 kg of high calcium quick lime plus about 17.6 kg of water is equal to 72.6 kg of calcium hydrate. Practically, an excess of moisture over the theoretical amount is essential to achieve complete hydration since some water will be lost through evaporation precipitated by the heat of hydration and invariably there is some, at least a fractional percent of absorbed, free water that is not chemically combined but that envelopes the hydrate particle, like a film or bound water. This latter moisture cannot be removed by mechanical means, only by heat, so in a sense it is not free. Consequently, if only the theoretical amount of water is added, the lime will be incompletely hydrated and unstable; oxides will still be present with the hydroxide. Practically, the minimum amount of water required for complete hydration of a high calcium quick lime is at least 52% of the lime solids weight of the average commercial products. Variance in this value is dependent upon purity and degree of reactivity of a given quick lime.

11.3 TYPE OF LIME HYDRATES

The forms of hydrated lime depending upon the amount of excess water they contain are :

Dry hydrates, putty, slurry, milk of lime, lime water and air slacked lime.

11.3.1 DRY HYDRATE

It is the most concentrated form of hydrate a dry fine white powder which is known commercially as hydrated or slaked lime. Commercial product contains 72-74% of calcium oxide and balance 23-27% of chemically combined moisture rest are impurities and minute amount of free water. Generally dry hydrate manufacture requires one part by weight of quick lime to 0.5-0.75 parts of water.

11.3.2 PUTTY

It is a wet, amorphous appearing, plastic paste form of hydrate that has body so that it is moldable mass. It contains 30-45% free water in addition to the normal chemically combined water. Corresponding to the free moisture content the CaO contents range from 40-60%. It is produced by adding more water during hydration, normally 1 part of quick lime to 1-1.4 parts of water by weight are mixed.

11.3.3 SLURRY

This is a colloidal suspension form of hydrate and has cream like consistency. Unlike putty it has no body or plasticity. It can flow and is pumpable like viscous liquid. It contains about 60-73% free water and lime solid contains of 25-35%. It is produced by adding 1 part of quick lime to about 2 part of water by weight.

11.3.4 MILK OF LIME

This has a consistency of the whole milk and flows almost as readily as water. White wash is the example of milk of lime. This aqueous colloidal sol suspension is employed in broad concentration, ranging from 1-20% lime solids and rest is free water. If prepared directly from quick lime then the reaction recommended are 1:3 to 1:4.5 at a slaking temperature of 65.5-82°C.

11.3.5 LIME WATER

It is pure-saturated or unsaturated aqueous solution of calcium without any lime solids. Depending upon temperature, Ca(OH)_2 contains about 1.4-0.054 CaO equivalent of hydroxide in gm/lit. sat. sol. Lime water is obtained from such suspension by filtration or sedimentation followed by decantation.

11.3.6 AIR SLAKED

If quick lime is exposed to atmosphere of moderate to high relative humidity, the moisture vapours in the air causes the quick lime to hydrate and this phenomena

is called air slaking. In air slaking disintegration into hydrates particles occurs very gradually. Presence of moisture catalyzes carbonation due to CO₂ present in air.



This material is of no commercial significance. Infact it is undesirable reaction and illustrates that all limes are perishable unless adequately protected.

11.4 SUITABILITY OF WATER FOR MANUFACTURE OF HYDRATED LIME

It is reported that small amount of inorganic and organic impurities in water affects the extent of rate of solubility of lime water as compared to distilled water. Hence quality of water plays an important role in slaking.

It is reported (23) that :

1. Recycled water from SO₂ scrubbing is unsuitable because it retards slaking rate, lime reactivity, hydration yield and creates coarse to granular particles that sediment rapidly.
2. It should not contain over 500 mg/l sulphide, sulphate and bisulphate ions.
3. Saline or brackish water can be used but corrosion problems must be considered.
4. Potable water is safe to use.

11.5 SLAKING AND HYDRATION STUDY

Samples of lime calcined at 950, 1000 and 1050°C for 60, 90 and 120 minutes were slaked on a platform. On a thin bed of lump quick lime, water was added in small quantity until the lime slakes and falls into a fine powder. The amount of water added was slightly more than the theoretical amount of water needed for complete conversion of CaO into Ca(OH)₂. Additional amount of water was added gradually to keep the mass warm to facilitate the reaction. It was observed that in all the samples, except burnt at 950°C in 60 minutes the slaking takes place within 10 minutes after addition of water. Thus the quick lime produced was found to be rapid slaking lime.

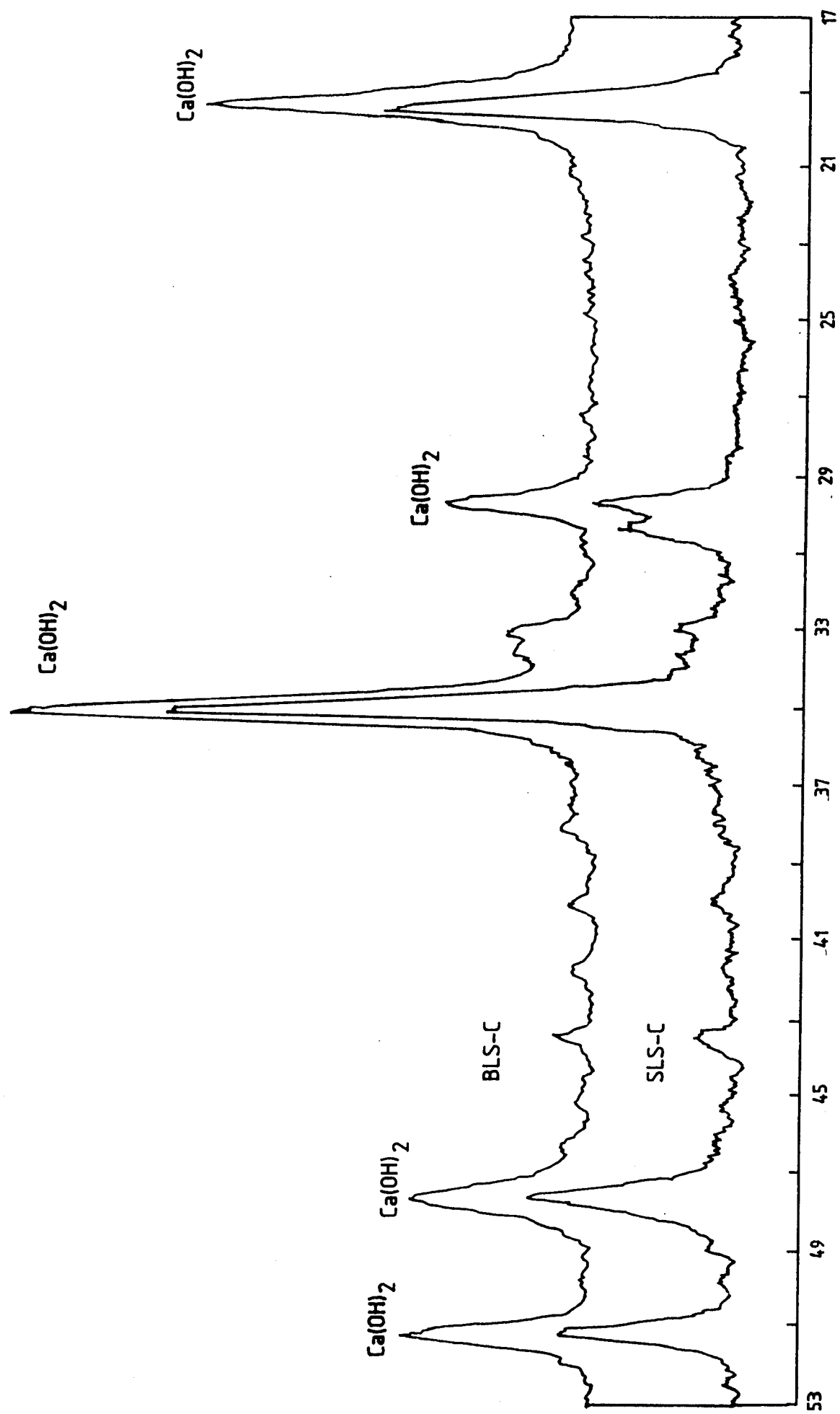


FIG. 19 X-RAY DIFFRACTOGRAM OF HYDRATED LIME MUD

11.5.1 MINERALOGICAL EVALUATION OF HYDRATED LIME

X-ray diffraction study of selected lime samples indicated substantial amount of portlandite at 950°C/60 minutes sample but considerable amount of uncalcined CaCO_3 was also present. However at 90 & 120 minutes the predominant phase in 10 minutes hydrated samples was Ca(OH)_2 . In CaO formed at 1000 & 1050°C also the predominant phase was Ca(OH)_2 . (Fig. 19)

11.5.2 CONSUMPTION FACTORS FOR PRODUCING HYDRATED LIME

About two tonnes of lime sludge is required for manufacture of one tonne of quick lime (CaO), from lime sludge CaCO_3 weight loss is 44%. Since certain impurities are associated with lime sludge calcination is not 100%, double the amount of lime sludge is generally required.

To obtain hydrated lime, theoretically 56 kg of quick lime require 18 kg of water. The conversion factors are shown in Table 16.

TABLE – 16

Raw Materials	Quantity	Product	
		Quick Lime	Hydrated Lime
1. Lime Sludge	1 t	0.5 t	0.66 t
2. Coke	0.2 t		

Conversion factor 1.5 t of lime sludge for one tonne of hydrated lime. Water content in 100% hydrated lime is about 25% by weight.

11.6 MANUFACTURING PROCESS OF HYDRATED LIME

In order to produce desired quality of Lime hydrate attention is required is correct proportion and distribution of slaking water for a given lime as well as method of hydration.

11.6.1 MANUFACTURE BY BATCH PROCESS

The batch method is the oldest and simplest method of slaking lime, involving minimum equipments. However, this has been replaced by continuous automated slaking machines due to high labour cost, less safety problems from lime burns and wastage of the lime. The basic type of lime slaking equipment that possesses two main compartments for hydration and dilution of the resulting lime slurry is shown in (Fig. 20).

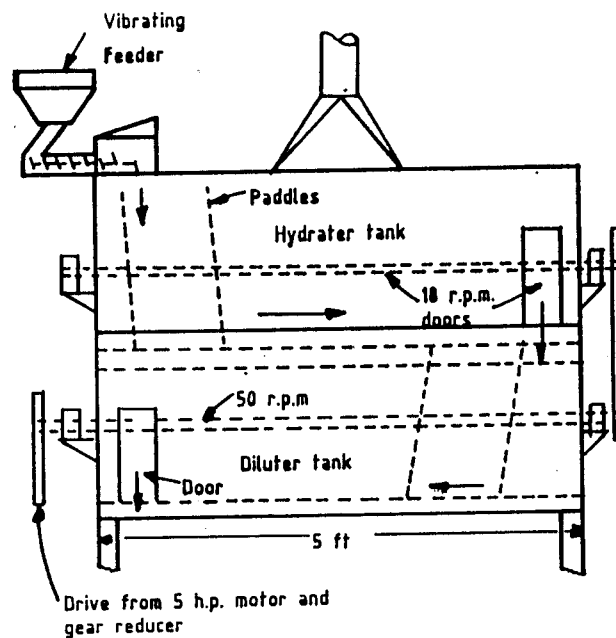


Fig. 20 : Basic Lime Slaking Equipment

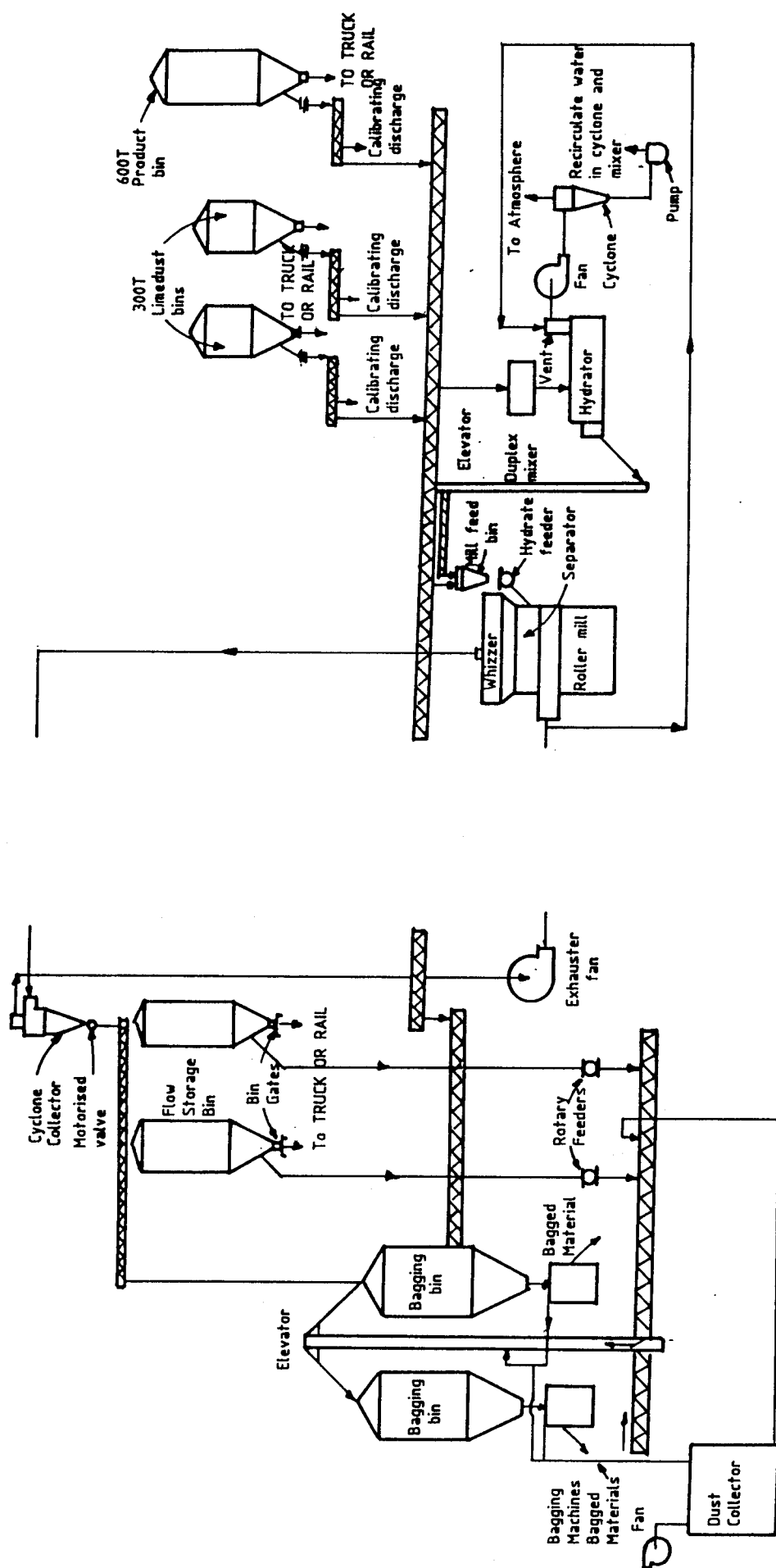


FIG. 21 FLOW DIAGRAM OF HYDRATED LIME PLANT

A majority of lime consumers do not prefer to purchase quicklime and slake it for their own consumption simply due to cost constraints. Instead, they prefer to purchase commercial hydrated lime. Commercial hydrate is a dry powder representing the most concentrated form of hydrate. These dry hydrates can be readily mixed with water and reduced to any desired consistency, hence making it a second major product of the lime industry.

11.6.2 MANUFACTURE OF COMMERCIAL HYDRATE

The commercial hydrate is produced in a closed circuit system to prevent re-carbonation. The flow diagrams of typical lime hydrate manufacturing process are shown in Fig. 21. Following variables should be kept in mind before influencing any modification in plant design and equipment.

- Porosity and slaking rate of the quicklime.
- Chemical purity of the quicklime (% of the impurities and core)
- Physical size and gradation of quicklime to be fed into the hydration system.
- Temperature of hydration water.
- Particle size requirement of resulting hydrate, predicated on markets for which hydrate will be sold.

Generally, equipment in commercial hydration plants, utilizing atmospheric pressure, include the following:

11.6.2.1 **GRINDING EQUIPMENT** is usually employed in most plants to reduce lump or pebble quicklime to at least 0.25 – 0.5" (6.4-12.7 mm). Finishing hydrates that command a premium price are invariably derived from the best quality of quicklime available. A uniform and reasonably restricted gradation is desirable for consistent and high quality hydrate rather than variable fractions.

In some plants the fines are hydrated separately from the large crushed and screened material. With reactive quicklime the heat of hydration with coarser fractions can be controlled more easily than with fines; with quick limes of low reactivity finely divided material of Nos. 8-100 mesh (2.4-0.15 mm) are more efficient to hydrate.

The most adaptable types of grinders are the hammer mill, impact breaker, small gyratory, and cone mill. The comminuted material is conveyed to a raw-lime storage silo or bin.

11.6.2.2 **STORAGE BINS AND CONVEYORS** are required for the classified quicklime raw feed and to convey the quicklime to the hydrator. Storage facilities are of a silo type with hopper bottom and with capacities of 100-600 tons, depending on the capacity of the plant. The conveyor is usually an enclosed-circuit bucket elevator since most storage silos are elevated.

11.6.2.3 A **FEEDER** of constant weight or volumetric type introduces quicklime from the silo-hopper to the hydrator or a premixing chamber.

11.6.2.4 A **HYDRATOR MACHINE**, equipped with agitation devices, that will intimately mix a predetermined proportion of lime and water is the "keystone" of a hydration plant. Temperature-control equipment and provision for venting off some of the heat of hydration and lime dust through a stack with a dust control apparatus are necessary auxiliary equipment in modern plants.

Hydrator chambers or troughs are both vertical and horizontal types with paddles, blades, or rabble arms for agitation and for impelling the mixture through, like a screw conveyor. Water is sprayed through an inlet into the stack and, as it descends to the hydrator, ascending exhaust heat preheats the water for more rapid hydration. The lime dust that is emitted up the stack is recovered in a washer-scrubber collector, and the resulting milk-of-lime is recycled back to the hydrator or to a premixer chamber, where it is initially intermixed with the quicklime before entering the hydrator. Hot, clean air is vented from the stack into the atmosphere, thus averting atmospheric pollution and lime wastage.

Meanwhile in the hydrator the fine, fluffy hydrate particles form and rise above the heavier unhydrated particles, core, and impurities, and overflow a dam or weir and are discharged. Thus, feeding and discharging occur continuously. Much of the core and impurities are collected in a sump and removed as "tailings".

11.6.2.5 An **ENCLOSED CIRCUIT CONVEYOR** for transporting the semi processed hydrate from the hydrator to the air separator, cyclone, or storage or curing compartment is of many diverse types, depending on plant design. Usually a system of horizontal screw conveyors in tandem and bucket elevators is employed.

11.6.2.6 Enclosed, **MECHANICAL AIR SEPARATORS** of the centrifugal type that are conical with a hopper bottom are universally employed in the final milling of the hydrate to classify the material to a fine state of subdivision. The final product must contain 98% passing a No. 325 mesh (44 μ). Some grit escaping from the hydrator is easily ejected at this point.

The principle behind the centrifugal separator is that the fine particles are lifted by strong ascending air currents, generated by a fan operating countercurrent to the combined effect of gravity and centrifugal force. The coarser, heavier particles settle out; thus this operation resembles a dry version of sedimentation.

These mills are adjustable, so that in some plants a series of several separators may be employed to produce hydrates of several different particle sizes and gradations. Hydrates that are not air separated would be considered crude, unrefined products, like agricultural hydrate, and of less value. This operation also further dries the moist, crude hydrate powder that enters the separator.

Rejects are usually conveyed to the waste pile along with "tailings" from the hydrator, providing the percent of waste is small, as it should be if a well-burned quicklime is efficiently hydrated. But much of this rejected material may contain lime. Often pure lime agglomerated in granular form and also clinging to core and impurities. If there is an appreciable amount of this waste material, there is often economy in reprocessing these "tailings" to recover usable hydrate. Special machines are used that violently agitate the rejects in water, separating them from

the grit, which is removed by sedimentation, like wet sand. The recovered lime in "milk" form is then reintroduced into the hydrator with the mixing water or into the premixer.

11.6.2.7 After milling, the finished hydrate is conveyed or fed by gravity to **STORAGE SILOS**, located above the automatic bag-filling machines, or to special silos designed for bulk shipment.

11.6.2.8 **BAG- PACKING MACHINES** encompass a number of highly automated patented types that can accommodate various kinds of multiwall bags, like the sewn-valve, sewn open-mouth, pasted open-mouth, and pasted valve. The cylindrical machines are made with 4, 6, 8 or 12 filling spouts that can be operated by one man. The nozzle of the spout is inserted through the valve opening and the bag is filled and weighed automatically, with the valve of the bag closing automatically when the bag is full. Bag spouts are located in tandem or circularly, and the filling cylinders rotate around them.

11.6.2.9 Many plants utilize initially a **PREMIXER** that partially hydrates the quicklime in a smaller chamber before discharging the mixture as a slurry to the hydrator. Agitation is necessary, and such mixing is achieved in equipment resembling a small pug mill. The high initial heat of hydration stimulates violent agitation and intimacy of contact between quicklime and water.

11.6.2.10 Other supplemental equipment are **AGING BINS**, which are similar to **RETENTION SILOS**. These are usually employed only in plants that use hard-burned, slow-slaking quicklime. The raw hydrate is fed into these tanks directly from the hydrator in a wet condition (15-20% excess water), permitting the hydration to be completed with varying retention periods. After hydration is complete, the crude hydrate is fed to the air separator for milling. Such mills may be intermittently used to contribute flexibility to the operation in the event that slaking time of the lime lengthens and to abet coordination of the flow of material through the com-minuter , hydrator and milling equipment.

11.7 MANUFACTURE BY PRESSURE HYDRATED METHOD

This technique is based on the principle that at atmospheric pressure quick lime hydrates completely into calcium hydrate within minutes to an hour without difficulty. The simple flow diagram of a pressure hydrated lime process is shown in Fig. 22.

It is a known fact that hydrated lime is more profitable product than quicklime simply from the fact that 125 tons of hydrates are made from 100 tons of quick lime. Secondly, hydrates are sold about 15% higher price per tonne is compared to quicklime.

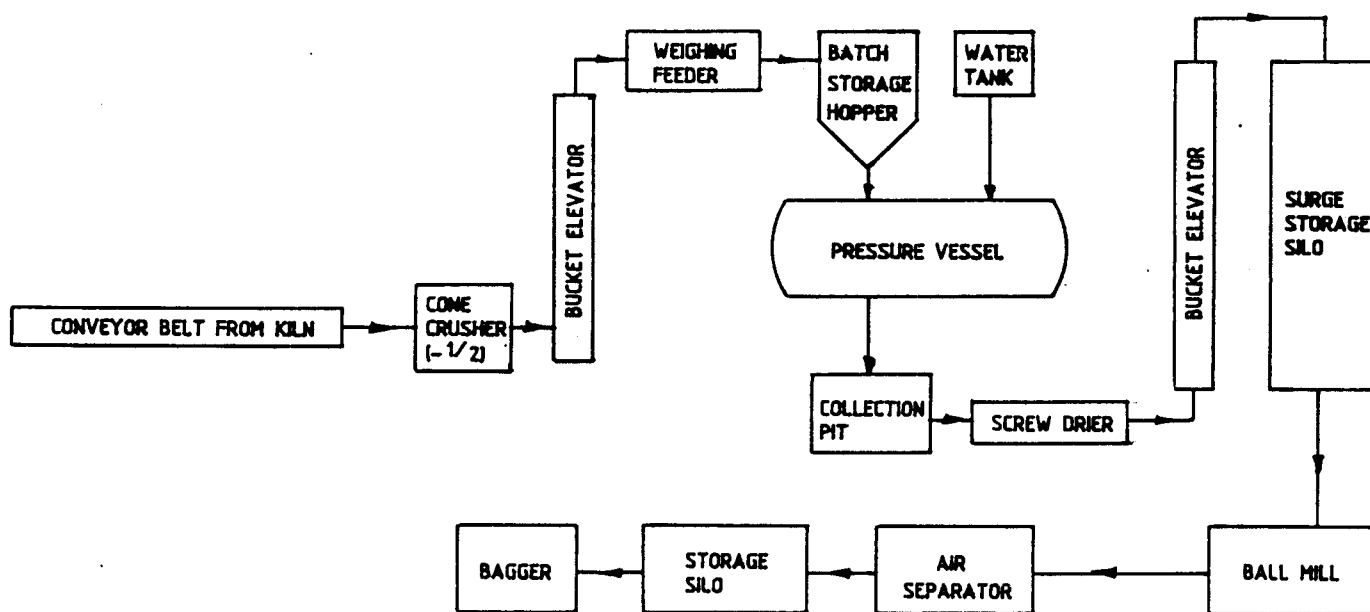


Fig. 22 : Flow diagram of a pressure hydrated lime process

12.0 ECONOMICS OF QUICK/HYDRATED LIME MANUFACTURE

12.1 PROJECT COST

The project cost estimates have been prepared based on the quotation received from machinery suppliers. Total cost of project of setting up 50 tpd Hydrated lime plant is estimated Rs. 461 lakhs which include the cost of quick lime plant, Rs. 336 lakhs. The details are given in table 17. Contingencies provision of 10% towards Civil Cost and Plant & Machinery has been provided.

12.2 COST OF PRODUCTION

Production cost of quick lime per tonne and hydrated lime per tonne works out to be Rs. 1335 and Rs. 1186 respectively. The details of these are shown in table 18 & 19.

TABLE 17

**SUMMARY OF TOTAL CAPITAL COST OF SETTING UP
50 TPD HYDRATED LIME PLANT**

Sl. No.	Items	Quick Lime Plant	Hydrated Lime Plant
		Cost in Rs. Lakhs	
1.	Land & Site development (Lump Sum) Area of land (119*95)m ²	10.00	10.00
2.	Building & Civil Works	60.00	90.00
3.	Plant & Machinery (As erected)	180.00	250.00
	3.1 Main Plant and Equipment		
	3.1.1 Vacuum filter etc.	30.00	30.00
	3.1.2 Rotary Drum Dryer etc.	50.00	50.00
	3.1.3 NCB Mixed Feed VSLK	25.00	25.00
	3.1.4 Hydrator (3-tier)	-	20.00
	3.1.5 Storage Silo etc	-	10.00
3.2	Other Equipment (Details given in table -8)	50.00	85.00
	3.3 Taxes , Duties etc.	25.00	30.00
4.	Misc. Fixed Assets	10.00	10.00
5.	Preliminary & Pre operative Expenses	40.00	55.00
6.	Contingencies(10% of items 1 to 4)	26.00	36.00
7.	Margin Money	10.00	10.00
	Total capital cost	336.00	461.00

TABLE 18**COST OF PRODUCTION OF QUICK LIME**

Sl. No.	Item	Unit	Consumption factor	Rate/ Unit (Rs.)	Amount Rs. per tonne of Quick Lime
1.	Lime Sludge	Tonne	1.00	10.00	10.00
2.	Coke	Tonne	0.20	2500.00	500.00
3.	Power	Kwh	30	3.50	105.00
4.	Repairs & Maintenance				50.00
5.	Stores & Consumables				15.00
6.	Salaries & Wages				145.00
7.	Overheads				10.00
8.	Depreciation				250.00
9.	Interest on long term loan				150.00
10.	Packing charges				100.00
11.	Cost of production				1335.00

TABLE 19

COST OF PRODUCTION OF HYDRATED LIME

Sl. No.	Item	Unit	Consumption factor	Rate/ Unit (Rs.)	Amount Rs. per tonne of Hydrated Lime
1.	Quick Lime	Tonne	0.75	1335.00	1001.25
2.	Water	Tonne	300.00	-	-
3.	Power	Kwh	10	3.50	35.00
4.	Repairs & Maintenance				10.00
5.	Stores & Consumables				5.00
6.	Salaries & Wages				10.00
7.	Overheads				5.00
8.	Depreciation				75.00
9.	Interest on long term loan				40.00
10.	Cost of production				1186.25

* Break-up is given in Table 18

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