THE JONES AND ASSOCIATES LIME KILN

DESIGN AND OPERATION

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Introduction:

As part of Western Sugars commitment to modernizing facilities and minimizing costs, the lime kilns at various factories were studied. The lime kilns at three different factories were converted to or replaced with Jones & Associates lime kilns. These kilns were individually designed for each location based on existing equipment, funding and factory requirements. This paper will present the theory and design principles the Jones and Associates lime kiln is based on and the operating history of the Jones and Associates lime kiln compared to the previous installations.

Kiln Design:

The Jones and Associates lime kiln is based on the fundamental processes involved in calcining limestone. In order to adequately describe the design, some of these principles must be presented. In its most basic form, the calcination of limestone occurs when heat is added to calcium carbonate (limestone) causing it to dissociate into calcium oxide (quick lime) and carbon dioxide which leaves as a gas. Theoretically, this seems simple, but several complications arise when applied to the practical world. High quality quick lime requires that the calcium oxide be very reactive and the conversion of calcium carbonate to calcium oxide be very high. These two requirements compete against each other in most kiln designs.

In order to obtain a high conversion rate of calcium carbonate to calcium oxide, the limestone particle must be elevated to above the dissociation temperature of calcium carbonate and held there for a certain duration. The limestone particle obeys the laws of heat transfer during heating and a temperature gradient is set up with the outside of the particle being hotter than the center of the particle. In order to have a high yield, the core must be heated above the dissociation temperature and held there long enough for the carbon dioxide to migrate to the surface of the particle and leave the system. According to heat transfer laws, there are two extremes to accomplish this. The particle can be exposed to very high heat for a relatively short time where the surface of the particle will be much hotter than required for calcining or the particle can be exposed to heat just above the calcining temperature and held for a very long time where the surface temperature is only slightly above the calcining temperature. Either method will yield a high calcium oxide product, but there are compromises with each.

The reactivity of calcium oxide depends on the rate at which heat is put into the particle during calcination. More specifically, it depends on the crystalline structure of the calcium oxide particle. Calcium carbonate is generally found in a rhombic crystalline structure. Calcium oxide prefers the cubic crystalline structure. However, high quality, reactive quick lime is predominantly rhombic in crystalline structure. This is due to the rhombic crystalline structure being less dense allowing water better access to the calcium oxide increasing the reactivity. The rhombic structure of the calcium carbonate continues to exist when the carbon dioxide leaves the crystalline lattice and there is not sufficient energy available for the lattice to convert itself to the preferred cubic shape for calcium oxide. A high rate of heat input caused by a high calcining temperature provides the energy for the crystalline structure to reorganize and thus creates quick lime with poor reactivity. Low rates of heat input with low calcining temperatures do not provide the energy needed to change the crystal structure and thus produce a reactive quick lime. Thus, kilns are designed with lower heat input rates to create reactive lime, but this requires long retention times and thus, large kilns with high construction costs. These are the compromises associated with the two extremes of calcination.

The central idea behind the Jones & Associates lime kiln is to provide a steady state reaction vessel with the proper controls to allow for process adjustments. The solids are uniformly distributed and move in a laminar plug flow through the reaction chamber. The air or air and gas is uniformly placed in measured amounts allowing for precise control of calcining temperatures. A constant controllable ratio of flows between air, fuel and rock is maintained. This creates the steady state counter current reaction vessel which results in high conversion rates, high reactivity and low energy requirements.

The Jones and associates lime kiln is designed to provide both reactive quick lime and high through put rates. This is accomplished by providing two heat input levels with varying rates. At the upper burner beams, the rock is relatively cool and is still predominantly calcium carbonate, thus it can absorb a lot of heat rapidly. The air to gas ratio fed to this burner level is lean providing a short hot flame to heat up the stone rapidly and dissociate the surface carbon dioxide quickly. The middle burner level has a rich air to gas ratio providing a long cooler flame giving the particle a long retention time at a lower heat input rate. This lower temperature puts the heat in slow enough to allow it to penetrate to the core of the particle and allows the carbon dioxide enough time to migrate to the surface of the particle and leave the system. Thus the Jones lime kiln combines the two extreme approaches to calcining limestone and produces a highly reactive lime with high through put rates and lower construction costs.

The Jones & associates lime kiln combines good thermal efficiency with mechanical simplicity. The mechanics of the system include the stone charging system, the grate system and the air/gas system. The stone charging system includes typical conveying systems with an air lock system to maintain gas quality. Particular attention is paid to stone distribution. Uniform size distribution is critical in optimal kiln operation. A uniform bed prevents channeling of gasses and thus provides uniform heat distribution. This prevents areas of high core or areas of excessive heat. Uniform distribution of the rock is accomplished through the use of a distributor cone. This specially designed cone minimizes the segregation caused by most rock handling systems. The charging system also includes a generous preheat zone where the off gas is cooled and the raw rock is preheated. This improves the thermal efficiency of the kiln.

The grate system is the discharge mechanism of the kiln. The Jones and associates kiln uses the angle of repose of the rock to create a stable bed on the discharge plate. A pusher bar or rotating eccentric then pushes the rock off of the plate causing the bed to move. The critical design parameter of the grate is uniform bed movement. The bed should move as a laminar plug. In other words, a particle at the center of the kiln should travel straight down through the kiln at the same rate as a particle along the wall or a particle half way in between. In this way, each particle will see the same temperature for the same length of time and will have the same degree of calcination. Each kiln is tested after construction to make sure this design specification is met. The lime discharge of the kiln must also have an air lock to ensure off gas quality.

Finally, the air/gas system consists of a blower, flow controls, burner beams and a cooling system. Air and gas are premixed and added at two levels of two to four burner beams per level. The air and gas are controlled through flow control loops and injected into the kiln through orifices in the burner beams. The orifices and piping are designed to provide a uniform amount of heat to each increment of cross sectional area. Thus each particle experiences the same amount of heat at each level through the kiln. The design takes into account such details as average particle size in heat penetration and bridging characteristics. The burner beams are water jacketed for cooling with a closed loop cooling system. A third level of orifices is found in the grate system. Here, the excess air required for complete combustion is added. At this level, the air removes heat from the calcined stone, cooling the stone for easier and safer handling. The air is preheated at the same time, improving the thermal efficiency of the kiln.

It should be noted that the Jones lime kiln can be used as a mixed feed lime kiln. As long as the fuel is uniformly mixed, the kiln will operate nearly as well as the gas fired kiln and much better than the old style mixed feed kilns. Again, the kiln design will allow control of where the air is added to the fuel. This in turn controls the temperature profile allowing high heat where it is needed and lower heat where it is needed. The solids distributor will prevent segregation of the fuel, but it will not correct poorly mixed fuel. Thus, some solids handling changes may be required.

Kiln Operation:

The driving force for improved kiln design varied at each factory. The previous Fort Morgan lime kiln was a Union Carbide gas fired lime kiln. It was producing 95 - 100 tons of CaO per day at an average of 20.1% CO2 and 86.2% CaO. The energy usage averaged 5.34 MMBTU per ton of CaO. The factory was operating as a steffens house and required more lime with better gas quality to improve purification. The retrofit of the existing kiln with a Jones designed kiln was the most cost effective alternative. The kiln was designed to fit in the rectangular cross section of the existing kiln to minimize refractory work and costs. This design had some limitations due to being a retrofit. The primary concern was the corners of the kiln where the wall effect of the reaction chamber was magnified. A conservative design was taken where it was expected that the corners would have some what higher core than the rest of the kiln. This design was undertaken to reduce the chances of overburn and clinkering in these areas.

The Jones kiln accomplished all of its design requirements. The capacity of the lime kiln was increased to 120 tons of CaO per day and the off gas quality improved to 28.5% CO2. These were the primary objectives of the redesign. The additional benefits included an increase in calcination of 1.4% and a reduction in energy usage of 12.8%. The overall cost of lime decreased 5.3% with the benefits of increased capacity and increased off gas quality.

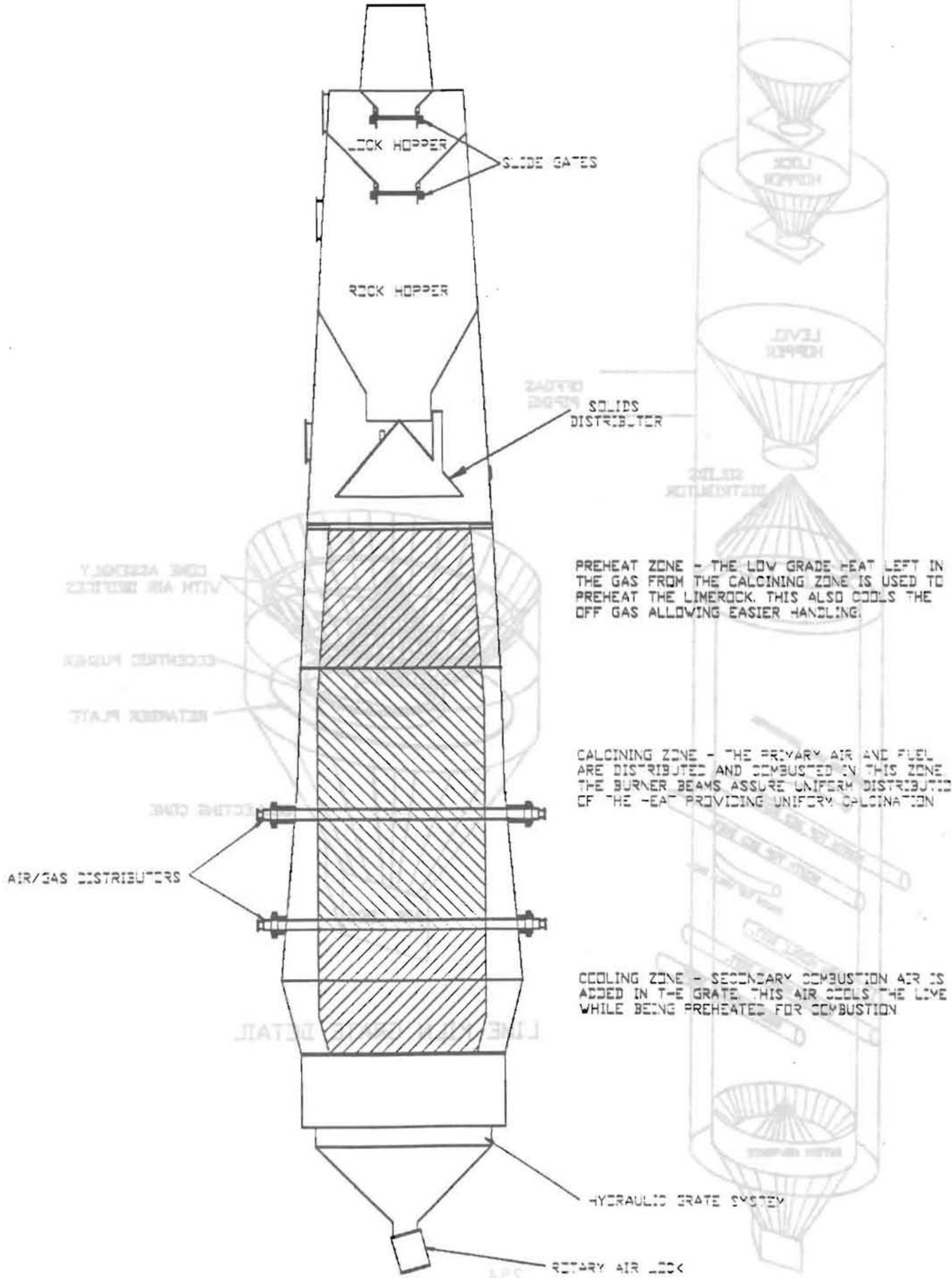
The Greeley factory was operating with a turn of the century mixed feed kiln. The capacity of the kiln was limited to 45 tons per day of CaO with off gas quality of 28 - 31% CO2. At higher capacities, the gas quality was near 28% CO2. The lime averaged 83.6% CaO and the kiln averaged 5.47 MMBTU per ton of CaO. The kiln had air and heat channeling problems. High core material as well as overburn material and even unburned fuel was discharged from the kiln at the same time. The thermal bed was unstable moving up and down the kiln with factory demands. The driving force for installing a Jones kiln was the high cost of solid fuels, lack of lime kiln capacity and low calcination rate of the mixed feed kiln.

The retrofit in the existing kiln provided several challenges. The biggest challenge was the high cross sectional area of the existing kiln. Bed movement was going to be one sixth of typical Jones and Associate designs. This caused worries about lateral heat distribution and thus calcination and thermal efficiencies. With these reservations, the kiln was designed and installed. The operations of the kiln met all design objectives and operation continues to improve as it is fine tuned. The kiln will produce 70-80 tons of CaO per day at 88% CaO. The off gas qualityis in excess of 28% CO2 with the kiln using 5.13 MMBTU per ton of CaO. Energy costs have been cut in half with total lime costs being reduced by 27.8%.

The Scottsbluff factory had two mixed feed lime kilns which were in need of major repair. It was decided to replace both kilns with a single, smaller Jones and Associates lime kiln to reduce maintenance costs, offset one time major repair costs and reduce energy costs. The major challenge with this kiln installation was scaling down the design from other commercial installations. This was the first Jones design with a 6 1/2 foot inside diameter and several scaling problems arose. These will be addressed this intercampaign and more accurate information on this kiln's operation will be available next year. Early indications are that it will be more energy efficient than expected while meeting all other design requirements.

Conclusion:

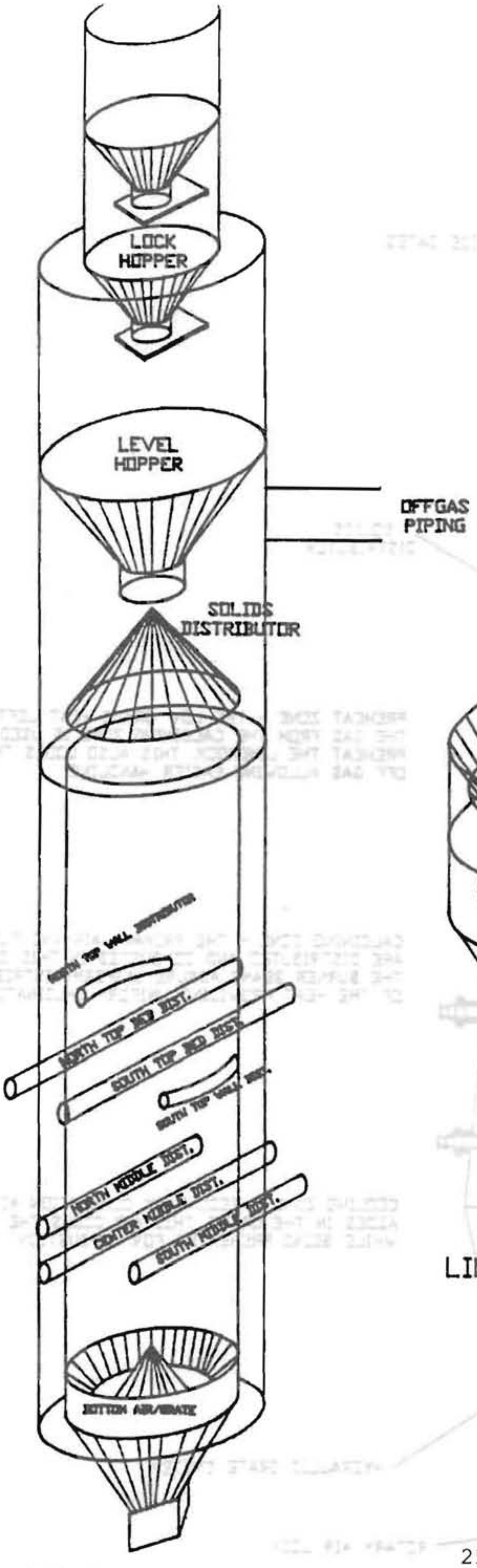
Three different lime kilns in Western Sugar were replaced with a Jones and Associates multiple fuel kiln. These kilns are being operated using natural gas, but can be operated as mixed feed kilns. The Fort Morgan and Greeley lime kilns met all major design specifications in their first year of operation while the Scottsbluff lime kiln had some size scaling problems which will be corrected. The lime kilns combine high quality lime and off gas with low capital and production costs. The kilns can be retroffitted to existing installations in most cases increasing capacity or can be designed as a new installation. Although this kiln design is new to the sugar industry, it has 20 years of operating history in the commercial manufacture of lime.



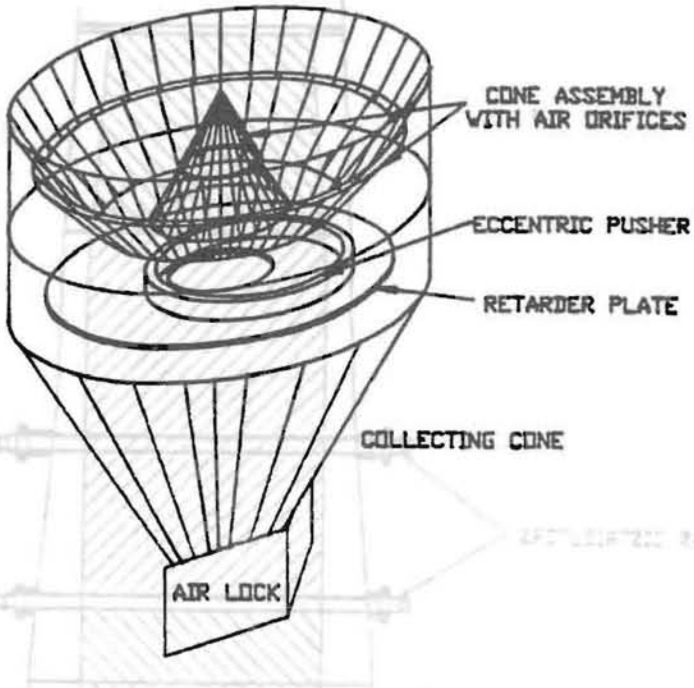
PREHEAT ZONE - THE LOW GRADE HEAT LEFT IN THE GAS FROM THE CALCINING ZONE IS USED TO PREHEAT THE LIMEROCK. THIS ALSO COOLS THE OFF GAS ALLOWING EASIER HANDLING.

CALCINING ZONE - THE PRIMARY AIR AND FUEL ARE DISTRIBUTED AND COMBUSTED IN THIS ZONE THE BURNER BEAMS ASSURE UNIFORM DISTRIBUTION OF THE HEAT PROVIDING UNIFORM CALCINATION

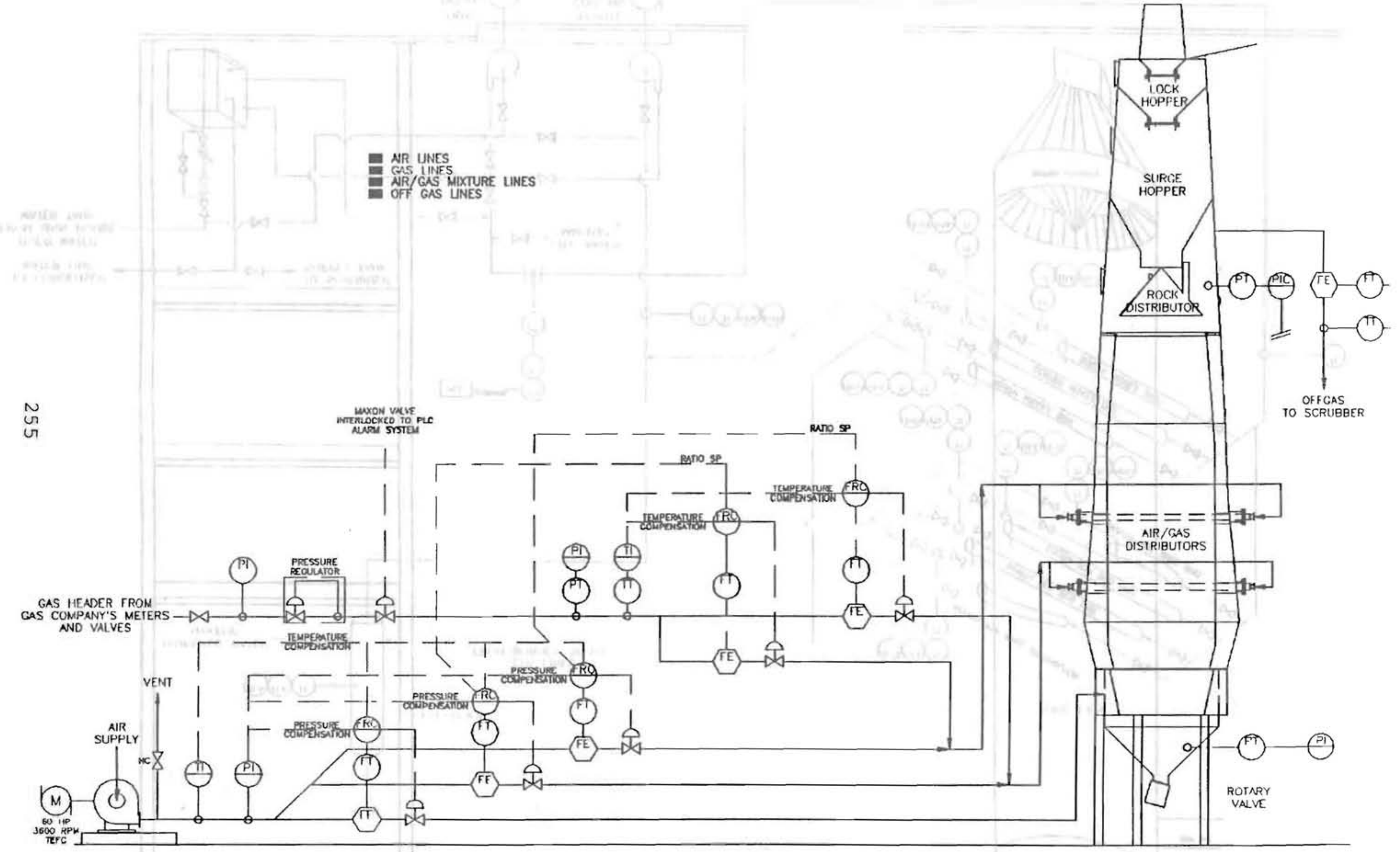
COOLING ZONE - SECONDARY COMBUSTION AIR IS ADDED IN THE GRATE. THIS AIR COOLS THE LIME WHILE BEING PREHEATED FOR COMBUSTION

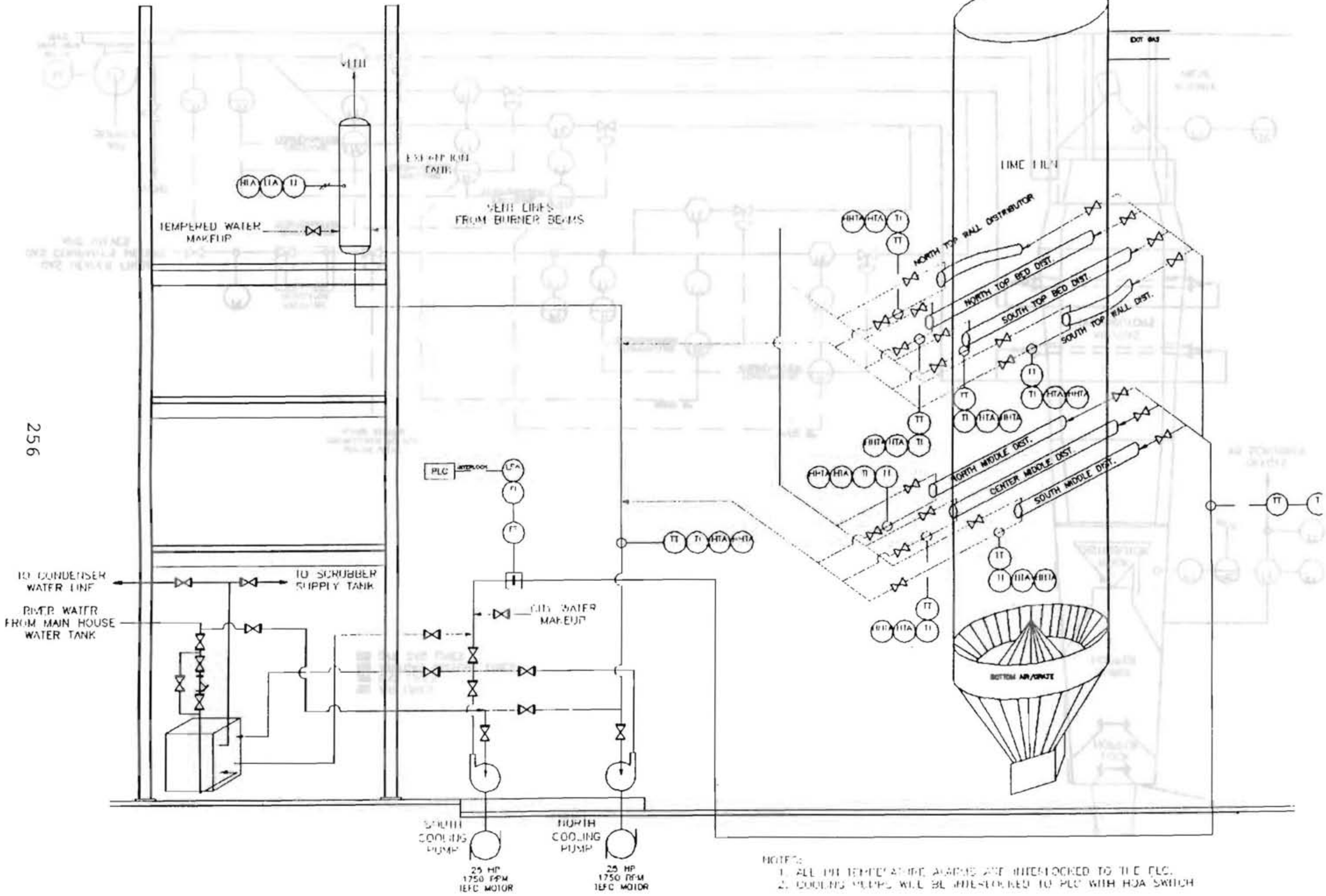


LIME KILN LAYOUT

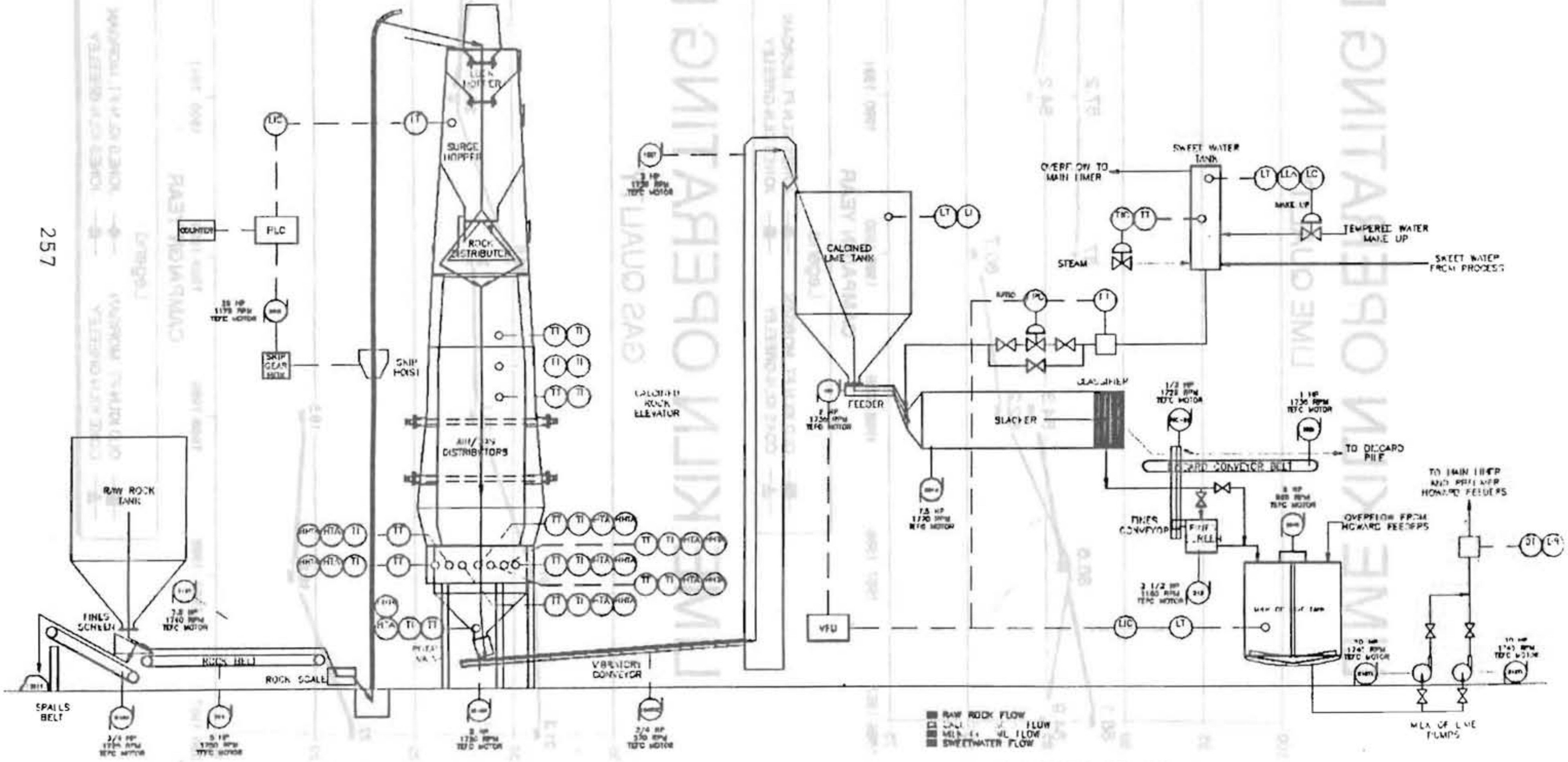


LIME KILN GRATE DETAIL


■ AIR LINES
■ GAS LINES
■ AIR/GAS MIXTURE LINES
■ OFF GAS LINES
LOCK HOPPER
SURGE HOPPER
ROCK DISTRIBUTOR
PT
PIC
FE
FT
TT
OFFGAS TO SCRUBBER
AIR/GAS DISTRIBUTORS
ROTARY VALVE
PI
MAXON VALVE INTERLOCKED TO PLC ALARM SYSTEM
RATIO SP
RATIO SP
TEMPERATURE COMPENSATION
TEMPERATURE COMPENSATION
TEMPERATURE COMPENSATION
PRESSURE REGULATOR
PRESSURE COMPENSATION
PRESSURE COMPENSATION
PRESSURE COMPENSATION
FRC
TI
TT
FE
GAS HEADER FROM GAS COMPANY'S METERS AND VALVES
VENT
AIR SUPPLY
NC
M
60 HP
3600 RPM
TEFC

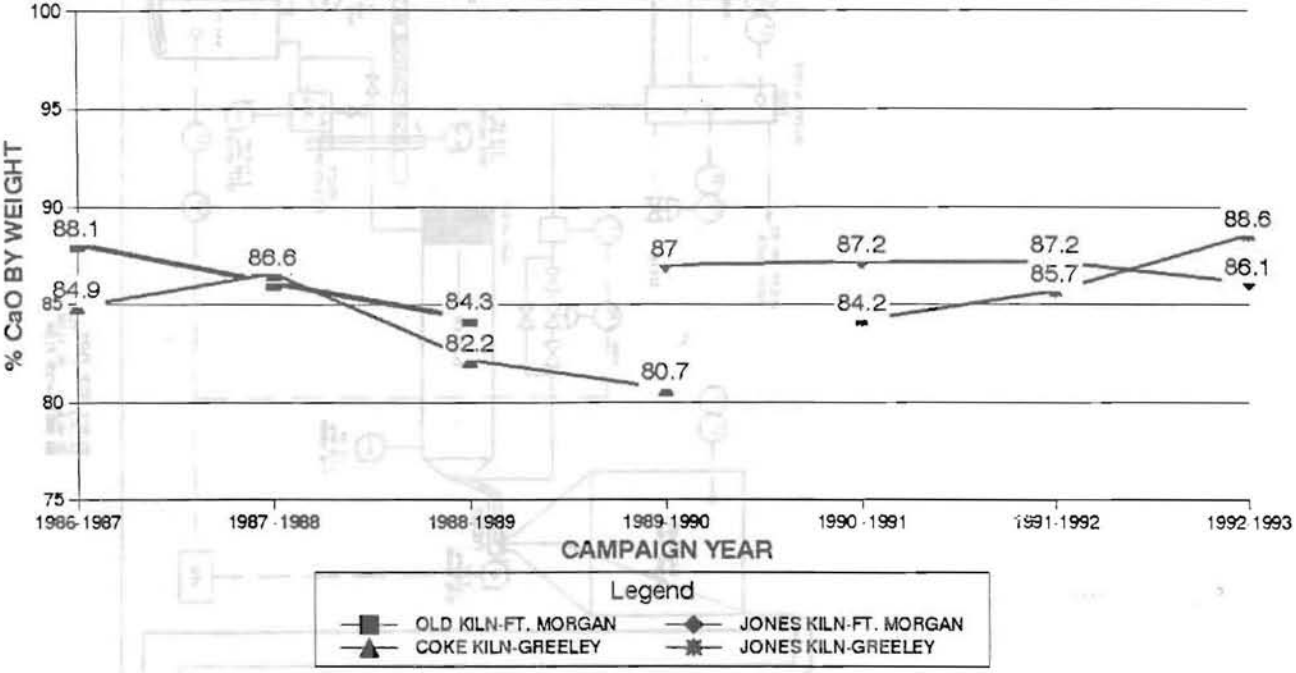


NOTES:
1. ALL HH TEMPERATURE ALARMS ARE INTERLOCKED TO THE PLC.
2. COOLING PUMPS WILL BE INTERLOCKED TO PLC WITH HOA SWITCH


LOCK HOPPER
SURGE HOPPER
ROCK DISTRIBUTOR
AIR/GAS DISTRIBUTORS
SKIP HOIST
SKIP GEAR BOX
PLC
COUNTER
LIC
LT
TT
TI
HTA
HHTA
25 HP 1175 RPM TEFC MOTOR
RAW ROCK TANK
FINES SCREEN
ROCK BELT
ROCK SCALE
SPALLS BELT
3/4 HP 1725 RPM TEFC MOTOR
5 HP 1750 RPM TEFC MOTOR
7.5 HP 1740 RPM TEFC MOTOR
2 HP 1730 RPM TEFC MOTOR
3/4 HP 370 RPM TEFC MOTOR
VIBRATORY CONVEYOR
CALCINED ROCK ELEVATOR
3 HP 1730 RPM TEFC MOTOR
CALCINED LIME TANK
LT
LI
FEEDER
2 HP 1730 RPM TEFC MOTOR
VFD
SLACKER
CLASSIFIER
7.5 HP 1770 RPM TEFC MOTOR
RATIO
FIC
FT
STEAM
TIC
SWEET WATER TANK
OVERFLOW TO MAIN LIMER
LT
LLA
LC
MAKE UP
TEMPERED WATER MAKE UP
SWEET WATER FROM PROCESS
1/2 HP 1725 RPM TEFC MOTOR
1 HP 1730 RPM TEFC MOTOR
TO DISCARD PILE
DISCARD CONVEYOR BELT
FINES CONVEYOR
FINES SCREEN
3 1/2 HP 1160 RPM TEFC MOTOR
5 HP 865 RPM TEFC MOTOR
OVERFLOW FROM HOWARD FEEDERS
MILK OF LIME TANK
TO MAIN LIMER AND PRELIMER HOWARD FEEDERS
DT
10 HP 1745 RPM TEFC MOTOR
MILK OF LIME PUMPS
RAW ROCK FLOW
CALCINED LIME FLOW
MILK OF LIME FLOW
SWEETWATER FLOW

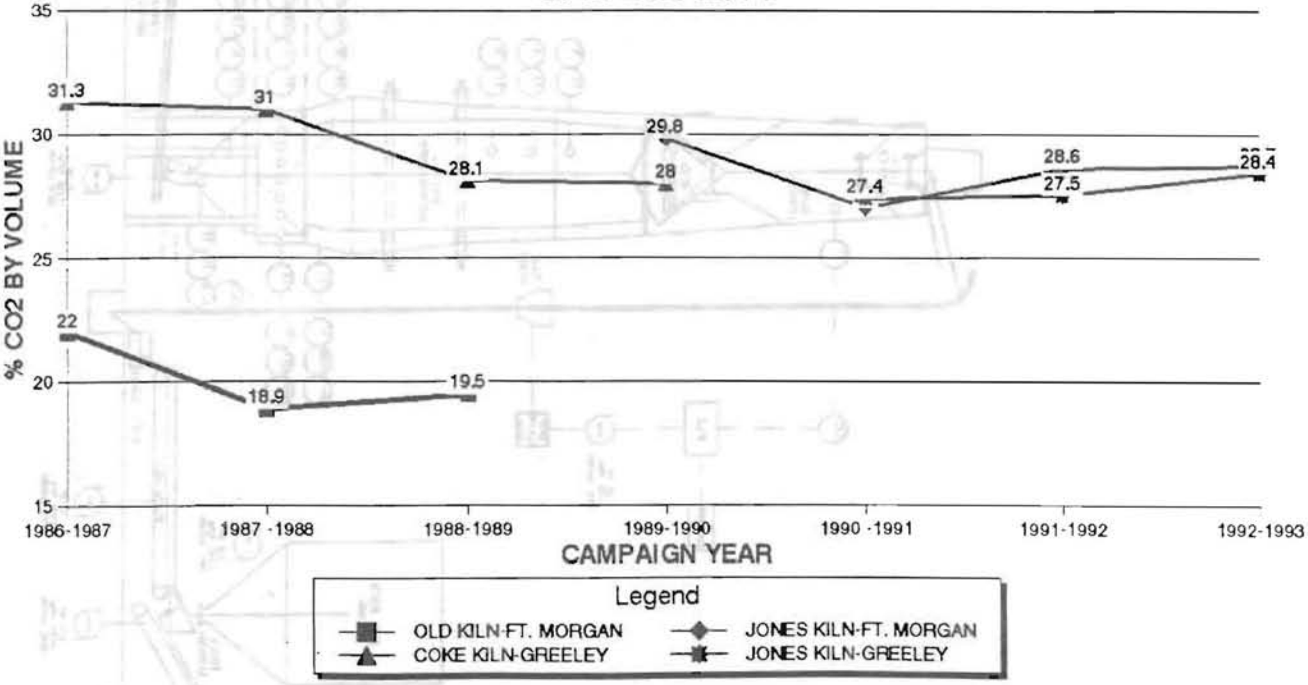
LIME KILN OPERATING DATA

LIME QUALITY



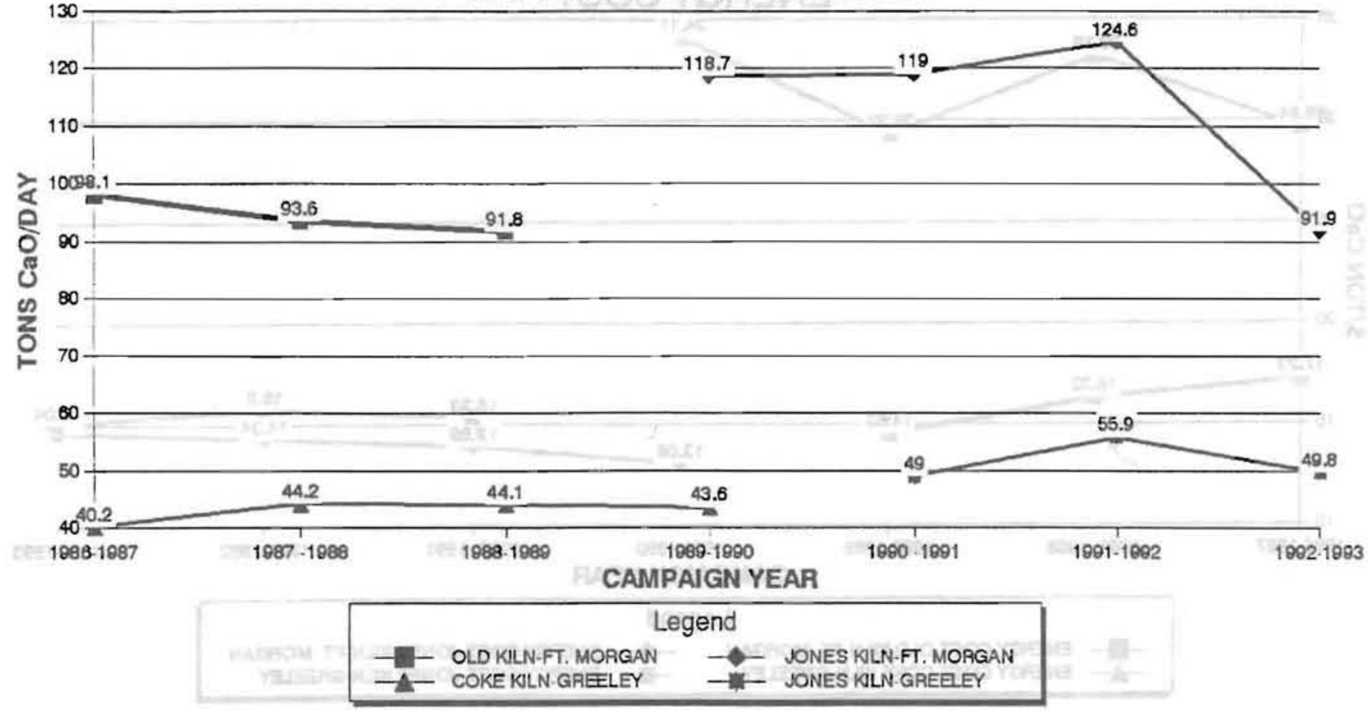
LIME KILN OPERATING DATA

GAS QUALITY



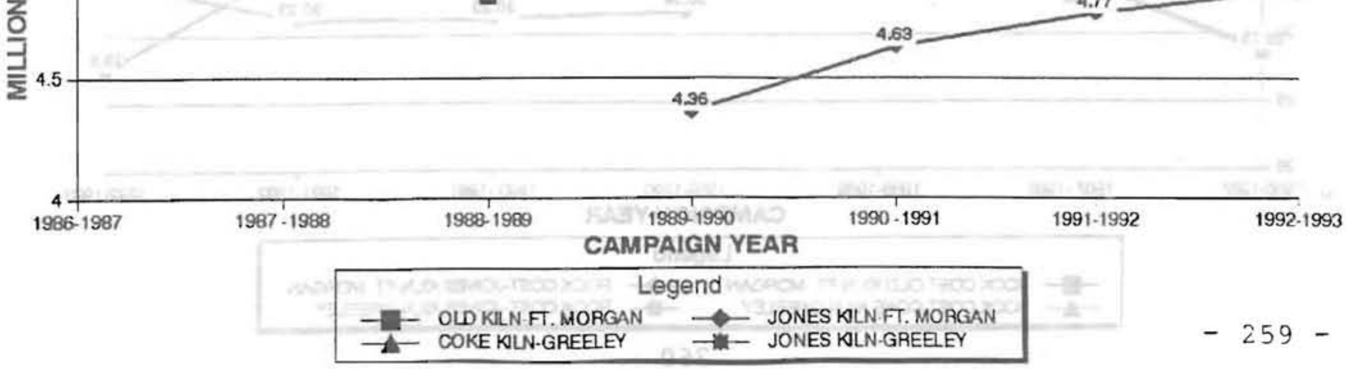
LIME KILN OPERATING DATA

CAPACITY COMPARISON

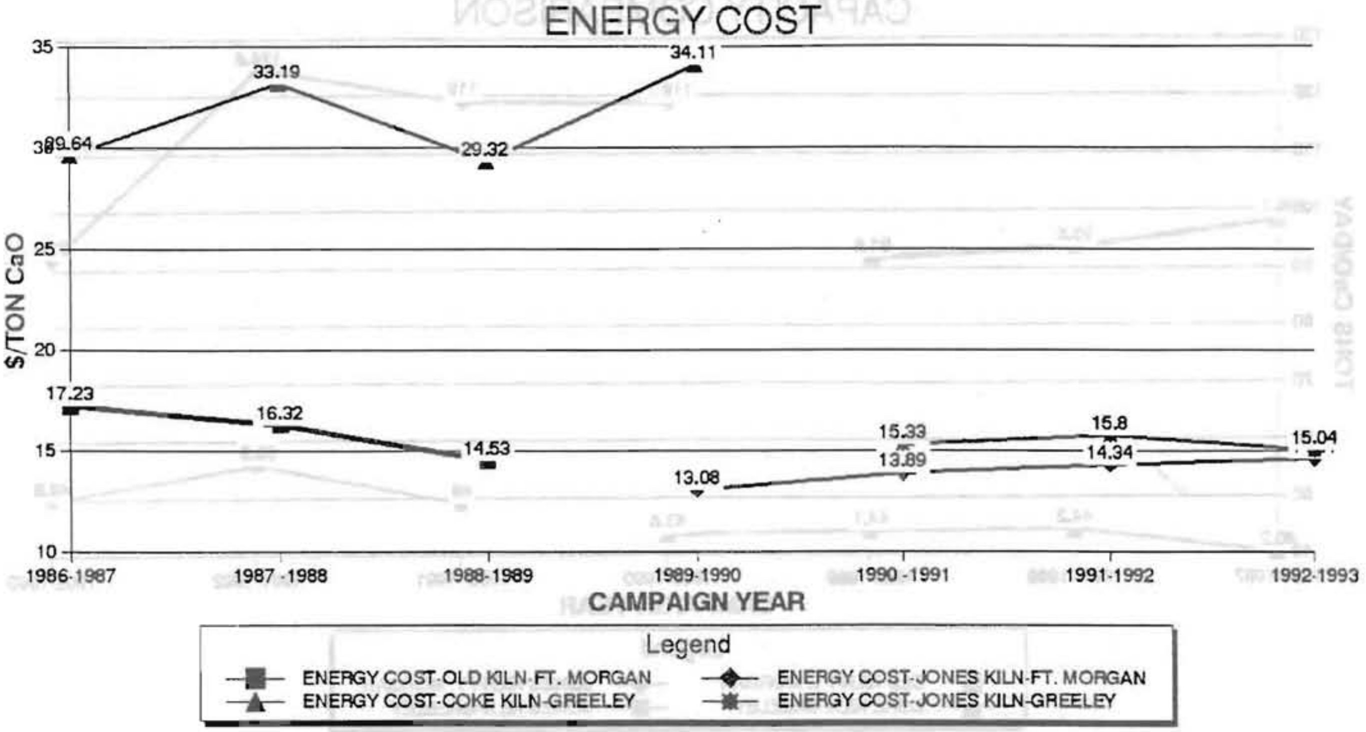


LIME KILN OPERATING DATA

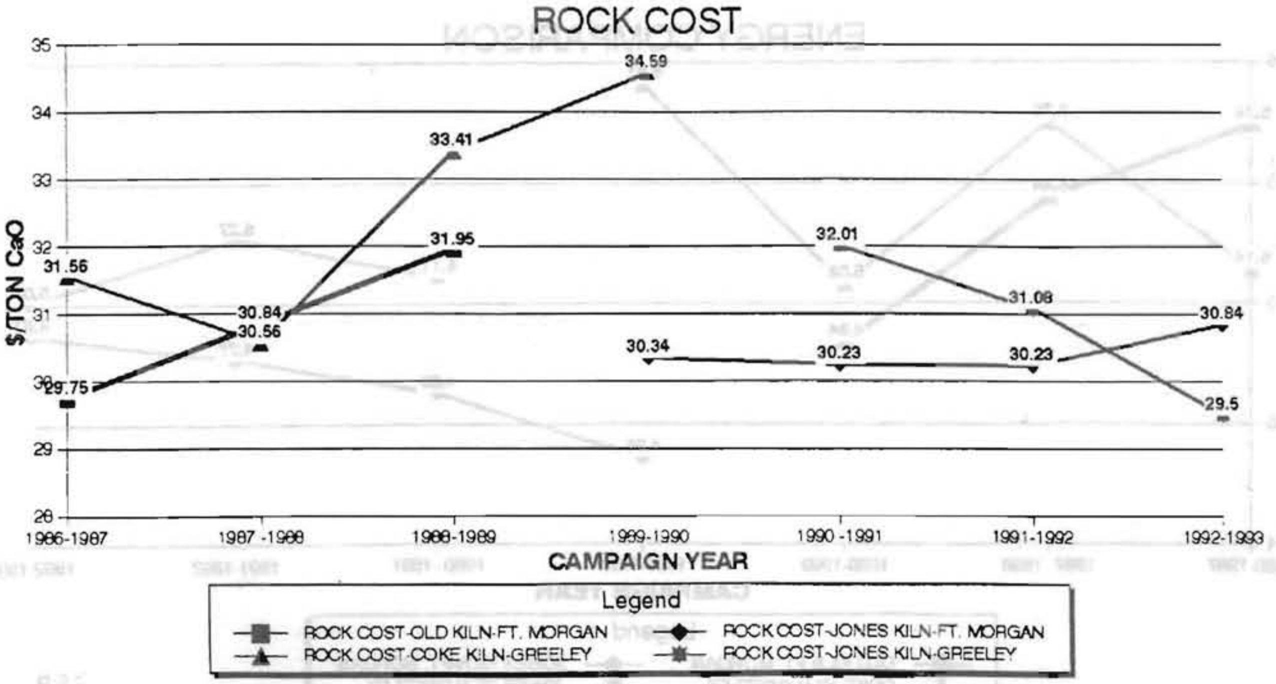
ENERGY COMPARISON



LIME KILN OPERATING DATA

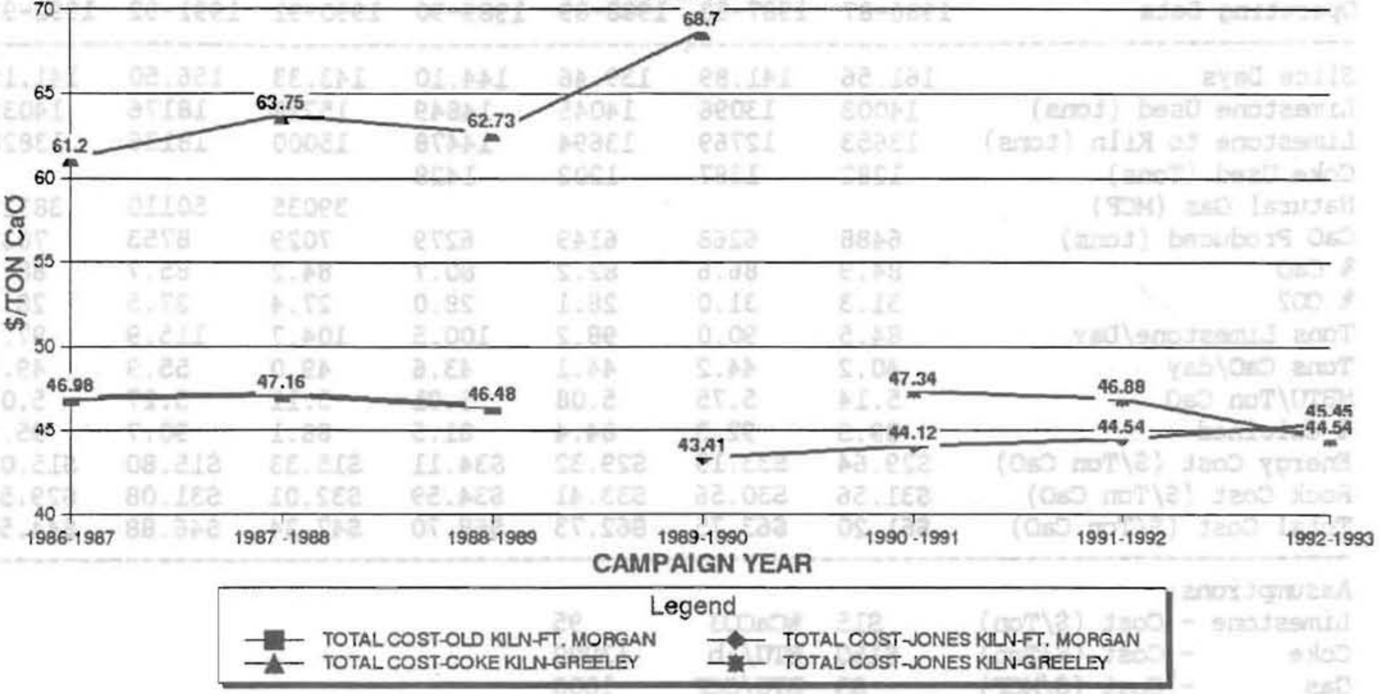


LIME KILN OPERATING DATA



LIME KILN OPERATING DATA

TOTAL COST



The Western Sugar Company
Greeley Factory

Lime Kiln Operating Data

Operating Data	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93
Slice Days	161.56	141.89	139.46	144.10	143.33	156.50	141.19
Limestone Used (tons)	14003	13096	14045	14849	15228	18176	14039
Limestone to Kiln (tons)	13653	12769	13694	14478	15000	18136	13828
Coke Used (Tons)	1282	1387	1202	1428			
Natural Gas (MCF)					39035	50110	38325
CaO Produced (tons)	6488	6268	6149	6279	7029	8753	7032
% CaO	84.9	86.6	82.2	80.7	84.2	85.7	88.6
% CO2	31.3	31.0	28.1	28.0	27.4	27.5	28.4
Tons Limestone/Day	84.5	90.0	98.2	100.5	104.7	115.9	97.9
Tons CaO/day	40.2	44.2	44.1	43.6	49.0	55.9	49.8
MBTU/Ton CaO	5.14	5.75	5.08	5.91	5.11	5.27	5.01
% Calcined	89.3	92.3	84.4	81.5	88.1	90.7	95.6
Energy Cost ($/Ton CaO)	$29.64	$33.19	$29.32	$34.11	$15.33	$15.80	$15.04
Rock Cost ($/Ton CaO)	$31.56	$30.56	$33.41	$34.59	$32.01	$31.08	$29.50
Total Cost ($/Ton CaO)	$61.20	$63.75	$62.73	$68.70	$47.34	$46.88	$44.54

Assumptions:

Limestone	- Cost ($/Ton)	$15	%CaCO3	95
Coke	- Cost ($/Ton)	$150	BTU/lb	13000
Gas	- Cost ($/MCF)	$3	BTU/SCF	1000

Summary Table

Kiln Averages	Previous Kiln	Jones & Assoc.	% Change
Slice Days	146.75	147.01	
Limestone (tons)	13648	15655	
Coke Used (Tons)	1325		
Natural Gas (MCF)		42490	
CaO Produced (tons)	6296	7605	
% CaO	83.60	86.17	3.07%
% CO2	29.60	27.77	-6.19%
Tons Limestone/Day	93.3	106.2	13.80%
Tons CaO/Day	43.0	51.6	19.98%
MBTU/Ton CaO	5.47	5.13	-6.24%
% Calcined	86.88	91.46	5.28%
Energy Cost ($/Ton CaO)	$31.57	$15.39	-51.25%
Rock Cost ($/Ton CaO)	$32.53	$30.86	-5.12%
Total Cost ($/Ton CaO)	$64.10	$46.25	-27.84%

The Western Sugar Company
Fort Morgan Factory

Lime Kiln Operating Data

Operating Data	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93
Slice Days	156.60	140.81	142.50	147.89	152.83	154.83	140.78
Limestone Used (tons)	34099	29760	31527	31527	38558	40203	27606
Limestone to Kiln (tons)	30470	27090	27857	35489	36640	38890	26589
Natural Gas (MCF)	91889	74657	65991	79686	87720	95895	65587
CaO Produced (tons)	15362	13175	13080	17548	18182	19299	12931
% CaO	88.1	86.1	84.3	87.0	87.2	87.2	86.1
% CO2	22.0	18.9	19.5	29.8	27.0	28.6	28.7
Tons Limestone/Day	194.6	192.4	195.5	240.0	239.7	251.2	188.9
Tons CaO/day	98.1	93.6	91.8	118.7	119.0	124.6	91.9
MBTU/Ton CaO	5.74	5.44	4.84	4.36	4.63	4.77	4.87
% Calcined	94.8	91.4	88.3	92.9	93.3	93.3	91.4
Energy Cost ($/Ton CaO)	$17.23	$16.32	$14.53	$13.08	$13.89	$14.31	$14.61
Rock Cost ($/Ton CaO)	$29.75	$30.84	$31.95	$30.34	$30.23	$30.23	$30.84
Total Cost ($/Ton CaO)	$46.98	$47.16	$46.48	$43.41	$44.12	$44.54	$45.45

Assumptions:

Limestone - Cost ($/Ton)	$15	%CaCO3	95
Gas - Cost ($/MCF)	$3	BTU/SCF	1000

Summary Table

Kiln Averages	Previous Kiln	Jones & Assoc.	% Change
Slice Days	146.64	149.08	
Limestone (tons)	31795	34473	
Natural Gas (MCF)	77512	82222	
CaO Produced (tons)	13872	16990	
% CaO	86.17	86.88	0.82%
% CO2	20.13	28.53	41.68%
Tons Limestone/Day	194.1	229.9	18.43%
Tons CaO/Day	94.5	113.5	20.16%
MBTU/Ton CaO	5.34	4.66	-12.81%
% Calcined	91.48	92.73	1.36%
Energy Cost ($/Ton CaO)	$16.03	$13.97	-12.81%
Rock Cost ($/Ton CaO)	$30.85	$30.41	-1.42%
Total Cost ($/Ton CaO)	$46.87	$44.38	-5.32%