The Design, Operation and Economic Evaluation of a Gas-Fired Lime Kiln

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The common objective of all our company activities is to make a profit. In 1958 a survey of our operations at Nyssa and Nampa indicated that it would be profitable to increase our Steffens capacity at Nyssa. This was brought about by our increase in beets sliced at our Nyssa and Nampa factories, and the subsequent upset in molasses balance.

The increase in Steffens capacity called for:

One new cooler

Two additional saccharate drum filters 8' diameter by 12'

Two new carb drum filters 8' diameter by 14'

One new direct drum filter 8' diameter by 14'

One new lime kiln of about 72 tons capacity of lime per day.

The large difference in BTU cost between gas and coke fuel indicated that a gas-fired kiln should be investigated.

Gas fuel available showed the following analysis: Nitrogen .7%, Carbon Dioxide .8%, Methane 91%, Ethane 5.9%, Propane 1.6%, Heat content 1042 BTU per cubic foot, Specific gravity .61.

Calculations show the optimum CO_2 for complete combustion of the above gas in air is 11.86%. The optimum combustion in air for straight carbon is 21%.

Research indicated that Victor J. Azbe[2] held patent numbers on the most desirable firing methods. Mr. Azbe offered his center-firing method, or multiple level side firing. We were reluctant to try center firing because it involved a tunnel beam through the center of the kiln. We were of the opinion that we might have clinkering difficulties above the center beam. We compromised on Mr. Azbe's multiple level side firing[3].

When using Mr. Azbe's BTU figure of 5 million BTU's per ton of lime, the maximum possible CO_2 is 32% by volume which requires an absorbtion of 72% at carbonation when using all available gas from the kiln. For our coke-fired kiln this figure is 62%. Previous carbonation absorbtion figures of 72% allowed

us a margin for kiln draft control by paralleling both coke and gas kilns to carbonation.

A kiln cross section six feet wide by twelve feet long was selected. The width was limited to six feet due to the difficulty of obtaining gas penetration of the rock mass moving down the kiln. Gases have a tendency to rise vertically in the kiln. The 6×12 cross section of 72 square feet allows one square foot per ton of lime.

A rectangular steel shell was selected in place of an oval shell for the sake of simplicity. Figure 1 is a cross section of the kiln at the upper burner level. The use of the rectangular shell made it easier to sectionalize the brick work for easier repair which is standard practice in large soaking furnaces at the steel mills.

The inlet ports were sized to give a high inlet velocity. The ten lower ports were sized one and one-half inches square and twelve upper ports were sized two inches square. The $5/32''$ diameter gas jets were placed directly in front of the ports to force the gases into the kiln. This induces approximately one inch of additional draft across the ports. Normal gas pressure is five pounds on lower burners and eight to nine pounds on the upper burners. The normal flows are shown on Figure 3.

The next item was the selection of a suitable draw system. Three types were considered:

1. Vibrating chutes

2. A time volume system with a surge hopper to allow a sizeable draw at definite time intervals.

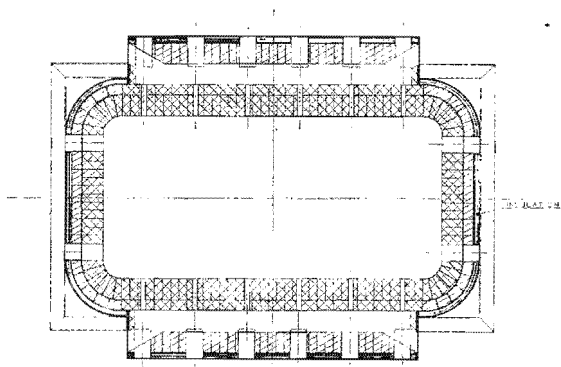3. A continuous volume displacement system with a step control.

Figure 1.—Upper burner cross-section, rectangular gas-fired lime kiln.

Number 3, shown on Figure 2 was selected because this system makes a metered draw on each chute and approaches continuous operation.

The system consists of a hydraulic pump with an unloading device. The lime is displaced by means of plate feeders actuated by hydraulic cylinders. The system is controlled by a stepping switch which is operated by a return stroke limit switch. The
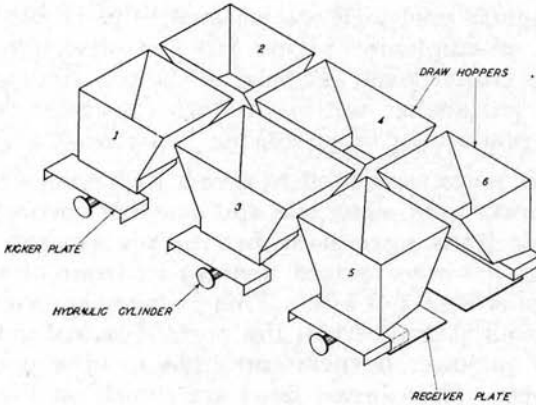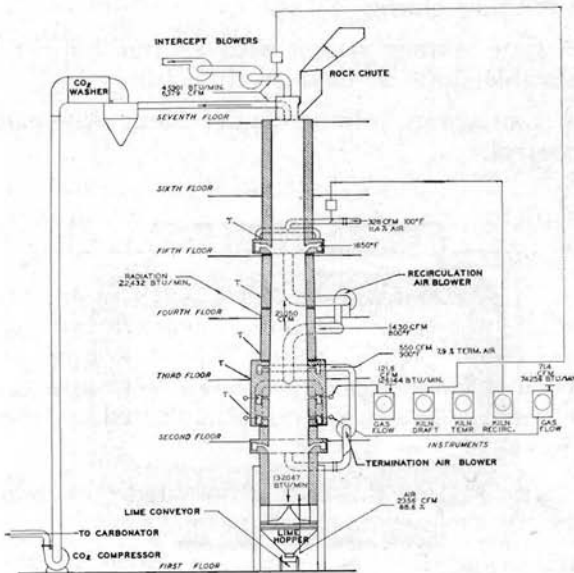

Figure 2.—Draw system.

Figure 3.—Rectangular gas-fired lime kiln.

draw chutes are sequenced by the stepping switch and draw in numerical order. Each draw cylinder has to complete its 8" stroke before the next chute starts. Draw rate is regulated by hydraulic flow control valves and the whole system is interlocked so that it stops or starts with the apron conveyor.

Previous research on the optimum burning time for Nyssa rock (size $3\frac{1}{2} \times 4\frac{1}{2}$) indicated an optimum burning time of 10 to 14 hours at 2,000 to 2,200° F. The calcining zone height was determined at 36 tons of CaO to allow 12 hrs. in the calcining zone.

A cross section of the lime kiln is shown in Figure 3. The lower ports are for air removal to the termination air fan. The second and third ports are the points at which the gas is introduced to the kiln along with the recirculation gases. Thirty-five to 40 percent of the gas is introduced at the lower burners and 60 to 65 percent is introduced at the upper burners. From 10 to 15 percent of the air required is introduced at the second and third port levels. At the fourth port level, heated air is admitted to terminate combustion. It is necessary to maintain uniform draw, draft and firing rate. If the draw rate is reduced, the fire zone will move up the kiln.

Instrumentation for the kiln consisted of two gas-flow recording meters; one for the twelve upper burners and one for the ten lower burners. The second instrument on the right (Figure 3) is a kiln draft recording controller which opens or closes the intercept damper to maintain the desired draft. The center instrument is a six point temperature recorder. By using a five point selector switch with each recording point, 30 temperatures can be measured in groups of six. The fourth instrument on the right is used to control and record the temperature of the re-circulation gases. This instrument also records the temperature of the exhaust gases from the kiln.

In order to check the level of rock in the kiln and thereby have a check on the draw system, we developed an automatic rock level recorder. This device consists of a long piece of shaft which is lowered into the kiln after each skip and automatically detects the rock level. The level is indicated on the first floor and recorded at a control panel.

At the present time the kiln is operated to produce 66 tons of lime per day.

Normal draft at kiln top   2.7" to 3" W.G.

Normal draft at recirculation outlet will be 2.5" to 2.8" W.G.

Normal Gases per Ton of Lime

Nitrogen   42,205 cubic feet @ 60° F.   30" H.G.
Carbon Dioxide   17,830 cubic feet @ 60° F.   30" H.G.
Oxygen   2,307 cubic feet @ 60° F.   30" H.G.
Water Vapor   8,540 cubic feet @ 60° F.   30" H.G.
Fuel to lower burners _____ ___ ___ __ _____ _____ ____ ___ 37%
Fuel to upper burners___ _____ ____ _ _____ _____ ___ __ 63%
Normal kiln outlet gas temperature   _____ 460 to 500° F.
Normal temperature at recirculation gas outlet   1650° F.
Normal recirculation temperature ___ ___ ___ _____ _____   800° F.

Kiln Heat Balance in BTU/min.

		BTU's per min.	Percent
Upper Burners		126,144	63%
Lower Burners		74,256	37%
Total Heat Input	(Item 1)	200,400	100%

Water Vapor Loss

480° F. and 60° F. reference 18.69 $\times$
    1130.4"   21,127   10.52%

Dry Products Loss

Nitrogen = 143.9 $\times$ .25 $\times$ (480-60 = 15,109   7.54%
Carbon Dioxide = 95.7 $\times$ .22 $\times$
    (480-60) =   8,843   4.41%
Oxygen = 8.9 $\times$ .22 $\times$ (480-60) =   822   .41%
Total vapor and dry gas loss   (Item 2) 45,901   22.88%

Heating and Calcining

175 lbs. $CaCO_3$ heated from 40° F. to
    1652° F. = 175 $\times$ .256 $\times$ 1612 =   72,218
Heat of dissociation at 1652° F. =
    91.7 $\times$ 1249[1] =   114,533
Post heating lime to 2200° F. =
    91.7 $\times$ .236 $\times$ (2200-1652) =   11,859
Total   198,610
Minus heat recovered from CO_2 (2200
    to 480) = 75.47% CO_2 from rock;
    72 lbs. $\times$ .25 $\times$ (1652-480) =   21,096

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[1] 1249 from Lime and Limestone, Part I, by N. V. S. Knibbs and B. J. Gee.

Difference   (Item 3)   177,514

Minus heat removed from 2200 ° F.
  of lime in cooler $= 91.7 \times .236$
  $\times 2100 =$ 45,447

Useful output   (Item 4)   132,067   66%

Radiation loss by difference: Item 5 $=$
  Item 1 minus 2 $+ 4 =$ 22,432   11.12%

Kiln efficiency $= \dfrac{132067}{200400} \times 100 =$ 66%

Kiln efficiency vapor removed $=$

$\dfrac{132067}{179273} \times 100 =$ 73.8%

This efficiency compares very favorably with gas kilns operating in the United States.

Another figure used for comparison between kilns is BTUs per ton of lime. For the Nyssa gas-fired vertical kiln this figure is 4.37 million BTUs per ton of lime, while gas-fired vertical kilns at Quincy, Illinois, run 4.8 million BTUs per ton of lime. A large company at Saint Genevieve, Missouri, operates fourteen gas-fired vertical lime kilns with a BTU figure of 5.8 to 6.0 million BTU per ton of lime. Gas-fired vertical lime kilns designed by Mr. Azbe at Branchton, Pennsylvania, achieve a figure of 4.2 million BTUs per ton of lime.

The highest efficiency figure for coke-fired kilns is 81% for a vertical kiln in Germany. This compares with 68.4% for our Nyssa coke-fired kiln and 73.5% for our Nampa coke-fired kiln.

The additional labor required of the gas-fired kiln over a comparable coke-fired kiln amounts to one man on the day shift. The cost of the gas-fired lime kiln over a coke-fired lime kiln amounted to approximately $46,000. The saving of gas over coke follows:

	1959	1960
Coke cost per therm	11.72¢	12.23¢
Coke in million BTU per ton rock	2.1	2.17
Gas in million BTU per ton rock	2.43	2.29
Coke cost per ton rock	$2.46	$2.57
Gas cost per ton rock	$ .84	$ .79
Saving per ton rock	$1.62	$1.78
Tons rock through gas kiln	16,750	17,000 (est.)

The additional cost of the gas-fired lime kiln over the installation of a comparable coke-fired lime kiln has been realized in fuel saving. It would be possible to use gas entirely in place of coke with suitable kiln, compressor and carbonator design.

Acknowledgments

Figures 1, 2 and 3.

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J. H. Grantham—Kiln Charging System and Piping Detail,

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