CASE STUDY:
MULTIPLE FUEL FIRING IN A LIME KILN

Kenneth A. Camino
Coen Company, Inc.
1510 Rollins Road
Burlingame, CA 94010 • USA
Phone: (415) 697-0440
Fax: (415) 579-3255
e-mail: kcamino@coen.com

Pierre Begin
Coen Canada, Inc.
226 Rue Roy
St. Eustache, Québec J7R 5R6 • Canada
Phone: (514) 472-7922
Fax: (514) 472-3350
e-mail: pbegin@coen.ca

Scott A. Drennan
Coen Company, Inc.
1510 Rollins Road
Burlingame, CA 94010 • USA
Phone: (415) 697-0440
Fax: (415) 579-3255
e-mail: sdrennan@coen.com

ABSTRACT

Lime recovery kilns have widespread use throughout the world as part of the Kraft pulping process in the paper industry. Burners used in kilns face unique requirements including flame shaping for best product quality and the ability to accommodate waste incineration. This paper presents a case study for the development and demonstration of a multiple-fuel burner for retrofit on a lime recovery kiln. The kiln burner uses residual oil as its base fuel and turpentine as a supplementary fuel. Additionally, stripper-off gas and non-condensable gases are fired in the kiln for destruction. A specially designed kiln burner, rated at 65 MBtu/hr, was developed for co-firing of these multiple fuels while maximizing the quality and quantity of the lime product. Computational fluid dynamics (CFD) was used in the burner design process to guide the positioning of the kiln burner and the waste gas lance, and to visualize the expected flame shape. The CFD model featured two-phase droplet combustion of simulated residual oil and turpentine, radiation heat transfer, and standard k-ε turbulence models. A step-down dual-zone air inlet system was used in the burner design. The paper concludes with operating performance from the kiln start up process.

INTRODUCTION

Lime recovery kilns are used in the paper industry as an integral part of the Kraft process of pulp processing. The interlocking cycles of the Kraft process[1] are shown in Figure 1, with the role of the lime recovery kiln highlighted in the grayed region. Pulp is produced by pressure cooking wood chips in a solution of white liquor, which is a mixture of NaOH and Na_2S. At the completion of this process, the residue washed from the pulp—called black liquor—is further processed into a substance known as green liquor by burning the organic materials from it. The liquor cycle is closed by adding $Ca(OH)_2$ to the green liquor, which chemically reacts (causticizes) to form mixture of white liquor and lime mud, or $CaCO_3$. When the lime mud is dried and heated in the lime recovery kiln, it oxidizes to form lime (CaO). The solid cycle is closed by adding water to the lime, then heating and agitating it in the slaking process to form $Ca(OH)_2$. The primary purpose of the lime kiln is to recover lime from the calcium carbonate lime mud in a heating and drying process known as calcination.

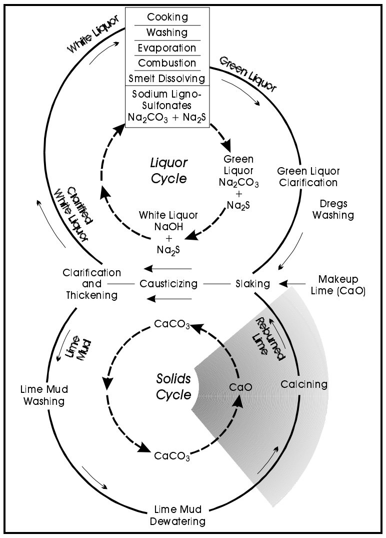


Figure 1. The Kraft process cycle.

Lime kilns also have a secondary purpose, which is to incinerate waste gases that are evolved in the Liquor Cycle shown in Figure 1. Byproduct gases formed in these processes (methanol and various sulfur compounds) must be destroyed, and the lime kiln provides an ideal environment to do this because of the high temperatures and long residence times involved. As an added benefit, the waste gases often have a significant heat content so that reduced usage of the primary fuel is sometimes allowed.

In general, a lime kiln is a very large device consisting of a long, slightly inclined, rotating cylinder usually around 10 feet (or more) in diameter and about 300 feet in length. At the raised end kiln, a wet mixture of calcium carbonate, called the lime mud, is fed into the kiln where drying and chemical reduction can take place. At the lower discharge end of the kiln, the highly specialized kiln burner produces a long, narrow flame which is necessary for drying, heating, and calcining the lime product. Lime kilns frequently have a dam near the discharge end to ensure that complete calcination occurs. In addition, lime kilns often have planetary coolers which serve to cool the discharged lime and to preheat the secondary combustion air. An example of planetary coolers arrayed around the barrel of an under-construction lime kiln[2] is shown in Figure 2.

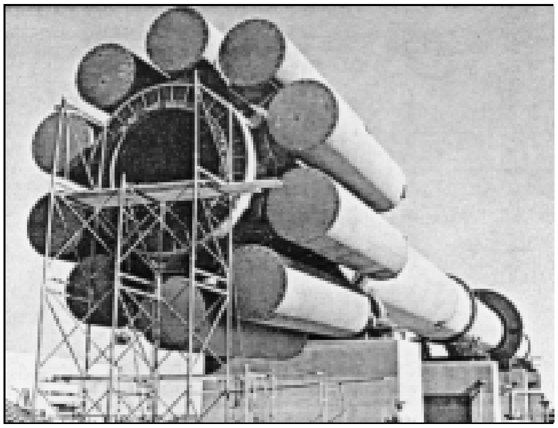


Figure 2. Lime kiln with planetary coolers.

Designing and positioning the burners necessary for firing multiple fuels into a lime recovery kiln requires attention to the specific kiln geometry. Proper flame shaping is very important, because irregular heating patterns can lead to poor product quality, inefficient performance, or even more serious problems like damage to the kiln's refractory lining. Consequently, each kiln burner installation requires some insight into the position of the kiln burner itself, as well as any waste gas burners. For this reason, modeling is used to obtain an initial estimate of the burner locations prior to installation. Fine-tuning of the positions can be done at start-up.

In this particular case study, the lime recovery kiln is used to simultaneously fire as many as four different fuels at one time. The kiln is operated by a paper mill in eastern Québec. This mill had experienced poor flame shape and high refractory wear in the past, and they were looking to retrofit the kiln with a new kiln burner, as well as installing a new waste gas burner. This particular kiln has an internal diameter of 8'-10" and a total length of 250 feet, and is inclined at a slope of 3/8" per foot (1.8°). The kiln has six planetary coolers, and an 11"-high dam that is 9'-8" from the burner-end of the kiln. The kiln rotates at approximately 2 RPM.

The kiln is used to fire a variety of fuels, including Number 6 residual oil, turpentine, stripper-off gas (SOG) and concentrated non-condensable gases (NCG). The residual oil and turpentine are fired through the main kiln burner, while the SOG and NCG are fired through an auxiliary waste gas burner. There are a number of combinations in which these fuels can be used, all of which are summarized in Figure 3. The first combination shown in this figure (A) is the startup condition, where residual oil is fired at 3 MBtu/hr. For the remaining six combinations, the total firing rate is 65 MBtu/hr and consists of firing with residual oil either alone or in some combination with the other fuels.

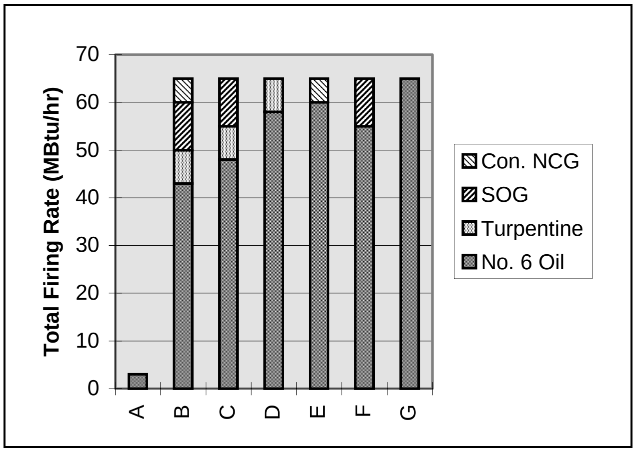


Figure 3. Fuel combinations.

The kiln burner will fire between 77 and 100 percent of the total kiln load. In addition, about 15 percent of the stoichiometric air flow is passed through the kiln burner. This is the primary combustion air. The remaining combustion air (i.e., secondary air)—including excess air—is passed through the planetary coolers where it is preheated to about 600°F.

BURNER DESIGN

The kiln burner used on this project is a Coen step-down Dual Air Zone burner. In this design, primary combustion air is split into two individually-controlled streams. The inner stream, or core zone, passes through a spinner to provide the angular momentum necessary to ensure flame stabilization. The outer zone provides the remaining combustion air as well as cooling for the burner air tube. By adjusting the flow split between the two zones, optimum flame-shaping can be achieved. Generally, the kiln burner is configured so that about one-third of the primary air flow passes through the core and the remaining two-thirds passes through the annulus. This burner design has proven to be extremely versatile in various kiln applications because it allows the operator to make adjustments to the flame shape by changing the air flow proportions. The result is a high-quality lime product. An example of a two-gun step-down burner is illustrated in Figure 4. The kiln burner is ignited using a gas/electric pilot.

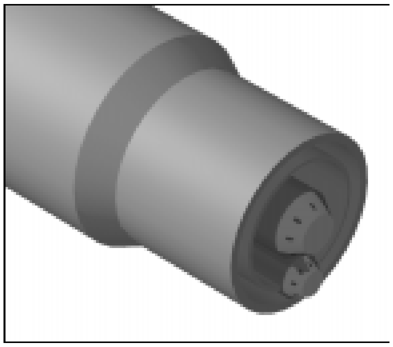


Figure 4. Step-down kiln burner.

Residual oil and turpentine are fired through the kiln burner using Coen steam-atomized burner guns. The atomizer in these guns is a multi-venturi nozzle, with primary atomization taking place inside the nozzle and final atomization taking place after the mixture of pre-atomized oil and steam emerges from the nozzle cap. The nozzle caps are custom-drilled for each individual job, thereby producing a tailored flame shape.

The residual oil gun is a Coen 2MV burner gun assembly and is located on the centerline of the kiln burner. It has the capability of providing the full-firing capacity of the kiln (65 MBtu/hr) and has an 8-to-1 turn down. The Number 6 fuel oil has a heat content of 145,000 Btu/USgallon and is supplied at 150 psig and 200 SSU at the train inlet. The maximum oil flow rate is 7.5 USGPM with 130 psig at the gun inlet. The required atomizing steam flow for this gun is 700 lb/hr at 140 psig at the gun inlet.

The turpentine gun is a Coen 1MV burner gun assembly and is located 3.25 inches below the centerline of the oil gun. The turpentine has a heat content of 17,200 Btu/lb and a specific gravity of 0.86. The maximum turpentine flow rate is 1.0 USGPM with a gun inlet pressure of 50 psig. The required atomizing steam for this gun is 100 lb/hr at 65 psig at the gun inlet.

The waste gas gun is a water-jacketed lance next to the burner that is used to inject Stripper-Off Gas (SOG) or concentrated Non-Condensable Gases (NCG), or both. The SOG is a typical waste gas resulting from the pulping process and consists mostly of methanol that is mixed with conveying steam. The NCG is mixture of various of sulfur compounds mixed with conveying air and steam. Depending on the firing conditions (as shown in Figure 3), the waste gas gun can provide up to 23 percent of the total firing capacity of the kiln.

MODELING APPROACH

At the request of the customer, modeling of this kiln was required prior to installation of the retrofit burners. In recent experiences, Coen Company has had successful results simulating kiln flames through the use of Computational Fluid Dynamics (CFD). This approach utilizes a computer to obtain a numerical solution to the mathematical equations governing the physical processes within the kiln. Prior to the availability of CFD, physical models using water or air provided designers with a limited tool, but could not accurately predict the heat transfer mechanism or flame shape characteristics within the kiln. However, the continual improvements in both computers and CFD codes has made the computer modeling approach more viable in recent years. Through the use of this numerical technique, all the major mechanisms including fluid flow, heat transfer, and combustion effects are taken into consideration—without the costs involved in building scale models for physical modeling.

The CFD software used for the numerical analysis is Fluent/UNS Version 4.1. The code[3] works by first constructing a geometrical representation of the volume of interest, called the computational domain, which is then subdivided into a large quantity of control volumes, or cells. For each of these cells, the code simultaneously solves the governing fluid dynamic equations of continuity, momentum (Navier-Stokes equations), and energy to obtain a steady-state solution. Velocity and pressure coupling are resolved via the Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm. Turbulence closure is obtained using the well-understood standard k-ε turbulence model. The turbulent boundary layer conditions for momentum and heat transfer in the near-wall region follow the logarithmic law of the wall. Where possible, buoyancy effects were also included for completeness.

The transport equation for energy is solved using a conjugate heat transfer model, with radiative heat fluxes calculated by solving additional conservation equations. Fluent offers a variety of radiation models, but in this case the P-1 submodel was selected because it allows interaction between the liquid droplets and the gas phase. In addition, species-dependent radiative properties were used. Gas phase combustion was modeled using a PDF-based mixture fraction approach, with user-specified fuel and oxidant components reacting to form combustion products. Oil and turpentine combustion were simulated by the injection of individual droplets that are tracked as a discrete phase within the CFD code. The droplets interact with the gas phase through momentum transfer, heat transfer, and evolution of volatile constituents through evaporation.

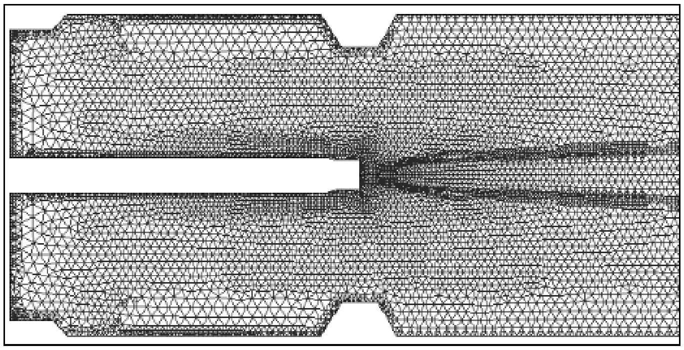


Figure 5. Triangular mesh used in the 2-D analysis.

Computer modeling was used to estimate the positions and orientations of both burners within the kiln. In order to reduce the complexity and solution time of the modeling effort, some simplifying assumptions and strategies were made. First, only the burner end of the kiln (about 80 feet) was modeled since this is where all the combustion effects take place. This dramatically reduces the size and solution time of the model. Second, the combustion process was simplified by assuming that all gaseous fuel species introduced into the model, including the gas evolved from the liquid oil droplets, consists of pentane (C_5H_{12})—an assumption that also satisfies some of the limitations of Fluent's combustion submodels. The location of the kiln burner was determined through a separate modeling effort by temporarily ignoring the effects of the waste gas gun and locating the burner on the centerline of the kiln. This allowed the kiln to be simulated as a two-dimensional axisymmetric problem rather than the far more complex three-dimensional approach. In this way, the axial position of the kiln burner was determined far more rapidly.

For the two-dimensional model, an unstructured triangular mesh was constructed for use by the Fluent solver. Figure 5 shows a portion of this grid, although only the top half of the mesh was used by the model; the lower half is a graphical mirror-image of the top. Note that adaptive mesh refinement was used to increase the cell density in the vicinity of the flame front, thus providing a more accurate solution.

Once the axial position of the kiln burner was established, a three-dimensional representation of the kiln (i.e., the lower 50 feet) was created to examine the effects of the waste-gas lance and the effects of tilting the kiln burner. The use of this model, in conjunction with design restrictions on the burner position, helped to determine the best location of the waste gas gun. From this model, flame shape estimates were presented to the customer.

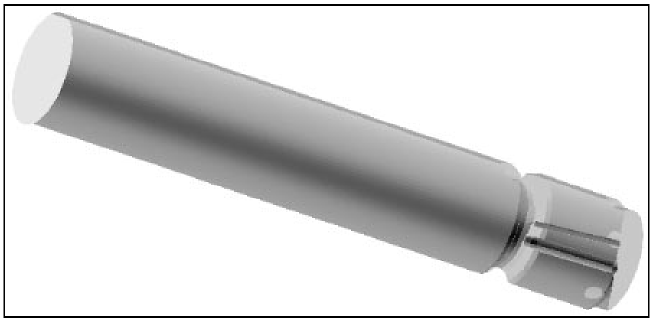


Figure 6. Surfaces of the 3-D model.

For the three-dimensional model, a far more complex (although coarser) grid was created. This mesh utilizes the more computationally efficient six-sided brick-shaped elements. The mesh includes individual inlets for the gaseous fuel and air inlet zones, a tilting kiln burner, and a tilted off-axis waste gas gun. The actual locations and tilt angles of the two burners were modified from one computer run to the next. Figure 6 shows the surfaces of the model's grid, where half the kiln walls have been removed (for illustration purposes) to show the internal components. Figure 7 shows the surface features of this mesh at the burner-end of the kiln model, where the use of brick-shaped elements is more apparent. In this figure, the secondary air inlets (i.e., the flow out of the planetary coolers) is shown as the lighter colored circles around the circumference of the cylinder. The kiln burner can be seen as the indentation/hole near the centerline of the kiln, and the waste gas lance is the indentation just slightly above it.

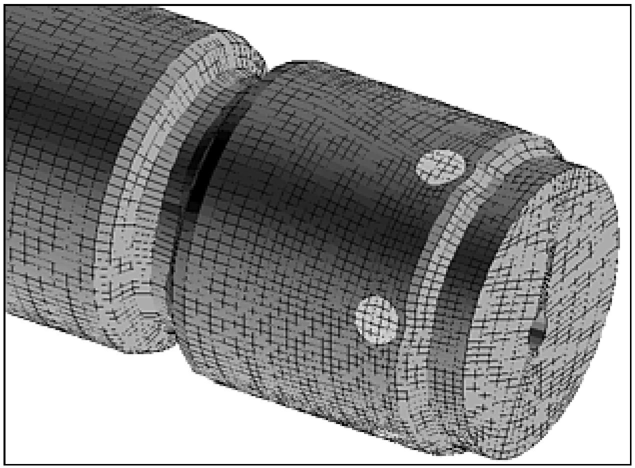
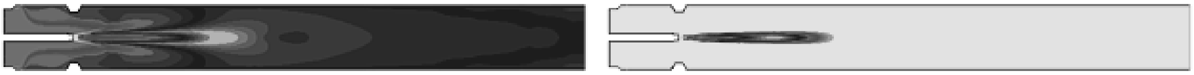


Figure 7. Detail of surface mesh for the 3-D model.

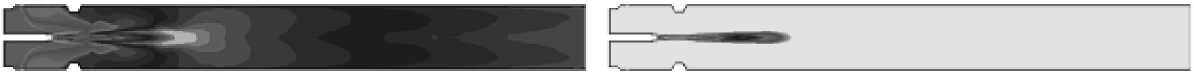
MODEL RESULTS

In the first part of the study, the position of the kiln burner was established. Three possible burner positions were examined to try to bracket the preferred location. Based on past experience, the estimated best position would have the tip of the burner placed in the narrowest part of the dam section, or just slightly behind it. Consequently, the first of the three positions that were examined had the burner located with its tip at the feed-end edge of the dam's crest. The second burner position was equivalent to retracting the burner 3 feet from its initial position, and the third position was another 3 feet behind that.

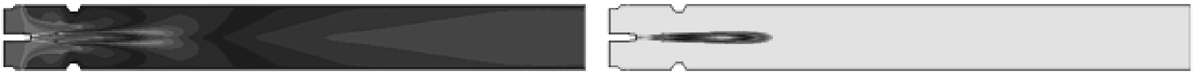
The results of the two-dimensional analysis are shown in Figure 8, where temperature distributions are shown on the left and CO concentrations are shown on the right. The distribution of CO is used to illustrate the approximate flame shape. Because these are axisymmetric models, the flame remains aligned on the kiln centerline; off-axis effects such as burner tilt or buoyancy are not included. Based on these results, it was determined that the optimum location would be approximately 3 feet behind the dam. In the case where the burner was 6 feet behind the dam, the flame was too wide as it enters the dam section, leading to the possibility of major damage to the kiln. In the case where the burner tip is located within the dam section, the majority of combustion takes place well beyond the dam, so there is likely to be inadequate heating of the lime product that builds up at the base of the dam. Furthermore, there is no benefit derived from the air flow expansion caused by the dam, which can contribute significantly to the flame shaping. Therefore, the selected location is just slightly behind the dam.



Temperature with Burner at the Crest of Dam *Flame Shape with Burner at the Crest of Dam*



Temperature with Burner Retracted 3 feet *Flame Shape with Burner Retracted 3 feet*



Temperature with Burner Retracted 6 feet *Flame Shape with Burner Retracted 6 feet*

Figure 8. Results of two-dimensional CFD analysis.

The next stage of the modeling effort involved creating the three-dimensional grid (as shown in Figure 6) and finding the correct positions and orientations of the kiln burner and the waste gas gun. In these sets of models, the firing conditions corresponding to Combination “B” in Figure 3 were used for the two burners. The first case that was run had the kiln burner located on the centerline of the kiln and oriented parallel to the centerline. The waste gas lance was oriented parallel to the kiln burner and offset by 2 feet above it. The results of this configuration are shown in Figure 9 and illustrate what can happen if the burners are not correctly installed. The waste gas does not sufficiently penetrate into the kiln, and consequently a significant amount of combustion takes place at the top of the kiln immediately behind the dam. This would most certainly cause rapid refractory wear.

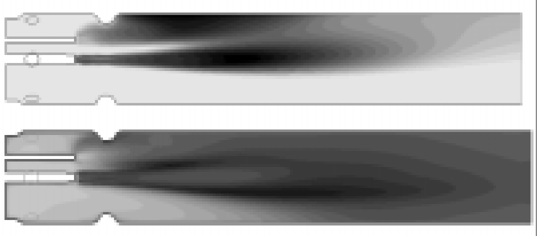


Figure 9. CO concentration (top) and temperature distribution (bottom) for trial configuration.

When the final configuration was obtained, the results were as shown in Figure 10. The kiln burner is placed so that it is parallel to the ground (i.e., tilted 1.8° downward from the kiln centerline). The kiln burner is also mounted 6 inches off the kiln centerline in the direction of the lime bed. This allows more room for the SOG gun at the top of the kiln. The waste gas gun is 6 inches shorter than the kiln burner and is offset from the kiln burner by 2

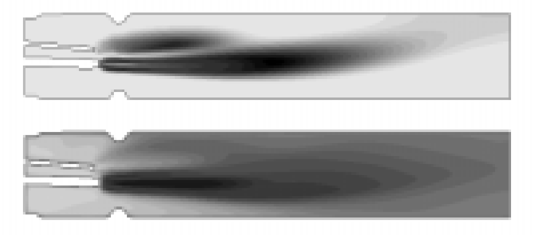


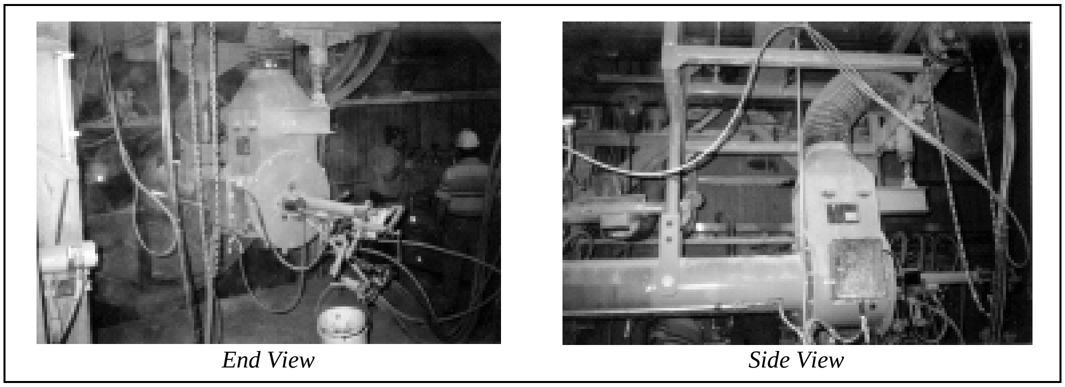
Figure 10. CO concentration (top) and temperature distribution (bottom) for final configuration.

feet in the direction opposite of the lime bed. In addition, the waste gas gun is tilted at a 5° angle toward the kiln burner.

Based on the CO concentrations shown in the 50-foot length of model in Figure 10, the kiln burner flame is about 35 to 40 feet in length (measured from the tip of the kiln burner). The flame bends upward at its end due to buoyancy effects. The waste gas burns above the main kiln burner flame as a cooler, separate flame and is about 15 feet in length. At no point is the refractory exposed to excessively high temperatures, and the lime bed at the bottom of the kiln is exposed to fairly consistent temperatures over the length of the main flame.

FIELD RESULTS

Unfortunately, at this time there is only a limited amount of anecdotal information available from the installation site. Shortly after the new burners were installed in late 1996, the kiln started to experience various problems at the feed end (unrelated to the burner operation), such as broken feed screws and problems in the lime mud filtering system. Reports from the kiln area manager indicate that prior to the feed system problems, the burner was working properly with all the desired reliability and flexibility. The mill batch-burns its turpentine every other day, a procedure that saves a lot of fossil fuel energy while incinerating the unwanted turpentine at the same time.



End View

Side View

Figure 11. Installation of the kiln burner and waste gas gun.

Photographs of the installation are shown in Figure 11. Before the installation of the new kiln burner, the kiln was producing 80 to 82 percent heat availability with good material quality. After the new burner was installed, the heat availability was found to have increased to about the 92 percent level, while the quality of the lime (color and texture) was also improved. The waste gas burner also appears to function well, although the waste gases to not have as high an energy content as was originally believed. Still, the lime kiln is a excellent facility for incinerating these unwanted gases.

SUMMARY

In this case study, a lime recovery kiln was retrofitted with equipment for firing multiple fuels. Specifically, a custom-designed kiln burner was installed with the capability of firing the liquid fuels, which consist of either heavy residual oil or turpentine. A separate waste gas gun was designed to fire and incinerate the waste gases, which consist of SOG and concentrated NCG.

Computer modeling was used to determine the positions and orientations of both the kiln burner and the waste gas burner relative to the kiln's internal contours. The results of the computer modeling simulated the conditions within the kiln, and helped to depict information that would otherwise be impossible to obtain at the actual installation. By making close initial guesses for the burner locations based on the experiences of design engineers, the modeling process was greatly streamlined. Through the use of computer modeling, an improper burner configuration could be clearly shown and modifications to the design could be made accordingly. Modeling allowed the kiln burner to be built and installed with a minimum amount of *in situ* hardware modifications.

Information from this study was used to establish the final design of the burners, and was also used in determining the positions of the burners at installation. The result was a trouble-free start-up with satisfactory performance in the actual kiln. Although limited, the reports from the field site indicate improved performance of the kiln burner (increased availability) and improved quality of the lime product.

REFERENCES

[1] The Babcock & Wilcox Company, *Steam*, 40th Edition, 1992.

[2] Douglas J. Kramm, "1984 Update on Lime Sludge Kilns in the Pulp Mill Environment", 1984.

[3] Fluent Incorporated, *User's Guide for Fluent/UNS & Rampant*, Release 4.0, April 1996.