# REPORT

# ON A US DEPARTMENT OF ENERGY SPONSORED STUDY

## TO DETERMINE THE

## APPLICABILITY AND EFFECTIVENESS

## OF THE

# DELTA T DRYER/MOISTURE CONTROL SYSTEM

## IN CONTROLLING
## A
## LIME MUD KILN

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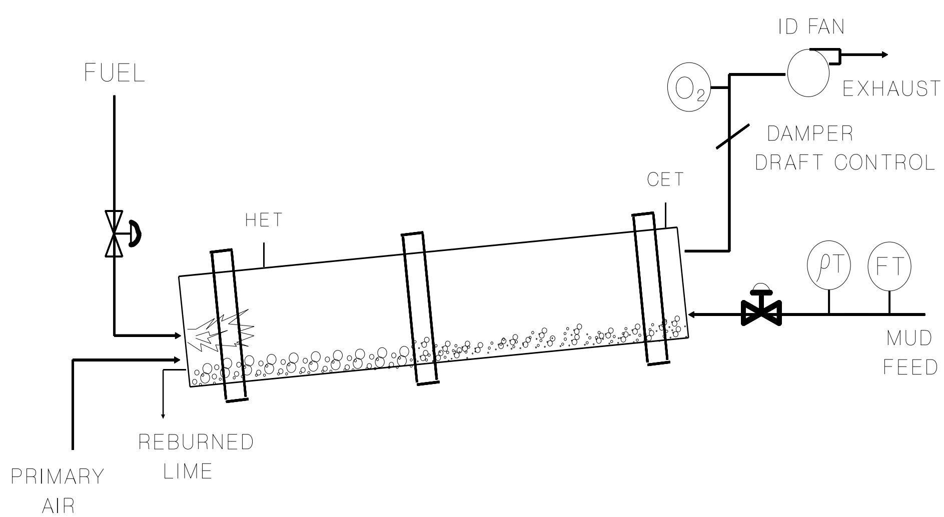
## I. INTRODUCTION:

A US Department of Energy grant financed the installation of the **patented DELTA T** dryer/moisture control system on No. 3 rotary lime mud kiln at Temple-Inland's paper mill in Evadale, TX. Operation with the DELTA T system began in 1994 and runs were conducted intermittently into 1995. No. 3 kiln was started up in the early 1950s. The purpose of the trial was to evaluate the use of the DELTA T, a special dryer control system, for improving the control of a lime mud kiln. The DELTA T is a past winner of the American Paper Institute/National Forest Products Energy Innovation Award. Figure (1) shows schematically a typical vintage rotary lime mud kiln.

**FIGURE 1 - LIME KILN SCHEMATIC**



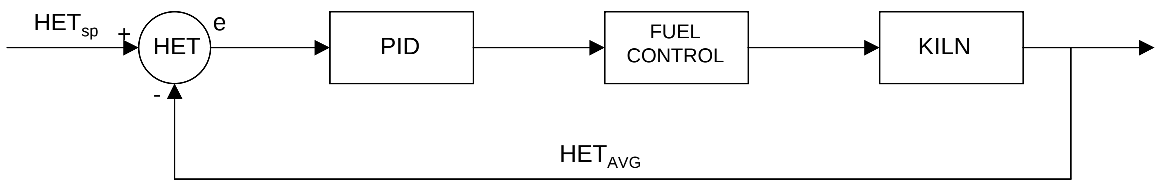

The kiln may be characterized as a series of four unit operations within a fixed length of the kiln: drying, heating, calcining and burning. For a constant hot end temperature (HET), cold end temperature (CET), mud feedrate, kiln rotational speed and mud MC (steady-state), there exists a time-temperature factor for each zone that produces the proper quality of burned lime at the kiln exit. Since the kiln is of fixed length and each zone occupies a finite length of the kiln, any departure from the initial steady-state conditions ultimately affects the final zone (burning) and produces poor quality lime.

## II. PRESENT CONTROL SYSTEM - CET & HET:

### A) HOT END CONTROL LOOP:

Most rotary lime kiln control systems on older kilns employ a Hot End Temperature (HET) loop as part of the control scheme (Figure 2). To insure proper burning, the HET must be 1800 - 2000 degrees F. Overburning may occur if the temperature is too hot or the time in burning zone too long. Likewise, underburning occurs if the temperature is not high enough and the time in the burning zone is too short. The HET loop controls the front end temperature by manipulating the fuel valve.

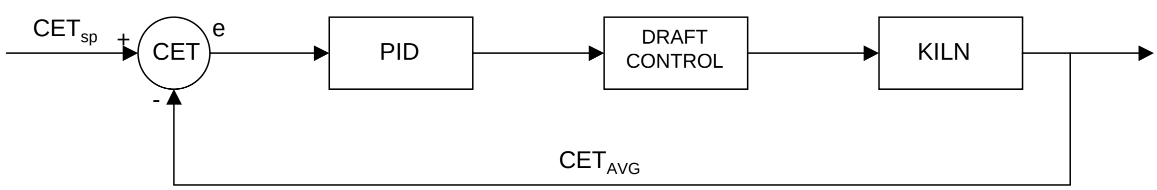
**FIGURE (2) - HOT END TEMPERATURE CONTROL**




### B) COLD END CONTROL LOOP:

The Cold End Temperature (CET) loop is described by Figure (3).

**FIGURE (3) - COLD END TEMPERATURE CONTROL LOOP**




The CET loop controls the cold end temperature by manipulating ID fan draft to increase or decrease the amount of heat "pulled" to the cold end.

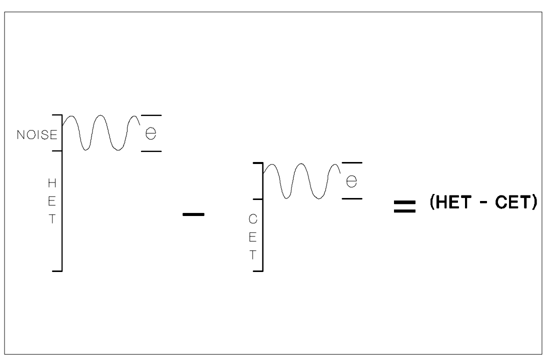
## C) CET/HET CONTROL SYSTEM:

Normally, the HET and CET are controlled to setpoint values established for production rates. Changes in entering water load to the kiln, either by a change in mud MC or mud feed rate, causes the CET to change. For example, if the water load increases, the CET falls below the setpoint value. As a result of this negative error, the CET loop controller will open the draft damper to "pull more heat" to the cold end in order to raise the CET back to its setpoint value. This action causes a disturbance to the HET loop (interaction) since more heat is now being pulled from the hot end the HET is reduced below its setpoint value. Consequently, the HET controller adds more fuel and combustion air to restore the HET to its setpoint value. This action disturbs the CET unless a decoupler is included in the control scheme.

Although present control systems may include a decoupler to handle a portion of the interaction effect, such enhancements are unable to automatically supply a new CET setpoint required by the newly established drying conditions resulting from the disturbance to the system. It falls to the operator to hunt for the new setpoint. If the new setpoint is not found, lime quality suffers.

In addition to the problem with interaction and setpoint adjustment requirements, noise and loop errors associated with the HET control loop show up (erroneously) as variations in water load to the kiln. For example, at steady-state conditions, any noise that causes a deviation in the HET from the setpoint is transmitted through the kiln to the CET as a real disturbance. Such condition causes over or under-control and contributes to the lengthening or shortening of the drying zone. Noise and control loop errors transferred from the HET loop to the CET (Figure 4) are eliminated by subtraction using delta T as the controlled variable.

**FIGURE 4 - DELTA T ELIMINATES NOISE AND ERRORS**



[HET + errors + noise] - [CET + errors + noise]

[HET - CET]

= delta T

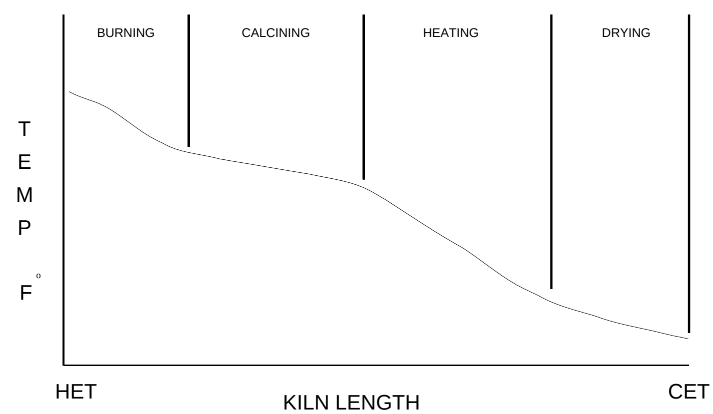
The remaining signal (delta T) is more indicative of drying load to the kiln than CET since errors and noise have been eliminated.

## III. THE CONTROL PROBLEM:

Changes affecting the drying zone contribute significantly to poor control and the production of poor quality lime. Drying of lime mud is affected mainly by four variables: mud feed rate, entering mud MC, air flow rate and air temperature through the kiln. Changes in one or more of these variables requires new CET and HET setpoints. Since under ordinary operation there are changes in feedrate, air flow, air temperature, and entering MC, existing control methods, using a constant CET and HET setpoints, are inadequate for good kiln control. This is evidenced by the operator frequently having to manually adjust each setpoint in an imprecise and "after-the-fact" manner.

At steady-state operation, the drying, heating, calcining and burning zones require a given length of kiln for each in order to produce a lime of good quality. Figure (5) shows the typical temperature profile of a lime mud kiln.

**FIGURE 5 - TEMPERATURE PROFILE OF A LIME KILN**




The time-temperature factor for each zone is fixed for a given production rate, HET, etc. Any disturbance entering with the feed such as a change in moisture content (MC) or feedrate will cause the drying zone length to change if not corrected for. Since the kiln has a fixed length, any change affecting the length of the drying zone will be transmitted through each zone and ultimately ends up affecting the length of the burning (last) zone. Consequently, the lime is either under or over-burned. For example, lime mud entering with a higher water load will cause the drying zone to lengthen which, if not corrected, will ultimately causes the burning zone to be shortened. Under such conditions, lime will be inadequately burned. If the water load entering the drying zone is less than normal, the lime will be overburned because of the longer time in the burning zone. In each case, lime quality suffers.

## IV. <u>THE DELTA T CONTROL SOLUTION</u>:

### A) <u>THE DELTA T DRYER CONTROL MODEL</u>:

Considering the control problem as primarily a moisture/dryer control problem, the latest in dryer control technology, the patented DELTA T control system, was used in this study. It is based on the **patented** model,

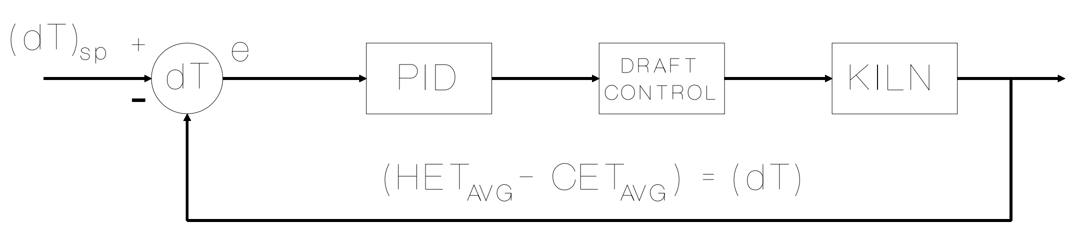
$$MC = K_1(\Delta T)^p - K_2/S^q$$

that relates the lime mud moisture content MC to: (1) the temperature drop ($\Delta T$) of hot air after contact with the mud; and (2) the lime mud feed rate (S).

### B) <u>THE DELTA T CONTROL SYSTEM</u>:

The HET is maintained as previously described. The CET is replaced by the loop shown in Figure (6).

**FIGURE 6 - DELTA T COLD END CONTROL LOOP**




The controlled variable is temperature drop (delta t) which, for convenience in this study, was the difference between the HET and the CET. However, it is preferable to employ an intermediate temperature to serve as the hot side temperature from which the CET is subtracted to obtain the delta t value.

When there is a disturbance to the system such as a change in water load, the delta t loop detects the change in evaporative load and pulls more air to the back end. The delta t setpoint is adjusted for the change in operating conditions by proprietary means. The HET control loop detects the reduction in temperature and manipulates the fuel valve to move the HET to a ***new adjusted HET setpoint***. Interaction between the two loops and the changing drying conditions are handled quite efficiently by this proprietary method of adjusting setpoints for new operating conditions established as a result of the disturbance entering the kiln.

## V. ADVANTAGES OF THE DELTA T:

In comparison with the CET/HET control method and the newer model predictive control (MPC) methods, the DELTA T is:

Relatively simple to operate.
No calibration time for moisture sensor required
Cruise-control startup
Offers control of moisture content of mud inside kiln.
Significantly less expensive than MPC.
Requires less engineering support than MPC.
Automatically adjusts setpoints for new operating conditions.
More effective than CET/HET method.
Can be easily applied to old kilns.
Automatic control of TRS.
New system can be placed in control mode immediately.

## VI. RESULTS AND CONCLUSIONS:

Comparison of fuel consumption for the old control system Vs the DELTA T indicated fuel savings of approximately 3 - 4% when using the DELTA T. Savings would have been higher had there been a source of air for controlling TRS. At high loads, there was no secondary air source for properly maintaining the oxygen level to prevent TRS excursions. At high operating rates, for both the DELTA T and the existing control system, the fuel input consumed most of the available oxygen and the TRS level exceeded the maximum level. Consequently, we had to reduce the fuel rate at the expense of lime quality. This reduced our ability to show additional fuel savings. Total energy savings could possibly be 10% or higher with the proper air control.

The DELTA T Kiln Control System should be installed on a kiln that has a secondary air source and should employ intermediate temperatures obtained by installing either (1) an FM radio temperature transmitter on the rotating kiln and a receiver for converting the signals to temperature, or (2) inserting a pipe into the kiln (open to the outside and closed on the inside of the kiln) and measuring the temperature of the closed end of the pipe using an infrared temperature sensor. This same device can be as an indirect measure of the lime mud MC at the point of measurement by using two infrared sensors and taking temperature at different positions in the 360 degree rotation of the kiln.

Finally, the DELTA T was proven to be effective in automatically controlling a lime mud kiln with proper corrections for disturbances entering with the feed and the ambient air ***without experiencing TRS excursions***. It is considerably less expensive and less complicated for operators than model predictive control methods requiring neural networks and long periods required for model development. Installation of a DELTA T on a lime mud kiln should result in energy savings and improved quality.

Temple-Inland did not purchase a DELTA T kiln control system because they had already ordered a new kiln system that included a flash dryer ahead of the rotary kiln. This type of kiln could be more easily controlled using the DELTA T method. We could control the lime mud leaving the flash dryer at a more uniform MC because the DELTA T has the capability of handling disturbances entering the flash dryer with the feed such as (1) changes in feed rate, and (2) changes in entering MC. By controlling the MC entering the rotary kiln to a constant MC, most of the variation would be removed and the heating, calcining and burning zones would remain relatively uniform in length for a given production rate. The rotary section could be controlled as outlined above using HET and DELTA T loops.

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