Automation of a multiple kiln plant

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Introduction

Each lime kiln automation project offers unique challenges. As each lime plant and kiln is different, so are the problems that are encountered in trying to automate them. This paper discusses the automation of five rotary kilns at Tarmac America's Millard lime plant in Annville, Pennsylvania.

In March 1995, Wimpey Minerals USA awarded Process Automation Systems Inc. a contract for automating five rotary lime kilns at the Millard lime plant located in Annville, Pennsylvania. Process Automation Systems Inc. is a member of the Universal Dynamics Group of companies. Process Automation Systems combined the engineering services of Universal Dynamics with hardware, software, and installation services to provide a turnkey control systems solution. Tarmac America purchased all of Wimpey Minerals' North American stone and lime facilities, including the Millard lime plant in the first quarter of last year just after Phase 1 of the automation project was completed. The final phase was completed in September.

Millard lime plant overview

The Millard lime plant's five existing rotary kilns range in age from over 65 years for No. 1 kiln to about 25 years for No. 5 kiln. The lime plant is arranged in two separate lime producing areas. Kilns 1 to 4 comprise one lime production area, and kiln 5 is the second lime production area. Kilns 1 and 2 are 6.5 x 290 ft long kilns with an 8 ft dia. flared burning zone. Kilns 3 and 4 are 8 x 318 ft long. All four small kilns have satellite coolers, no preheaters and are protected from the weather by a common building enclosure. Kiln 5 is the largest kiln at 12 ft dia. x 405 ft long with the front 75 ft of the burning zone flared to 13 ft dia. All five kilns are direct coal-fired with Raymond bowl mills.

The oldest part of the plant is the kilns 1 to 4 area. These four small kilns are served by a common stone feed system; product from all four kilns discharges to a common lime handling and storage system. An unusual feature of the four small kilns is that they also share a common baghouse and a single 1000 hp I.D. fan. This arrangement complicates the draft control of the individual kilns.

The kiln 5 lime production area is the newest part of the plant. Kiln 5 also has no preheater, but it does have a contact cooler and its own dedicated dust collection system powered by an 800 hp I.D. fan. Kiln 5 has a stone, and lime storage system that is separate and independent from the kilns 1 to 4 systems.

The four small kilns were controlled by one operator from local control stations at the common firing floor for kilns 1 to 4. Kiln 5 is located about 500 ft from the four small kilns and has a separate firing building and a local control room manned by another operator. The plant's overall nominal lime production capacity prior to starting the automation project was about 1100 tpd. Kiln No. 5 accounted for approximately 55% of the total production.

**Based on a paper presented at the NLA Operating Meeting, Salt Lake City, Utah, September/October 1996.*

Goals of automation project

The goals of this project were to improve lime quality and reduce production costs. Lime quality is improved by stabilising and reducing the variability of lime slaking rate and LOI. Production costs are reduced by:

- Improving fuel efficiency.
- Increasing production.
- Reducing labour costs (by consolidating all kiln controls to a central control room).
- Improving plant availability.

The universal kiln automation system (UKAS) was used to achieve these goals. The UKAS strategy is to:

- Improve controls and display of process information by upgrading kiln instrumentation and converting controls to a PLC system with personal computer based graphical operator stations.
- Improve lime quality and stabilise kiln parameters with the advanced instrument loop controllers known as the universal adaptive controller (UAC).
- Optimise fuel use with an expert system module called the combustion advisor.
- Maximise lime production with an expert system module called the production advisor.

Scope of Millard kiln automation project

Field instrumentation upgrade

Kilns 1- 4 instrumentation

Accurate and reliable kiln instrumentation is essential for a successful kiln automation project. Unfortunately, the existing instrumentation level at kilns 1 to 4 was inadequate for maintaining high production rates and the condition of some of the instruments was poor. Existing instruments available to operators on kilns 1 to 4 included:

- Radiation pyrometer (aimed at product).
- Kiln exit gas thermocouple.
- Draft Transmitters (at feed end manifold and baghouse).
- Coal mill outlet gas thermocouple.
- Coal weigh scale.
- Stone weigh scale.
- Oxygen analyser (unreliable).

Existing kiln 1 to 4 control actuators included:

- ID fan air flow damper actuator (common to all four kilns).
- Feed end kiln air flow damper actuator (one per kiln).
- Kiln drive four speed motor controller.
- Manual coal mill tempering air damper (no actuator).
- Manual mill primary air flow damper (no actuator).

The following new field instruments and actuators were provided for kilns 1 to 4:

- Coal mill air flow measurement.
- Oxygen and combustibles analysers.
- Mid-kiln non-contact temperature measurement.
- Coal mill tempering air damper actuator.
- Mill primary air flow damper actuator.
- CCTV cameras and monitors.

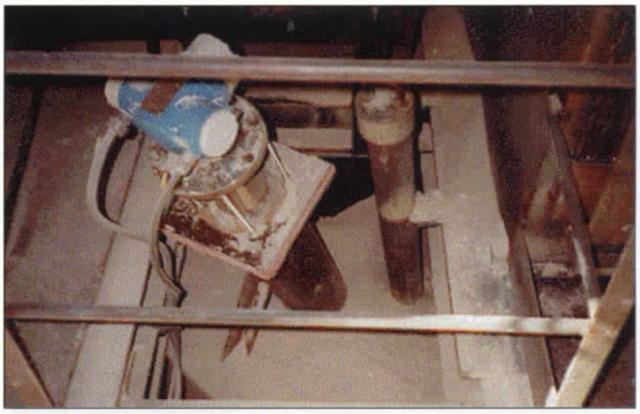
In addition to the field instruments listed above, all existing thermocouples and pressure transmitters were replaced with new ones. Also, the existing four speed kiln drive motors were replaced with four new variable frequency kiln drive units.

Kiln 5 instrumentation

The existing instrumentation at kiln 5 was more complete than what existed at kilns 1 to 4, and it was generally in good working order. Aside from replacing existing thermocouples and providing all new pressure transmitters, the only major field instrument improvements to kiln 5 were the addition of:

- Microwave cooler level transmitter.
- Cooler upper lime thermocouple.
- Cooler air flow measurement.
- Coal mill air flow measurement.
- Oxygen and combustibles analysers.
- Mid-kiln non-contact temperature measurement.
- CCTV cameras and monitors.

A new variable frequency drive was not considered for kiln 5, as the existing dual eddy-current slip drives were functioning satisfactorily at existing production rates.



Kiln 5 microwave cooler level transmitter.

Electrical equipment upgrade

Most of the 1 to 4 kilns' motor control was from very old wall-mounted starters with 440 V control circuits. These were located in several different areas of the firing building. Converting these old starters to PLC control would have required the use of interposing contactors and panels with dual voltages present. Therefore, two new motor control centres were provided in a new room to replace the obsolete and dangerous 440 V starters for kilns 1 to 4.

The kiln 5 area electrical equipment was much more modern and in very good condition by comparison. The metal enclosed motor control centres included individual 120 V control power transformers in each cell and therefore could be easily converted to PLC control without major modifications.

Control system upgrade

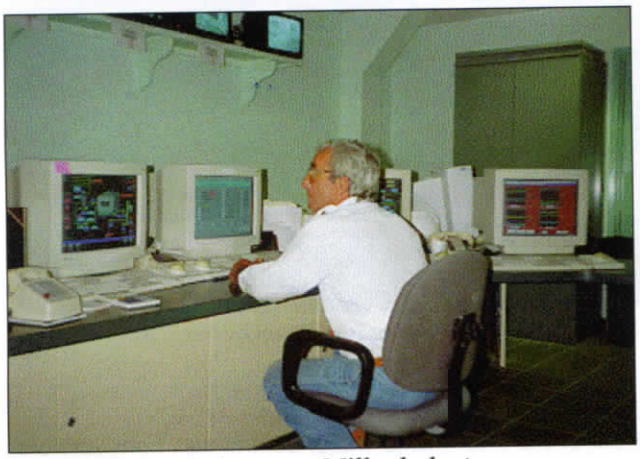
Existing controls

Kiln 5 was controlled from a conventional push-button control panel with analogue loop controllers. The panel is located inside a control room on the kiln 5 firing floor. The panel was built in the early 1970s, and had been upgraded over the years with new chart recorders and Honeywell UDC 5000 loop controllers. The panel was in good shape for its age, but most control loops were operating in manual mode.

Operators controlled the four small kilns from four separate push-button panels located on the open firing floor in front of each kiln. In addition, a small air conditioned control room had been built in recent years near the centre of the common kilns 1 to 4 firing floor. An analogue control panel containing Honeywell UDC 5000 loop controllers for regulating stone feed and coal feed to all four kilns was housed in this room. The analogue control panel also contained a multi-point chart recorder to display and record some of the kiln temperatures and oxygen levels. In addition, there was a PLC based 'PanelView' graphic operator station for controlling stone supply to the kilns and a separate PC control station for the lime handling system. Both systems were part of earlier control upgrade projects. This scattered control arrangement was impractical and operating became extremely difficult at times when problems arose simultaneously on different kilns.

Master control room

A secondary benefit of the automation project is the potential to reduce labour costs. This was achieved at the Millard plant by consolidating the operating positions of kilns 1 to 4 and kiln 5 to a new master control room. Unfortunately, a suitable location could not be found in the vicinity of the kilns, so a new control and laboratory building was constructed at a remote location approximately 1500 ft from the nearest kiln. The master control room is very spacious and has no windows, but closed circuit television cameras allow the operator to view critical areas.



New master control room at Millard plant.

There are some disadvantages in being this far away from the kilns, but a positive consequence is that the control room is now in a clean part of the plant. In addition, the new control room has been designated a no-smoking area.

Programmable logic controllers

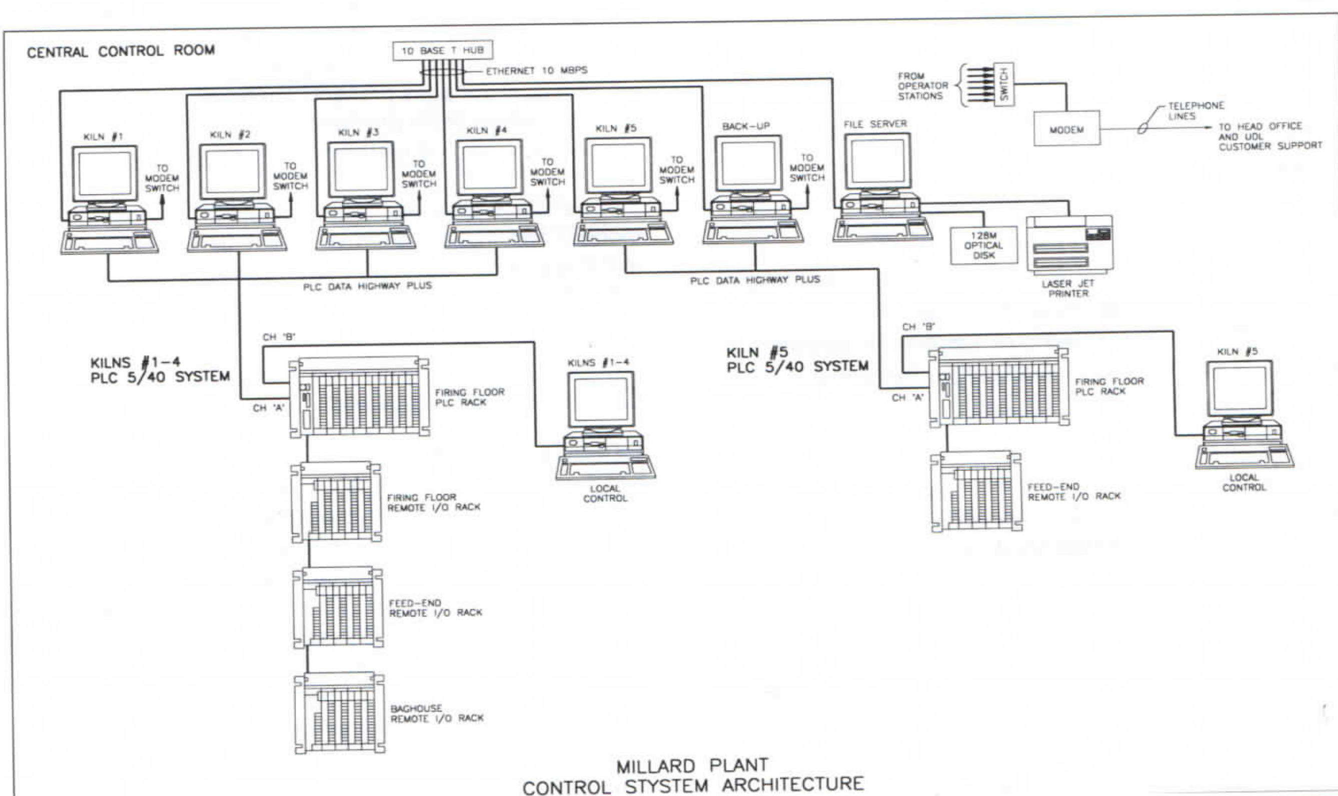
Two independent PLC systems were provided, one for controlling kiln 5 and one to control the group of four smaller kilns. The two PLCs are Allen-Bradley 5/40 series processors with 1771 series I/O. The two processors are interconnected by a data highway cable and can pass information back and forth between systems if needed. Each PLC system has a separate data highway to the operator stations in the central control room.

The field input/output (I/O) modules are housed in six field-mounted racks located at the firing and feed ends of the kilns. The I/O racks contain both analogue and discrete I/O modules for both analogue and motor controls. An uninterruptible power supply for each field rack was included to protect the PLC hardware.

Operator stations

The universal kiln automation system uses microprocessor-based Pentium computers to implement the control strategy. The system operates on the OS/2 multitasking operating system, which allows all control and reporting functions to run concurrently in real time. The operator graphical interface is implemented on the OS/2 version of USDATA's FactoryLink software. The system consists of the following (Figure 1):

- Five operator stations at the master control room (one station per kiln).
- One backup operator station at the master control room (backing up any kiln).



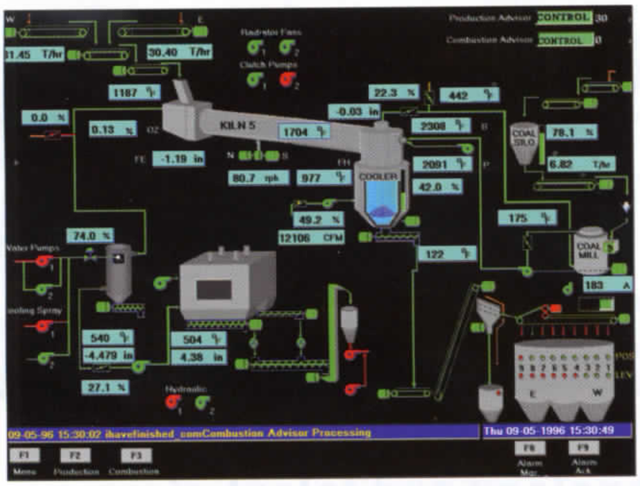
Millard plant control system architecture.

- Two operator stations at local control rooms (one station per local control room).
- One file server computer for local area network (LAN).

All of the operator stations are connected to a file server via a local area network (LAN). The file server and LAN provide the following important features:

- Acts as a central location for information storage and common utilities (i.e., printer, optical backup).
- Supports software revision control for all PLC programmes and operator station configurations.
- Provides a backup memory system, to ensure important dynamic information is not lost.
- Supports a modem for remote access to data for MIS and technical support from Process Automation Systems Inc.'s head office.

All master control room computers are housed in a custom console. The local control computers are provided with NEMA 12 enclosures with closed loop heat exchangers. All computers are provided with backup power supplies to protect and maintain the integrity of the computer system during power system upsets.



Kiln 5 overview graphic.

Remote support

Remote communication via modem was essential for the successful completion of this project. Design engineering, programming, and project management was performed from the head office almost 2500 miles from the plant site. Engineers provided remote on-line troubleshooting on many occasions during commissioning, and continue to provide fast and reliable remote service support.

Kiln optimisation

Manual control is difficult at any time, but even more so at higher production rates where flows are greater, material throughput is faster and operators must respond more quickly to an increasing number of disturbances. The approach of the universal kiln automation system is to stabilise the difficult control loops using the UAC advanced controller, and then programme an expert system that uses the knowledge and experience of the best kiln operators to consistently and continuously optimise production and quality while reducing fuel consumption. The main difference is that the computer is tireless and is not distracted by other events.

Universal adaptive controller (UAC)

The universal adaptive controller was developed specifically for use in controlling complex instrument loops on rotary kilns where conventional PID loop controllers are inadequate. The UAC is an adaptive controller that predicts the correct control action to handle process changes and never needs re-tuning once it is installed.

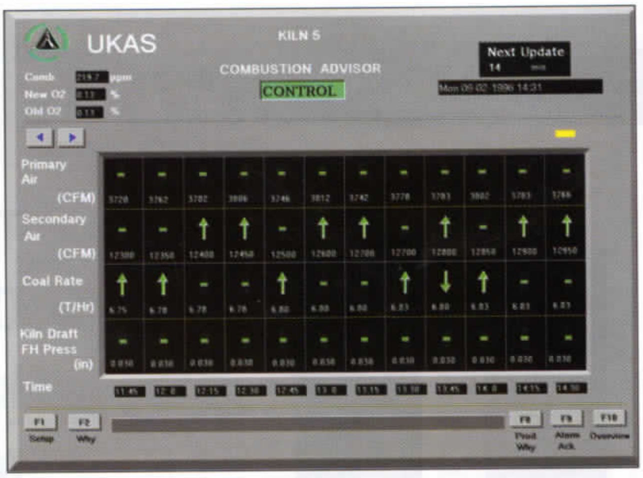
The UAC was used to stabilise all combustion control loops including firing hood draft control, primary and secondary air control and the oxygen trim control. The UAC was particularly useful in minimising kiln draft disturbances on the complicated draft control arrangement at kilns 1 to 4. The UAC for each kiln draft control loop was configured with three feed-forward signals from the individual damper positions of the other three kilns. With this arrangement, when one damper moved to regulate draft in a particular kiln, the controllers for the other three kilns were able to anticipate the disturbance and compensate for it.

Combustion advisor

The combustion advisor is an expert system that applies an operator's combustion control knowledge to operate the kiln combustion system consistently and continuously to optimise fuel use. The combustion advisor's programme is customised to match the characteristics of each individual kiln and automatically adjusts the:

- fuel rate;
- primary air;
- secondary air (on kiln 5 with contact cooler);
- firing hood draft.

This ensures optimum fuel use as measured by the oxygen/combustibles analysers at the kiln feed end.

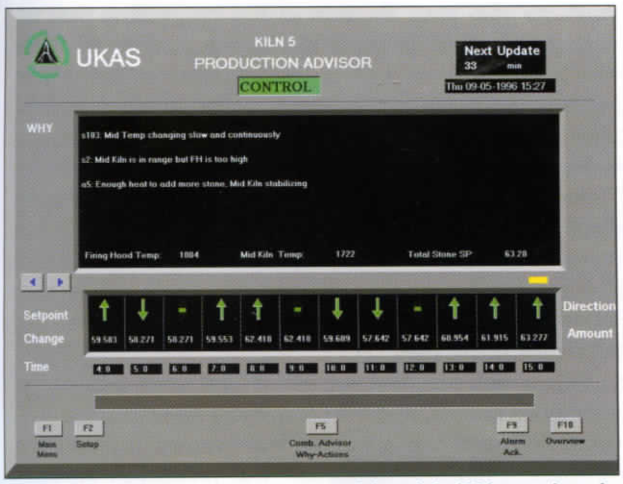


Combustion advisor operator graphic.

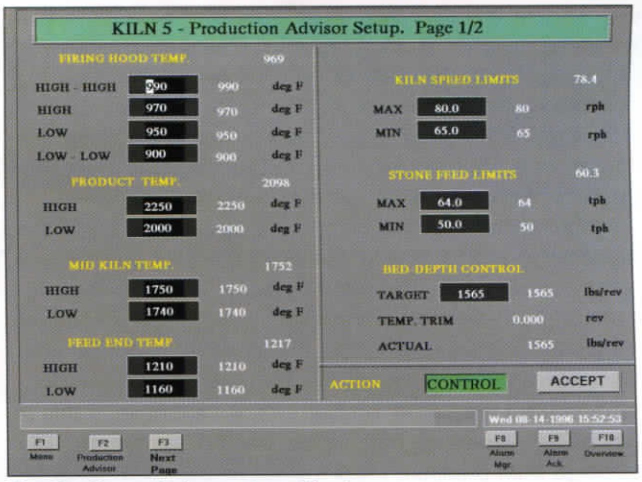
Production advisor

The production advisor is also an expert system that is uniquely adapted to the kiln being controlled. The production advisor automatically adjusts the kiln feed rate, and kiln speed to maintain a predetermined kiln temperature profile.

The kiln temperature profile is determined by the lime plant operator and is derived by regression analysis of LOI and reactivity of the lime being produced to the kiln temperatures. Once the operator chooses the temperature profile required for the lime quality desired, the production advisor continuously adjusts the kiln feed for maximum throughput consistent with the necessary kiln temperature profile. In addition to steady state control, the production advisor can be used to better handle some kiln upsets



Production advisor operator graphic with 'Why actions'.



Production advisor setup display.

caused by equipment failures and start-ups.

The production advisor and the combustion advisor work together to optimise fuel use and maintain the maximum possible kiln production level. An important feature of both the combustion and production advisors is their ability to explain the reason for taking actions to the operator.

Implementation schedule

The implementation schedule for automating five 'sold-out' operating kilns was very important. Once the decision to proceed with the project was made, management wanted as short a completion schedule as possible so the plant could reap the benefits of kiln automation as quickly as possible. This meant that engineering, equipment supply and non-shutdown work had to be completed in a well planned and timely fashion. Production outages had to be scheduled well in advance and their duration kept to an absolute minimum. However, the construction schedule also had to be flexible enough to allow work crews to be quickly reassigned from scheduled non-shutdown work to take advantage of any sudden unplanned kiln outages that might occur.

The schedule for the kiln automation system was divided into two distinct phases. The first phase was to upgrade and modernise the controls and instrumentation and consolidate the two control areas. A total of 10 months was originally scheduled for completing the first phase and the work was completed within this time frame. At the end of Phase 1, all five kilns could be operated manually at existing production levels from the remote master control room.

The second phase of the project was kiln optimisation. Commissioning in Phase 2 also had to be coordinated with plant maintenance outages. Critical control loops were placed in automatic mode, and the advanced controls, namely the production and combustion advisor expert systems, were commissioned in each kiln starting with kiln 5. Another important task completed in Phase 2 was operator training. Engineers spent many days and nights with each operator to ensure they understood the basic concepts of the combustion and production advisor.

The implementation sequence adopted for this automation project can be summarised as follows:

Phase 1 - non-shutdown work

- Install new instruments and electrical equipment such as MCCs and variable speed drives.
- Install basic PLC system infrastructure, including I/O cabinets, and operator stations at each local and central control room.
- Install new wiring from MCCs and PLC cabinets to new devices and to proximity of existing devices in preparation for cut-over during a shutdown.

Phase 1 - shutdown work

- One day shutdown of all kilns in each lime producing area to convert the flue gas and baghouse motors and analogue controls to PLC.
- Three day shutdown of individual kilns (including cool down time) for installation of mid-kiln thermal-wells, 15 ft long oxygen analyser probes, various feed end and firing hood process taps and, installation of new kiln drive motor bases and installation and alignment of the new drive motors.

Phase 2 work

- Implement UAC controls on difficult kiln loops for each kiln.
- Configure and commission the production advisor for each kiln.
- Configure and commission the combustion advisor for each kiln.
- Fine tune automation system on each kiln.

Operator acceptance

Operator acceptance of the new control system was a concern to plant management. When this project was first started it was not really appreciated how fixed in their ways some operators were. The original instrumentation at kilns 1 to 4 was very limited and some operators had been controlling this way for a very long time. One operator had worked there for over 35 years and new ideas were a hard sell.

When it became evident how high the level of hesitation among the older operators was, it was decided to place a few computers in the local control rooms and let the operators play with them off-line several weeks prior to the control system cut-over date for the first kiln. The operators then offered their comments on the graphic display and the contract engineers made minor changes and customised the displays slightly to make the operators feel at home with the system. Encouraging operator participation at this stage let them become familiar with the feel of the new interface and helped ease their fears about computers in general.

When the first kiln controls were finally cut over, the operators were quite nervous. On their first day or night operating in real time they were very slow and cautious in selecting motors to start and in changing set points. However, things went well and in a very short time all of the operators learned to use the graphic interface system effectively. No attempt was made to make the operators control from the master control room until some time after the control systems of all five kilns were cut over.

Although the operators learned to use the graphic interface rather quickly, some of them had difficulty accepting or using the information provided by some of the new instruments. They were possibly overwhelmed by the larger number of process variables being monitored now and resorted to operating the old way by using only the few original variables they were familiar with. An example of this is that some operators had to be trained to operate kiln dampers from pressure readings rather than damper position.

The toughest challenge was getting the operators to move from the local control rooms and into the remote master control room. Quite simply, none of them believed the kilns could be operated safely from 1500 ft away. However, the largest problem proved to be far more simplistic: the new control room was designated a no-smoking area, and six out of eight operators were heavy smokers. After management encouraged the operators to move down to the master control room, they quickly learned to use more of the new instruments for control, as well as relying on closed circuit cameras and communicating more effectively with their helpers in the field. Operators now feel comfortable operating all 5 kilns from the master control room.

Results to date

Kiln 5 was the last kiln to be cut over to PLC control, but it was the first kiln to be fully converted to full UKAS control because it accounted for more than half of the plant's production. The other four kilns have not been operating on full UKAS for very long, so most of the longer term data we have gathered so far is for kiln 5. The controls for kiln 5 were switched over to the PLC system at the end of January 1996. We can therefore compare the plant production data for the seven month period from February to August 1996 with the same period of the previous year.

As can be seen from Table I and Figure 2, the higher levels of automation have made significant production improvements. In addition, the fuel consumption per t of lime produced over the entire seven month period from February to August has averaged 12.3% lower than the same period last year.

Kiln 5 was the best run kiln in the plant prior to the automation project, and the contractors had predicted 10% fuel savings and only a 4 to 5% improvement in production from the automation proposal. The production increase gains and better fuel efficiency obtained over the last few months were, therefore, very pleasing.

At time of writing, only short term data is available for the smaller kilns. Kiln 4 was placed in full automatic control in the middle of August 1996. The remaining small kilns were put in full automatic mode starting in early September 1996. The production improvement in kiln 4 for the entire month of August was 12%, and the month of September yielded an 18% gain. Early results on the oldest and smallest kilns show even more impressive results. Production increases greater than 25%, and fuel savings in excess of 12% have been recorded on kiln 2 and kiln 3. Production increase data is not available for kiln 1, which was shut down in mid-September because the plant is now producing more lime with only four kilns running than with all five kilns last year.

In addition, product quality as measured by reduced variability of slaking rate and LOI has also improved significantly: changes that have been noted by the plant's major customers.

Table I. Kiln 5's improved performance after conversion to UKAS control

1996 months	Kiln 5 automation event	Average t per operating hour % improvement over 1995
February	Remote manual PLC control	0.8%
March	UAC loops added	2.7%
April	same	2.2%
May	Production advisor switched on	4.9%
June	Combustion advisor switched on	9.7%
July	same	7.4%
August	same	13.2%

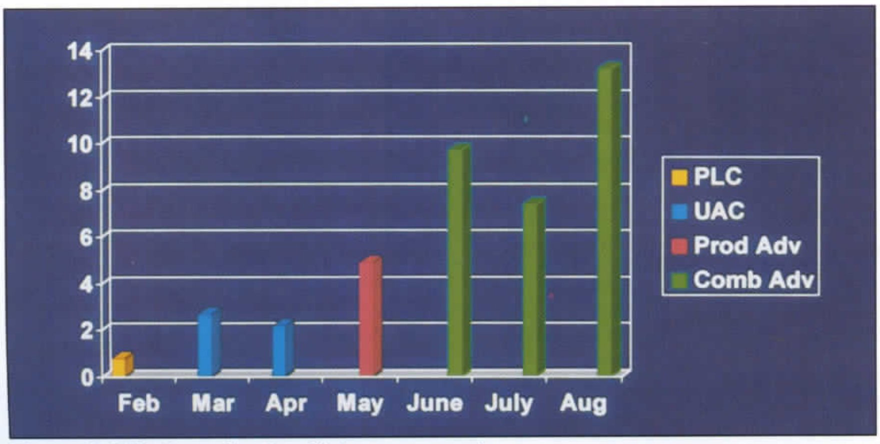


Figure 2. Kiln 5 production % improvement.

Conclusion

The kiln automation project at the Millard lime plant was a resounding success. The project was completed on time, on budget, and yielded much better production and fuel improvements than were needed to justify the project.

The automation project at Tarmac America's Millard lime plant has proven the following:

- Kiln automation brings a very high return on investment.
- Remote operation of widely dispersed kilns is economical and practical.

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