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INSULATION PERFORMANCE DATA AND ASSESSMENT
PROCEDURES FOR STEAM KILN ENERGY CONSERVATION
INVESTMENTS

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By
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September 1980

Work Performed Under Contract No. AC03-80CS40339

Scientific Service, Inc.
Redwood City, California

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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September 1980

prepared for
U.S. Department of Energy
Washington, D.C. 20585
Contract No. DE-AC0380CS40339

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EXECUTIVE SUMMARY

In 1978 Scientific Service, Inc., completed for the Department of Energy an industrial energy conservation demonstration study that included development of hard data on the costs and benefits of insulating concrete block curing kilns to isolate the kiln thermal mass from the curing cycle. For the demonstration, two kilns were insulated with FOAMGLAS[®] insulation, and the annual savings and total cost to install determined. Since the demonstration study was completed, additional data have been developed on related subject areas. These include: expected service life of FOAMGLAS[®] insulation, the effect of Johnson burners on the insulation and mounting, performance of an alternative insulation (a rapidly installed, spray-on polyurethane foam), and a simple incentive to promote implementation of industrial energy conservation concepts. The overall objective of this latest effort has been to accelerate implementation of the kiln-mass isolation concept.

The earlier study showed that energy savings of 35% to 40% could be expected from the insulation of commercial kilns. Total costs to implement amounted to about \$5,300 for each of the two kilns. Indicated gas savings were 1,000 Mcf/year per kiln at one plant and 600 Mcf/year per kiln at the other. The dollar savings at that time amounted to \$2,170/year per kiln and \$1,300/year per kiln, respectively, with the difference due, in part, to different energy prices, but mostly because of the different average ambient and curing temperatures at the two plants.

The study just completed and reported herein has demonstrated that FOAMGLAS[®] insulation works quite well in the more rigorous environment created by Johnson burners, that this insulation is cost beneficial even in one of the more efficient modern plants, and that its performance (in

indicated dollar savings) has increased substantially after one and a half years. Today, the indicated savings per year per kiln at the above two demonstration plants are \$3,600 and \$2,240, respectively.

The more recent study has also demonstrated that the use of the less expensive spray-on polyurethane insulation is limited to automated plants with central boiler systems, for safety reasons, and that curing temperatures in excess of 160°F cause rapid degradation of the material. The urethane insulation life expectancy is probably about half that of FOAM-GLAS[®] insulation in those kiln environments where it can be used, so that the return on investment will be about the same. In those kilns where it can be used, its principal benefits will be in a lower first cost, and in those applications where a shorter service life is desirable (because of expected plant modifications, etc.). Table 14 from the main text has been included here for purposes of comparison.

Because the successful promotion of energy conservation is closely tied to identification of economic benefits and beneficiaries, an analysis of some alternative distributions of benefits among the beneficiaries has been made to assess the costs and benefits of incentives. The conclusion is that, if industry were allowed to recover the total capital expended for demonstrated conservation options in the first year, then both tax revenues and industry profits are likely to exceed those for the alternative of letting normal market forces take their course. Additional, less tangible benefits that would accrue with accelerated implementations include: the rapid creation of 550 man-years of work; increased profits for insulation manufacturers and installers (and more jobs as a result); fewer foreign imports, which would enable more U.S. dollars to be kept at home (hence, fewer U.S. assets sold abroad)—all to the general benefit of the economy.

TABLE 14: INSULATION COMPARATIVE PERFORMANCES

Insulation Material	FOAMGLAS [®] Insulation	CPR 480 Polyurethane
Manufacturer	Pittsburgh Corning Corporation	The Upjohn Company CPR Division
Service Temperature Limit in Steam Kilns	300°F+	160°F
Estimated Service Life in Steam Kilns	10 years	5 years
Fire Safety	No restrictions	No open flames, No human traffic, without fireproof coat
Installation Costs per 2,000 sq ft kiln:		
Man-Hours	100 - 120	6 - 8
Cost/sq ft (Contractor installation)	\$2.20 - \$3.50	\$1.00 - \$1.60
Cost/sq ft (In-house installation)	\$1.50 - \$2.50 (including labor at \$10 to \$15 per hour)	n.a. (requires professional installation)
Installation Precaution:		
Mounting	Use only recommended mastics	Must have warm, dry surfaces
Labor	Unskilled	Skilled
Fireproofing	Unnecessary	Costs \$2.50/sq ft when required

Acknowledgements

We should like to express our appreciation to a variety of contributors to this program without whose support this study could not have been conducted.

We especially wish to thank John Rossmeissl and Ike Smith, of the Department of Energy, and Ken Rupp, of Superlite Builders Supply, Inc., for the support that made this program possible. And, we are also grateful to the Pittsburgh Corning Corporation for supporting the development of fundamental material presented herein.

To members of the block industry we continue to be indebted, particularly to those who have consistently given of their time and who have provided access to their plants so these studies could be made. For this kind of support we wish to thank Ken Best of Best's Blocks, Inc., William A. Grindle of Blocklite, Peter Janopaul of Graystone Block, Tom Morey of Calstone Company, and Don Lampus of R.I. Lampus Company.

To the above mentioned, we wish to add our acknowledgement and thanks to Ameron for access to its Madison plant, and to Don Buchignani for the on-site support provided there.

We would be remiss if we failed to mention the technical support received from John Nolan and Larry Brungess of Central Coating Company to insulate the Superlite kilns, and Joe Boyes of Joe Boyes and Associates in making the technical measurements.

Finally, among our own personnel, we wish to thank Gordon Shephard, Jr., for conducting the laboratory studies, Maureen Ineich for report artwork, and Evelyn Kaplan for editing and typing.

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Section 1 INTRODUCTION

Under contract with the Department of Energy (DOE), Scientific Service, Inc. (SSI) has completed an industrial sector energy conservation program to help promote use of the kiln-mass isolation concept by the concrete masonry industry. The purpose of this study was to develop additional performance and cost data on internally insulated steam kilns. The work was conducted under Contract No. DE-AC03-80CS40339 for the Conservation and Solar Energy Industrial Programs division of DOE.

The completed program is an outgrowth of a previous study in which the kiln-mass isolation concept proposed by SSI was tested at two participating concrete block manufacturing plants, each of which used a low pressure central boiler to supply steam to their curing kilns. Costs, benefits, and problems associated with implementing the concept were documented; implementing the option appeared to be profitable at both plants. However, subsequent to the release of the report on this initial study (Ref. 1), industry inquiries were made as to the performance to be expected when Johnson burners are used, rather than central boilers (i.e., the effect that hot combustion products might have on the insulation and mounting), and whether another insulation might be found and tested that would be less expensive to install. To maintain industry interest in the kiln-mass isolation concept as a means to conserve energy profitably, a follow-up program was initiated to answer these questions.

Answering questions that promote more applications of this particular conservation option is likely to be profitable because the concrete block industry uses about 30% of the 130×10^{12} Btu consumed directly and indirectly by the finished concrete products industry yearly (Ref. 2). Of the 39×10^{12} Btu/year that the block industry uses, it is estimated that about

half (90% of the industry's direct expenditures) is consumed in the block curing process and that 35% of this can be saved by insulating the kiln interior walls and ceiling. If this promising option is to be promoted vigorously, its economic aspects must also be presented.

In addition to the substantial energy saving, if this measure were applied nationwide, the monetary saving would amount to 13 to 26 million dollars annually (depending on whether gas or oil is used), and it would provide economic gain to a number of beneficiaries, some of which would benefit from energy savings and some from capital expenditures. In the latter category, the capital expenditure to retrofit all plants is estimated to range somewhere between 16 and 40 millions dollars.

By taking the middle ground for these estimates of costs to implement and corresponding savings, and evaluating the expected gain to all beneficiaries from a nationwide implementation by the block industry, the overall economic aspects were assessed. The outcome of the exercise was illuminating; it points up the importance of considering all the techno-economic aspects. Key among these is that the largest dollar benefit and the smallest risk accrue to the U.S. Treasury, which is essentially a 50% partner of industry. A concept that SSI feels might have been overlooked for its impact on an accelerated implementation of energy conservation options is a more equitable balance of risk and reward between the major partners. An assessment of such a better balance shows that the net outcome (profits and revenues) would be enhanced for all beneficiaries. In the interim, while the merit of this approach receives consideration, the DOE support of this program is intended to provide answers to questions that should lessen industry risk in insulating kilns by providing additional decision information.

Section 2

BACKGROUND

This section provides a review of the demonstrated energy conservation option, isolation of kiln thermal mass.

GENERAL REVIEW

In 1978, as part of a program to help accelerate industrial energy conservation, San Jose State University and Scientific Service, Inc., under contract with the DOE, conducted a demonstration program for the concrete block industry. Under the program a very simple insulation concept was demonstrated at two commercial block plants, and hard data on costs and benefits were obtained. The demonstration showed energy savings with simple payback periods somewhere between 2½ and 4 years.

The option was first identified by analyzing thermal loads at several block plants. A thermal load is readily calculated from the weight of the material that has to be heated, the heat energy required to raise each pound of the material one degree F, and the number of degrees F that its temperature must be raised. The analytical procedure is analogous to one suggested by Robert Dikkers, of the National Concrete Masonry Association, to size boilers for concrete curing plants. Basically, each thermal load represents a demand that must be met by the energy source at some energy and dollar cost. Proper analysis and allocation of energy expenditure by loads can lead to identification of effective means to lower curing costs. In conducting such an analysis, SSI discovered the mass of green concrete cured in each cycle was generally less than the mass of the kiln heated (and cooled) each cycle. Moreover, most of this kiln thermal load seemed avoidable, if a suitable insulation could be applied on the inside surfaces of the kiln to reduce the corresponding load demand on the boiler.

These particular load calculations were presented to the DOE and became the basis for obtaining support for studies to find a suitable insulation, and to verify the calculations experimentally. In the first study conducted by SSI, concrete block were taken off line at a plant and cured in a small-scale kiln made with 2 inches of FOAMGLAS[®] insulation (Ref. 1). The small-scale kiln had a capacity about 3% that of a typical commercial kiln. The energy expended to cure block in this insulated kiln was 56 Btu/lb, compared with a national average close to 160 Btu/lb. The 65% saving implied attains significance on examining the Bureau of Census "Census of Manufacturers" report (Ref. 2), which indicates the concrete block industry currently uses \$60,000,000 worth of energy annually. The lower energy demand in the small insulated kiln represented a target opportunity for the block industry to save almost \$40,000,000 worth of energy annually at a material cost for insulation of about \$16,000,000. Both the material cost and the dollar saving are estimates at today's (1980) prices.

When the two commercial kilns were insulated, only the ceilings and walls could be covered because of the forklift traffic. Consequently, a 65% saving could not be realized, but savings of 35% and 37% were observed, and the respective returns on these two investments, assuming a ten-year life expectancy for the insulation, were roughly 20% and 40%. The actual service life, therefore, will be important because it plays a major role in determining return on investment, or investment quality. The other factor in investment quality assessment is predicting insulation performance.

TECHNICAL REVIEW

The ability to analyze the thermal load demand in a curing cycle is basic to understanding and predicting kiln performance. The equation used by Dikkers is reproduced in Figure 1 (in the box) with each of the terms of this equation further defined in bold print below it. The appropriate values for the material constants in the equation can be looked up in a handbook, or measured.

As soon as the kilns at several plants had been analyzed, it became

LET H = heat required (BTU's),
 ΔT = total temperature in $^{\circ}F$ (which is equal to final temperature minus initial temperature)
 c = specific heat of material (BTU/lb / $^{\circ}F$)

$$H_{\text{total}} = H_{\text{steel}} + H_{\text{block}} + H_{\text{air}} - H_{\text{hydration}} + H_{\text{kiln}} + H_{\text{loss}}$$

$$H_{\text{steel}} = (\text{PALLET \& RACK WEIGHT})(c_{\text{steel}})(\Delta T_{\text{steel}})$$

$$H_{\text{block}} = (\text{BLOCK WEIGHT})(c_{\text{block}})(\Delta T_{\text{block}})$$

$$H_{\text{air}} = (\text{FINAL BTU CONTENT OF KILN AIR} - \text{INITIAL BTU CONTENT})$$

$$H_{\text{hydration}} = (\text{CEMENT WEIGHT})(\text{HEAT OF HYDRATION RELEASED})$$

$$H_{\text{kiln}} = (\text{WEIGHT OF KILN ROOF, WALLS \& FLOOR})(c_{\text{kiln}})(\Delta T_{\text{kiln}})$$

$$H_{\text{loss}} = (\text{KILN SURFACE AREA})(\text{"U" FACTOR})(\Delta T)(\text{TIME})$$

Fig. 1. Calculation of heat requirements for live steam curing of concrete block.

apparent that the third and the last terms of the equation represented relatively small portions of the total. This can be seen more simply in Figure 2, which summarizes the analysis completed at one plant. The load distribution before insulating is depicted on the left side of Figure 2. The smallest sliver in that diagram represents the load of the moisture-laden kiln air-mass, and the second smallest sliver represents heat transfer loss by conduction through the kiln surfaces. The two of these together are seen to constitute less than 5% of the total. Thus, heat transfer losses are relatively insignificant in this case. This can be seen more graphically from the following.

Assuming that two inches of FOAMGLAS[®] insulation were to be applied on all kiln surfaces for which application is practical (i.e., excluding the floor and door), it can be calculated that the heat conduction loss through the kiln during one curing cycle would be reduced by 67%. The saving is represented by the smaller of the two shaded slivers in the diagram on the right side of Figure 2. It really makes no material difference in the conduction load whether this insulation were placed on the inside or the outside surfaces of the kiln, but to the apparent thermal mass of the kiln, it makes all the difference in the world. Why this is true is also easier to understand with graphics.

In Figure 3, three temperature profiles have been depicted. These show the temperature at every location through different cross-sections of a kiln wall. On the left is an uninsulated wall, in the middle is a wall insulated on the inside, and on the right is a wall insulated on the outside. The temperature profiles are for a 110°F temperature rise* (above ambient) within the kiln. Assuming a steady state condition, the calculated temperature profile through each material is virtually a straight line.

* Selected as representative of the three plants in which measurements were made.

•ENERGY DEMAND BEFORE INSULATING • ENERGY DEMAND AFTER INSULATING•

CALCULATED $H_{total} = 5.35$ Mcf
 " DEMAND = 13.4 Mcf ($2.5 H_{total}$)
 MEASURED DEMAND = 13.81 Mcf

CALCULATED $H_{total} = 3.58$ Mcf
 " DEMAND = 9.0 Mcf ($2.5 H_{total}$)
 MEASURED DEMAND = 8.33 Mcf

SAVING: $\frac{13.81 - 8.33}{13.81} = 39.7\%$ (NOTE: 1 Mcf = 10^6 Btu)

Fig. 2. Energy balance analysis.

$$\begin{aligned}
 H &= M_w C_w \Delta T_w \\
 &= 30 \times .27 \times (125 - 70) \\
 &= 445.5 \text{ Btu/FT}^2
 \end{aligned}$$

$$\begin{aligned}
 H &= M_i C_i \Delta T_i + M_w C_w \Delta T_w \\
 &= 1.4 \times .18 \times (134.4 - 70) + 30 \times .27 \times (82.6 - 70) \\
 &= 16.2 + 102.6 \\
 &= 118.8 \text{ Btu/FT}^2
 \end{aligned}$$

$$\begin{aligned}
 H &= M_w C_w \Delta T_w + M_i C_i \Delta T_i \\
 &= 30 \times .27 \times (130.4 - 70) + 1.4 \times .18 \times (88.5 - 70) \\
 &= 489.2 + 2.1 \\
 &= 491.4 \text{ Btu/FT}^2
 \end{aligned}$$

Fig. 3. Temperature profiles through three different wall cross-sections and corresponding thermal loads per square foot of wall.

From the equation in Figure 1, the kiln thermal load was identified as the product of each element of mass, its specific heat, and the temperature rise that occurs within it. With a straight line gradient, it is unnecessary to integrate an infinite number of infinitesimal slices across the wall to account for the temperature variations, rather, the entire mass can be considered to be raised to the average temperature; i.e., the temperature at the mid-point of each material. These are marked in Figure 3. The specific heats can be considered constant in each material (the concrete and the insulation) and are 0.18 Btu/lb°F in FOAMGLAS[®] insulation, 0.27 Btu/lb°F in moisture-laden concrete, and 0.20 Btu/lb°F in dry concrete. (Unless the surfaces are waterproofed, the higher specific heat should be used for concrete.) Figure 3 indicates the apparent thermal load, H, per square foot immediately below the schematic for each case depicted. The large differences in the load, H, for the three cases is clearly evident in the values of H calculated in Btu/ft² for each wall profile. Comparison of these values for the two profiles on the left in Figure 3 pinpoints the reason for the large load reduction that is indicated by the upper shaded region in the right-hand diagram of Figure 2. This is where the real energy saving occurs.

Note in Figure 2 that, as a percentage change, the measured saving is 39%, while the calculated saving in H_{total} achieved by isolating the kiln load with FOAMGLAS[®] insulation is 33%.

$$\left(\frac{5.35 - 3.58}{5.35} \right) = 33\%$$

Based on an average energy expenditure of 13.8 Mcf/kiln-cycle at this plant, the 33% represents a saving of 4.6 Mcf/cycle. On the other hand, the calculated difference in H_{total} before and after insulating is seen to be only 1.77 Mcf. The reasons for this apparent discrepancy are discussed below.

In order to find the gas actually required at the boiler to provide a particular demand at one of the loads, boiler inefficiencies, heat

changes in the steam, exfiltration, and line losses must be taken into account. Each of these factors has a multiplicative effect on the energy required to satisfy the demand at every one of the thermal loads identified. Once again, these multiplicative factors (which we will call F_1 , F_2 , F_3 , F_4) can be measured or obtained from a handbook.

F_1 is the inverse of the boiler efficiency. It depends on the combustion efficiency of the burner and the efficiency of heat transfer at the boiler tubes. "Scale" in the tubes will act more or less like the insulation diagrammed in Figure 3, but in this case at a disadvantage; it will lock some of the burner heat out of the boiler. It is best to measure burner and boiler efficiencies, but in lieu of measured values, typical combined efficiencies are in the neighborhood of 65% to 70%. Thus, $F_1 \approx 1/0.675 = 1.48$.

F_2 is the ratio of steam heat content at input to the content it can give up when it condenses to water at the curing temperature (say, 180°F). Only the difference can supply load demand, the remainder being required to maintain the condensate at the curing temperature. Thus, $F_2 = 1150/(1150 - 148) = 1.15$.

F_3 is a factor that accounts for the thermal expansion of kiln gases at a constant kiln pressure of one atmosphere. All through the period that the kiln temperature rises, the constant-pressure expansion forces a portion of the kiln atmosphere and its steam content out of the kiln, where the energy content is then lost. A good estimate of this loss would be the ratio of the final gas volume to its initial volume. This is directly proportional to the ratio of the temperatures in degrees Rankine. Thus,

$$F_3 \approx (460^\circ + 180^\circ)/(460^\circ + 65^\circ) = 1.22.$$

F_4 is a factor that accounts for heat loss by conduction through steam lines and the boiler walls. This factor may vary

considerably, depending on the extent and quality of insulation around the boiler and the lines, and may vary from a few percent to twenty percent. As an intermediate value, assume $F_4 = 1.12$.

Each thermal load, therefore, places a demand at the burner that is the product of the calculated load and these four factors. Applied to the calculated total load, $H_{total} = 5.35$ Mcf, given in Figure 2, the averages give for the computed demand, Q , at the burner:

$$\begin{aligned} Q &= H_{total} \times F_1 \times F_2 \times F_3 \times F_4 \\ &= 5.35 \text{ Mcf} \times 1.48 \times 1.15 \times 1.22 \times 1.12 \\ &= 5.35 \times 2.33 \\ &= 12.5 \text{ Mcf} \end{aligned}$$

Thus, using average F values predicts an energy demand reasonably close to the metered value of 13.8 Mcf. More accurately, at this plant $F = 2.5$ so that the calculated energy demand would be 13.4 Mcf before, and 9.0 Mcf after, insulating — very close to the measured values.

INFORMATION EXCHANGE AND FOLLOW-UP

To make the information from the DOE study available to the concrete block industry, a final report was published in 1979 and circulated among the industry's regional associations. To provide the block industry with the above technical review and the opportunity for dialog and discussion on the subject, papers on the insulation measure were presented by SSI at the National Concrete Masonry Association (NCMA) convention in January 1979, at the American Concrete Institute (ACI) convention in March 1979, and before the Pennsylvania Concrete Masonry Association (PCMA) in April 1979, at the invitation of these organizations. The papers were very well received; many questions were asked and answered. Based on the questions and dialog, it appeared that additional studies would be desirable. Specifically, information on the following items was sought:

- 1) The expected life of the insulation in this application because it has a great impact on the quality of the investment.
- 2) Data on the performance of FOAMGLAS[®] insulation in a plant that uses Johnson burners.
- 3) Data on the performance of FOAMGLAS[®] insulation in a plant with a higher than average curing efficiency.
- 4) Circumstance and performance data for a sprayed-on polyurethane insulation reported to be still operating effectively in a pipe-curing kiln after four years.
- 5) Performance data for the same polyurethane insulation applied to concrete-block-curing kilns.

Late in 1979, under a contract with the Pittsburgh Corning Corporation, Scientific Service, Inc., conducted an investigation of items (1) and (2) above, which also provided data on item (3). At this juncture, FOAMGLAS[®] insulation had been installed for some time in a plant using Johnson burners, but the performance study had never been completed.

Under the Pittsburgh Corning Corporation study, thermocouples were used to determine insulation performance at each of three plants where FOAMGLAS[®] insulation had been in service for over a year. Two plants had the insulation in service for over a year and a half, and one for about a year and a quarter. The thermocouples were installed at each plant at a number of different locations in wall and ceiling sections to record temperature profiles. The measured profiles could then be compared with the theoretical profiles such as those depicted in Figure 3. Hence, the performance of the FOAMGLAS[®] insulation after a period of service could be inferred simply by comparing measured temperature profiles with profiles calculated for new material.

Figure 4 shows an example of both calculated and measured profiles in an uninsulated wall at one plant, and Figure 5 shows the corresponding case for a FOAMGLAS[®] insulated wall that had been in service for one and a half years. Wherever measured temperatures are lower than theoretical, the R values are better than expected. Figures 6 and 7 show ceiling profiles at the same plant for corresponding circumstances. What these figures indicate is that the insulation is performing as well as, or better than, the listed R values predict. The only shortcoming of this approach is that a temperature profile is limited to describing the local region where the measurements are made, so it is not necessarily indicative of overall kiln performance. By taking measurements at a number of locations picked at random, it is more likely that, in the aggregate, they provide a reasonable representation of overall performance. In this study, five to seven point temperature profiles through insulated sections were measured at seven locations. In all cases the indicated performance after more than one year was better than the rated R value for new material.

As a backup measure, samples of insulation were selected at random at each of the three plants and sent back to the Pittsburgh Corning Corporation for analysis. At each plant one sample was selected to be representative of the worst condition, and one was selected to be representative of the average condition, based on discoloration. The worst-condition samples ranged from a 12% to a 37% change in insulating property, and the average-condition samples ranged from less than 0.3% to a 2.5% change. It should be noted that there are over 600 panels in each plant, so that an occasional panel with a 37% change would not affect the overall energy saving enough to be detectable even with careful gas metering. On the other hand, a missing panel will reduce the effectiveness 100% over its entire 3-foot square area and affect the efficiency of a one-foot perimeter around it by, perhaps, another 50%. Thus, if 5% of the insulation (i.e., 30 to 40 panels) were missing*, at random, this could reduce the

* After a year and a half, about 2% were missing at one plant, due to forklift damage.

Fig. 4. UNINSULATED KILN WALL TEMPERATURE PROFILES

Fig. 5. INSULATED KILN WALL TEMPERATURE PROFILES

l i s l a e d

annual thermal load **632 Mcf**
PER 1000 FT²

Fig. 6. UNINSULATED KILN CEILING TEMPERATURE PROFILES

insulated

annual thermal load **32 Mcf**
PER 1000 FT²

Fig. 7. INSULATED KILN CEILING TEMPERATURE PROFILES

overall energy saving in a kiln by 10% — a measurable amount — while a 5% sprinkling of panels with reduced effectiveness (according to the worst case found) would reduce the overall energy saving about 2%; in the average case the effect would be less than 1%.

The net effect of the Pittsburgh Corning Corporation study was to show that the FOAMGLAS[®] insulation was still performing very well after a period of one and a half years, that it can survive in the environment created by Johnson burners, and that it appears to have a reasonable pay-back period even when installed in one of the more efficient curing kilns. Additional data were developed on the latter subject in the present study, as well as an evaluation of sprayed-on polyurethane foam. These findings are presented in the next section.

Section 3

KILN-INSULATION EVALUATION STUDIES

Evaluation studies of insulation that was installed on inside surfaces of kilns to lock the kiln-mass out of the curing cycle were carried out at three plants: the Blocklite plant in Selma, California; the Ameron pipe plant in Madison, California; and the Superlite plant in Phoenix, Arizona. At the Blocklite plant, the performance of FOAMGLAS[®] insulation, installed in a test kiln over one year earlier, was assessed. At the Ameron pipe plant, the performance of a sprayed-in-place polyurethane foam insulation, installed four years earlier, was assessed. At the Superlite plant, the performance of this same foamed-in-place material, installed in the higher temperature environment of concrete block curing kilns, was assessed. Each of these assessments is described in detail below.

BLOCKLITE PLANT

Kilns at the Blocklite plant were insulated during the earlier DOE study. This earlier study confirmed that the hydration cycle was the most efficient, in terms of Btu/lb, of four plants in which energy use measurements were made. Moreover, the energy use at this plant for the hydration cycle was roughly half the national average, according to the 1972 Bureau of Census data on this industry (Ref. 2). In addition to the exceptional energy efficiency without insulation, other unique factors at this plant dictated special interest:

- 1) The plant curing process included a drying cycle (which none of the other eleven plants visited did).
- 2) The plant utilized Johnson burners, which fired combustion products directly into the kiln, so represented a harsher

environment for the insulation than at the other plants studied.

- 3) The hollow-core walls of the kilns were filled with expanded clay, which is a very effective insulation for this kind of application.
- 4) Because of return flow ducts, portions of the kiln were inaccessible, so that a significant part of the kiln thermal mass could not be isolated.

In short, if retrofitting with FOAMGLAS[®] insulation were found cost beneficial at this plant, it would add credibility to the likelihood that it might prove cost beneficial, generally.

In addition, the subsequent study provided data on FOAMGLAS[®] insulation performance after it had been in place for over a year. Also, the current effort provided the opportunity to install water meters to provide data on the reproducibility of Johnson burner output converted to steam.

Figures 8 through 12 provide a pictorial summary of the plant curing system arrangement, and Figures 13 through 15 provide views of the procedures used to install the FOAMGLAS[®] insulation (September 1978). For the recent study, eight thermocouples were installed in each of the two kilns; i.e., the insulated kiln and one uninsulated reference kiln, to monitor the temperature histories at different locations. Additional thermocouples were used to monitor ambient conditions. Figures 16 and 17 show the location of these thermocouples in the two kilns and the portion of Kiln # 1 not insulated. It should be noted that the end wall of Kiln # 1 (the wall on the right-hand side of Figure 16) is made of 12-inch block, so that the thermal mass not isolated by insulation in this kiln constitutes a thermal load 50% greater than the corresponding portion of the uninsulated reference kiln.

Fig. 8. View of the kilns at the Blocklite plant. Penthouses above each kiln are where burners that supply the process heat are located.

Fig. 9. Closeup of a penthouse. Johnson burners fire directly inside, one for hydrating and one for drying.

Fig. 10. Closeup of the meter that monitors gas to the Johnson burner on the drying cycle.

Fig. 11. View of the burner port from inside the penthouse. Note the igniters.

Fig. 12. View inside penthouse.

Fig. 13. FOAMGLAS[®] insulation panels mounted on ceiling of penthouse.

Fig. 14. Applying silicone mastic to panel.

Fig. 15. Drilling for mechanical anchor used to hold panel until mastic sets.

Fig. 16. Schematic of Kiln # 1 showing insulated areas, uninsulated return flow ducts, and thermocouple locations.

Fig. 17. Schematic of uninsulated reference Kiln # 3 showing thermocouple locations.

Data and Results

The data collected throughout each cycle in each of the two kilns comprised: the gas volume for the hydration and for the drying cycles, metered individually; the water volume, evaporated in the hydration stage; and thermocouple output, printed every 15 minutes throughout the entire process.

Table 1 summarizes metered hydration-cycle data on gas usage (ΔV gas) in thousands of cubic feet (Mcf) and the quantity of water evaporated, in cubic feet. Dividing the latter by the former to get the ratio of water evaporated to energy expended (ΔV ratio) makes it apparent that the variation between Johnson burners and between cycles is small; the five cycle averages for evaporation rates in the two kilns differed by less than 2%, somewhat less than the small, 4% to 5%, individual burner variation from cycle to cycle. The conclusion is, there is no significant performance difference between burners to consider here.

Table 2 provides a typical hourly log of the eight monitored thermocouple temperatures in the insulated kiln, together with the means and the standard deviations for one complete curing cycle. The significance of the standard deviation, σ , is that it provides a quick appraisal of the variation in the data (the variation being less, the smaller the σ) and it enables the probability to be stated that a given datum of the set might differ from the mean by more than some multiple of σ . From an examination of σ in Table 2, it can be seen that, once the doors to the kiln are shut (at 2200 on 11/6) and the pre-set period begins, the kiln comes to a uniform temperature, and the temperatures at all the eight locations differ very little ($\sigma = \pm 2^\circ\text{F}$ at 2300 on 11/6). However, when the burner fires (between 0300 and 0400 on 11/7) and steam and hot gases swirl through the kiln, the variation increases substantially, to $\pm 13^\circ\text{F}$, and remains around $\pm 11^\circ\text{F}$ until the drying cycle commences (between 1200 and 1300 on 11/7). Immediately following the start of the drying cycle, the standard deviation for the eight thermocouples jumps dramatically. An examination of the columns of figures suggests that

TABLE 1: METERED GAS AND WATER USAGE

		Insulated Kiln					Uninsulated Kiln					
Cycle	Date/Time	Gas Meter (ft ³)	ΔV Gas (Mcf)	Water Meter (Ft ³)	ΔV Water (ft ³)	ΔV Ratio (ft ³ /Mcf)	Gas Meter (ft ³)	ΔV Gas (Mcf)	Water Meter (ft ³)	ΔV Water (ft ³)	ΔV Ratio (ft ³ /Mcf)	
1	11/5/2215	2211570		0.02								
	11/6/0900		7.750		51.77	6.68	5320870		2.09			
	11/6/2200	2219320		51.79				6.960		50.43	7.25	
2	11/7/0800		7.030		48.89	6.95	5327830		52.52			
	11/7/2300	2226350		100.68			27830	7.450	57.45 ⁽¹⁾	48.85	6.56	
3	11/8/0800		6.700		47.12	7.03	5335280		106.30			
	11/8/2200	2233058		147.80			35280	7.010	109.13 ⁽²⁾	47.85	6.83	
4	11/9/1100		7.170		49.90	6.96	5342290		156.98			
	11/9/2200	2240270		197.70				7.220		50.75	7.03	
5	11/11/1600		6.100		37.77	6.19	5349510		207.65			
	11/13/0900	2246320		235.47				6.730		45.13	6.71	
	11/13/0945						5356240		252.78			
						6.76± 5%						
						7.16± 6%						
</												

TABLE 2: KILN #1 HOURLY TEMPERATURE LOG

Thermocouple Time	(Degrees F)									Mean & Std Dev. All Thermocouples Less 22, 23 ($^{\circ}\text{F} \pm \sigma^{\circ}\text{F}$)	Remarks
	15	16	17	18	19	21	22	23			
11/6 2200	78	89	87	77	83	62	67	72		77 ± 9	Loaded at 2200
2300	82	83	84	83	87	82	83	81		83 ± 2	
2400	81	83	83	83	85	82	84	81		83 ± 1	Starting temp
11/7 0100	81	82	83	83	84	81	83	82		82 ± 1	
0200	82	83	83	83	83	82	83	83		83 ± 0	
0300	83	84	84	84	83	83	83	84		83 ± 1	
0400	96	96	115	111	131	124	106	100		110 ± 13	Burner fires
0500	107	108	105	105	105	103	104	104		105 ± 2	Burner off
0600	140	142	146	131	127	117	117	117		130 ± 12	Burner fires
0700	118	131	141	136	154	144	125	130		136 ± 10	
0800	158	159	162	153	171	159	139	143		156 ± 10	
0900	163	166	169	161	179	166	146	151		163 ± 10	<i>continued</i>

TABLE 2: KILN #1 HOURLY TEMPERATURE LOG

(continued)

Thermocouple Time	15	16	17	18	19	21	22	23	Mean & Std Dev. All Thermocouples (°F ± σ°F)	Less 22, 23 Std Dev. (°F ± σ°F)	Remarks
	(Degrees F)										
1000	171	173	177	170	186	171	153	158	170 ± 10		
1100	175	176	178	172	188	175	157	162	173 ± 10		
1200	178	179	183	177	194	179	161	165	177 ± 11		Hydration peak Drying burner fires
1300	202	209	214	203	234	204	162	164	199 ± 25	211 ± 12	
1400	218	230	231	226	249	217	162	166	212 ± 31	228 ± 12	
1500	226	242	245	238	259	229	158	170	221 ± 37	240 ± 12	
1600	233	250	250	244	259	230	162	169	225 ± 38	244 ± 11	
1700	237	258	259	254	270	235	166	172	231 ± 42	252 ± 14	Drying peak Burner off
1800	172	179	178	192	186	172	162	165	176 ± 10		Exhaust fan
1900	130	147	151	154	144	98	87	118	129 ± 25		
2000	118	131	132	131	135	71	80	100	112 ± 25		

all of this additional variation is due to thermocouples 22 and 23, and this is readily confirmed by calculating the standard deviations for the other six thermocouples alone (from 1300 hours through 1700 hours). The conclusion is that the variation observed is "systematic", rather than random; i.e., there is a consistent factor causing this perturbation (probably the location of the exhaust duct; see Figure 16).

The same general behavior implied by the data in Table 2 is apparent in the data in Table 3, which summarizes the corresponding information for one complete cycle in the uninsulated reference kiln. The close similarity in behavior in the two kilns indicates that little difference should be expected in a comparison involving all the channels of information, or just those remaining after the systematic anomalies are excluded. For this reason all eight channels of thermocouple data are included in Table 4, which summarizes the thermocouple temperatures at the peaks in the hydration cycle, together with the corresponding means and standard deviations. The means and standard deviations are given by cycle (numbers reading across) and by thermocouple location (the numbers reading down). The latter data, summarized across the bottom row, show remarkable consistency over five cycles for the peak temperatures recorded during the hydration cycle at each particular location in each kiln. Moreover, the variation in the average of the mean temperature peak over five cycles shows unusually good consistency in the uninsulated kiln ($\sigma = \pm 1^\circ\text{F}$) and quite good consistency in the insulated kiln ($\sigma = \pm 5^\circ\text{F}$). The fact that the average temperature peak of the insulated kiln (172°F) is generally higher than that in the uninsulated kiln (167°F) may be considered significant.

Table 5 summarizes the drying cycle data corresponding to the hydration cycle data of Table 4. Again, the consistency is very good, and the differences between the insulated and uninsulated kilns are significant. To facilitate evaluation of the significance of the differences in Tables 4 and 5, Table 6 has been compiled. Table 6 shows the temperature rise over each cycle that is directly due to energy input. Values

TABLE 3: KILN #3 HOURLY TEMPERATURE LOG

Thermocouple Time	6	7	8	9	10	11	12	13	Mean & Std Dev. All 8 Thermocouples (°F ± σ °F)	Remarks
11/7 0800	63	85	81	73	72	73	90	80	77 ± 9	Loaded at 0800
0900	80	85	88	82	82	86	83	80	83 ± 3	
1000	79	85	86	83	83	85	83	81	83 ± 2	Starting temp.
1100	81	85	86	84	84	86	84	82	84 ± 2	
1200	84	86	86	84	85	86	85	83	85 ± 1	
1300	85	86	87	86	86	87	86	85	86 ± 1	
1400	87	88	88	88	88	89	88	87	88 ± 1	
1500	96	123	130	108	113	112	108	105	112 ± 11	Burner fires
1600	107	140	144	121	126	123	120	116	125 ± 12	
1700	118	126	124	120	120	120	120	117	121 ± 3	Burner off
1800	128	160	165	143	145	144	142	137	146 ± 12	Burner fires
1900	135	168	173	151	138	152	150	137	158 ± 13	continued

TABLE 3: KILN #3 HOURLY TEMPERATURE LOG

(continued)

(continued)										
Thermocouple	6	7	8	9	10	11	12	13	Mean & Std Dev. All 8 Thermocouples (°F ± σ °F)	Remarks
Time	Temperature in °F									
2000	142	173	179	159	158	159	156	148	160 ± 2	Hydration peak Drying burner on
2100	146	178	184	165	162	164	161	150	164 ± 13	
2200	148	181	187	168	164	166	164	152	165 ± 13	
2300	147	208	204	176	171	177	176	161	173 ± 20	
2400	146	221	214	184	175	183	184	165	184 ± 24	
11/8 0100	143	222	214	182	170	187	189	170	184 ± 25	
0200	141	225	217	181	165	190	192	175	186 ± 27	
0300	142	229	221	187	168	192	198	178	189 ± 28	
0400	142	233	225	191	167	195	203	180	192 ± 30	
0500	142	155	153	152	143	146	145	144	148 ± 5	
0600	65	120	115	85	79	92	116	101	97 ± 20	Exhaust fan

TABLE 4: HYDRATION CYCLE RECORDED PEAK TEMPERATURES

Cycle	Insulated Kiln #1									Reference Kiln #3								
	15	16	17	18	19	21	22	23	Average of 8	6	7	8	9	10	11	12	13	Average of 8
1	171	173	177	173	186	172	154	158	$170 \pm 10^{(1)}$	180	186	162	152	150	166	165	165	$166 \pm 12^{(1)}$
2	178	179	183	177	194	179	161	165	177 ± 11	148	181	187	168	164	165	164	152	166 ± 13
3	175	177	182	176	189	175	158	163	175 ± 10	150	181	188	168	169	166	164	154	168 ± 13
4	174	177	180	174	189	174	158	162	174 ± 10	151	181	188	161	160	167	168	157	167 ± 12
5	161	164	169	163	185	164	155	153	164 ± 10	145	188	194	162	152	164	169	155	166 ± 17
									$172 \pm 5^{(3)}$									$167 \pm 1^{(3)}$
	$175 \pm 3^{(2)}$	177 ± 3	181 ± 3	175 ± 2	189 ± 3	175 ± 3	158 ± 3	163 ± 3		$155 \pm 14^{(2)}$	183 ± 3	184 ± 12	162 ± 7	159 ± 8	166 ± 1	166 ± 2	157 ± 5	

(1) Mean and standard deviation in the peak temperature for one cycle/8 thermocouples (horizontal rows).

(2) Mean and standard deviation in the peak temperature for one location/5 cycles (vertical columns).

(3) Average, and standard deviation in the average, of the mean temperature peaks/5 cycles.

TABLE 5: DRYING CYCLE RECORDED PEAK TEMPERATURES

	Insulated Kiln #1									Reference Kiln #3								
Cycle	Thermocouple Number								Average of 8	Thermocouple Number								Average of 8
	15	16	17	18	19	21	22	23		6	7	8	9	10	11	12	13	
1	228	253	249	244	260	229	159	167	224± 39 ⁽¹⁾	223	215	188	168	140	182	173	186	184± 26 ⁽¹⁾
2	237	258	259	254	270	235	166	172	231± 42	142	233	225	191	167	195	203	180	192± 30
3	238	264	257	252	265	232	160	175	230± 41	143	230	226	188	170	194	185	178	191± 29
4	227	257	256	247	262	227	159	163	225± 41	143	228	221	176	163	191	196	179	187± 28
5	224	218	237	220	261	219	158	171	214± 34	148	227	225	186	166	189	198	188	191± 27
									225 ± 7 ⁽³⁾									189 ± 3 ⁽³⁾
	231± 6 ⁽²⁾	250± 18	252± 9	243± 14	264± 4	228± 6	160± 3	171± 3		144± 3 ⁽²⁾	230± 3	224± 2	185± 7	167± 3	191± 3	198± 4	181± 5	

(1) Mean and standard deviation in the peak temperature for one cycle/8 thermocouples (horizontal rows).

(2) Mean and standard deviation in the peak temperature for one location/5 cycles (vertical columns).

(3) Average, and standard deviation in the average, of the mean temperature peaks/5 cycles.

TABLE 6: RECORDED TEMPERATURE CHANGES, BY CYCLE, DUE TO BURNER INPUT

Insulated Kiln #1						Reference Kiln #3					
CYCLE	HYDRATION			DRY		HYDRATION			DRY		
	Peak (°F)	Start Temp (°F)	Temp Rise ΔT (°F)	Peak (°F)	Temp Rise ΔT (°F)	Peak (°F)	Start Time (°F)	Temp Rise ΔT (°F)	Peak (°F)	Temp Rise ΔT (°F)	
1	170		<u>103</u>	224	<u>54</u>	166		<u>100</u>	184	<u>18</u>	
		67					66				
2	177		<u>94</u>	231	<u>54</u>	166		<u>83</u>	192	<u>26</u>	
		83					83				
3	175		<u>87</u>	230	<u>55</u>	168		<u>80</u>	191	<u>23</u>	
		88					88				
4	174		<u>88</u>	225	<u>51</u>	167		<u>83</u>	187	<u>20</u>	
		86					84				
5	164		<u>102</u>	214	<u>50</u>	166		<u>98</u>	191	<u>25</u>	
		62					68				

are given both for the hydration and for the drying stages in each kiln. The temperature difference between the hydration peak and the drying peak is the drying cycle temperature rise attributable to the drying cycle burner, and the temperature difference between the starting temperature before the burner fires the first time and the hydration peak is the hydration cycle temperature rise attributable to the hydration cycle burner. The starting temperature is selected as the recorded mean temperature two hours after the doors are closed, rather than just before the burner fires the first time, to give credit in the uninsulated kiln for heat transferred to the green block from the walls.

The energy consumed by the drying cycle burners is summarized in Table 7 (the energy consumed by the hydration cycle burner was listed in Table 1). Note the first cycle is missing in Table 7 due to a failure to record the initial gas meter readings. Table 8 integrates the information in Tables 1, 6, and 7 to present the energy required per degree rise ($H/\Delta T$) in each of the two kilns for the hydration and for the drying phases of each curing cycle. These values are derived simply by dividing the recorded energy consumed (Tables 1 and 7) by the observed corresponding temperature rise given in Table 6. At the bottom of each column in Table 8 the means and standard deviations have been indicated. The difference in these mean values implies a difference in efficiency between the insulated and the reference kiln, with the lower values indicating less energy required to achieve a one degree temperature rise.

A direct comparison of the values will indicate the potential energy saving for insulated versus uninsulated kilns. This turns out to be 8.4% in the hydration cycle and 53.8% in the drying cycle at this plant. Applied to the average values for energy consumed per curing cycle in the insulated kiln (7.16 Mcf for hydration; 4.84 Mcf for drying; 12.0 Mcf for the total cycle) the indicated gas saving for identical temperature cycles is 0.60 Mcf in hydration and 2.60 Mcf in drying, or 3.20 Mcf total out of 12.0 Mcf. Applied to standard block (8" x 8" x 16"), the insulated kiln energy usage would correspond to 74 Btu/lb to hydrate and 24 Btu/lb to

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(1) Meter reading not logged.

TABLE 8: ENERGY CONSUMED PER DEGREE RISE

Cycle	<u>Insulated Kiln #1</u>		<u>Reference Kiln #3</u>	
	Hydration Cycle H/ΔT (Mcf/°F)	Dry Cycle H/ΔT (Mcf/°F)	Hydration Cycle H/ΔT (Mcf/°F)	Dry Cycle H/ΔT (Mcf/°F)
1	0.0752		0.0696	
2	0.0748	0.0892	0.0898	0.1600
3	0.0770	0.0935	0.0876	0.2230
4	0.0815	0.1035	0.0870	0.2560
5	0.0598	0.0822	0.0687	0.1992
	0.0737 ± 11%	0.0969 ± 9%	0.0805 ± 13%	0.2096 ± 19%

Hydration Cycle Saving: $\frac{0.0805 - 0.0737}{0.0805} = 8.4\%$

Drying Cycle Saving: $\frac{0.2096 - 0.0969}{0.2096} = 53.8\%$

dry. Overall, this constitutes a saving of 26.7% per curing cycle. For 230 curing cycles annually, the dollar saving at \$3.20/Mcf corresponds to \$2,360. This should be compared with a total implementation cost of \$6,400. The investment constitutes a four-year payback at 12% interest, with a return on investment of 19.5%, assuming a ten-year life expectancy.

The predicted saving at the Blocklite plant from installing FOAM-GLAS[®] insulation was 22%. This is somewhat less than the 26.7% the above temperature comparison indicates, and considerably less than predicted for the kilns that were insulated at the other two locations. The reason a smaller saving was predicted at the automated plant was that it had built-in return flow ducts (Figures 16 and 17) that made part of the active kiln surfaces inaccessible. Inaccessible areas reduce the effectiveness of the insulation on accessible areas somewhat more than the relative areas indicate because of the edge effects along their perimeters. Even so, a four-year payback, at present interest rates (12%), is not an unreasonable risk, and an after-tax return above cost equal to 19.5% compounded annually is not a bad investment. However, to realize this dollar saving, an adjustment is required in the controller to make it follow the same curing cycle as in an uninsulated kiln.

AMERON PLANT

Discussions held in 1978 with personnel at the Ameron pipe plant in Oakland, California unearthed the information that one of the company's pipe curing kilns (in Madison, California) had insulation installed inside it sometime in 1974 or 1975. The material was reported to be a five-year-old sprayed-in-place polyurethane foam (CPR-480, manufactured by CPR Upjohn Corporation), which was still saving considerable energy. In seeking performance data, it was discovered that the boiler served uninsulated kilns simultaneously, and that it was oil fired, and the oil was a common supply for the plant's delivery trucks as well. For these reasons, no data were readily available to assess either the current or historical performance of the insulation, other than a less frequent purchase of oil.

There are several reasons why information on the pipe kiln environment, and the performance of this particular material in that environment after several years of service, are of considerable interest. These reasons are:

- (1) It was known that urethane insulations, both board and sprayed-in-place, had been tried in concrete block kilns with totally unsatisfactory results. Hence, there was interest in whether the particular material performing in the pipe kiln, or the kiln environment, were different somehow.
- (2) It was known that sprayed-in-place urethanes were less expensive to install than FOAMGLAS[®] insulation.
- (3) A clean, dry kiln could be retrofitted in one day with the sprayed-in-place materials, compared with several days of lost production per kiln to retrofit with the FOAMGLAS[®] insulation.

To evaluate the potential of this particular polyurethane insulation

applied to concrete block kilns, it was considered important to find out how well it was performing after five years of service in the Ameron pipe kiln. The complexity of monitoring and allocating fuel usage (discussed above) precluded a direct assessment of the saving. It was decided, therefore, to apply the procedure developed for the Pittsburgh Corning Corporation study discussed in Section 2; i.e., to determine temperature profiles through the kiln and compare them with theoretical values. In addition, a sample of the material was taken to the laboratory to examine.

It should also be noted that shortly before this study was begun, the Ameron plant had additional kilns sprayed with the same insulation, and a large portion of the material that had been in service for about five years was replaced. Consequently, the remaining material necessarily represented the better-than-average condition after five years, so that none of the profiles taken can be considered to represent the worst condition, which it was planned to evaluate as one of the three profiles. Nevertheless, the results of the profile analysis on the remaining five-year-old material may be expected to be informative.

Figure 18 shows a typical wall cross-section in the test kiln, identifies thermocouples (by their recording channel number), and indicates their relative locations through the wall. Note that insulation slightly over 2 inches thick covers both the inside and the outside wall surfaces because the latter surface is the inside of another kiln (not in use at the time). In the plane of the wall, each thermocouple was placed in its own individual hole drilled to the proper location (depth) from the outside surface. Each of these holes was sealed after the thermocouple was placed. No hole was located closer than 8 inches from another, and separate profiles were as much as 10 feet apart.

Data and Results

The data collected throughout each cycle comprise the output from 17 thermocouples plus two thermal flux sensors. These data were printed every 15 minutes. The thermal flux sensors were placed so that one was

Fig. 18. Cross-section of kiln wall showing thermocouple locations.

on the kiln inside surface and one on the kiln outside surface, directly in line.

Table 9 provides a typical hourly log of the 17 monitored thermocouple temperatures and the two thermal flux sensors. In Figure 19, thermocouple data from another cycle have been developed into a summary of the profile temperatures, bihourly, from the start of the steaming period (1400 hours) until the steaming ceases (2200 hours). The shaded region shows where the thermal load is concentrated at 2000 hours.

Assuming a steady state condition at the peak temperature (168°F), a theoretical temperature profile was calculated to compare with the measured profile at 1800 hours (Figure 20). The figure indicates the actual temperature profile through the insulation to be essentially that calculated for new material. Actually, the entire wall system never reaches a steady state condition, but parts of it come very close. This can be used to check insulation performance via another procedure.

In the four-hour period from 1800 hours to 2200 hours (Figure 19), the temperature inside the kiln was very nearly constant at 161°F. Thus, the rate of heat flow through the internal insulation plus the block wall remained essentially constant in that period. Likewise, the rate of heat flow through the external layer of insulation out of the wall also remained nearly constant. The latter is at a slower rate because the temperature differential driving it out is only 11°F (from 92°F down to 81°F) compared with the temperature differential of 69°F (from 161°F down to 92°F) driving it in. The overall effect is to cause essentially equal amounts of heat to be trapped inside the wall, between the two layers of insulation, in equal time periods, between 1800 and 2200 hours. Any stored heat (represented by a temperature rise) should equal the difference between the heat flow entering and the heat flow leaving the opposite face as recorded by the thermal flux sensors.

When the above cited calculations are made, the stored heat indicated by the temperature data corresponds to heat input of $10.1 \pm .6$ Btu/hr ft²,

TABLE 9: TYPICAL HOURLY LOG — MADISON PLANT

Time	Thermal Flux Sensors		Thermocouples																
	1	4	2	3	6	8	9	10	11	12	13	14	15	16	19	20	21	22*	23
	(Btu/hr ft ²)		(°F)																
1400	1.3	0	78	81	93	97	88	92	92	89	87	92	88	79	87	92	90	76	90
1500	1.8	0.5	82	82	92	97	88	92	92	90	87	92	88	80	85	92	90	78	90
1600	15.8	1.5	83	115	92	98	90	91	91	89	87	91	88	79	87	91	90	78	90
1700	22.8	1.2	83	111	93	96	93	93	91	89	87	92	88	80	89	92	90	81	93
1800	33.5	2.1	84	157	95	96	103	97	91	90	88	92	89	81	91	92	91	87	98
1900	25.0	2.1	88	158	98	97	107	100	92	90	88	92	89	83	93	93	91	87	104
2000	19.2	2.1	83	157	100	98	111	103	93	90	88	92	90	85	95	93	91	89	109
2100	16.2	1.8	82	155	102	98	113	105	95	91	88	92	90	87	96	94	91	90	110
2200	15.2	2.4	82	155	104	99	114	106	96	91	89	93	90	88	97	94	91	90	111
2300	16.5	2.7	81	151	105	100	115	107	97	92	89	93	90	89	97	94	91	90	109
2400	19.0	4.5	81	159	106	101	116	108	98	93	89	94	91	90	97	95	91	90	113
0100	2.0	5.7	81	130	107	102	114	108	99	93	90	95	90	90	97	95	92	89	113

* Thermocouple location compromised during loading.

Fig. 19. Typical profiles as a function of time (Starting time: 1400 hours).

Fig. 20. Temperature profile at eighteen hundred (1800) hours and corresponding theoretical steady-state profile.

while the thermal flux sensors indicate 14.5 Btu/hr ft² in and 2.6 Btu/hr ft² out, for a net flow of 11.9 Btu/hr ft². The agreement is very good, so the value of 14.5 Btu/hr ft² and the 69°F driving temperature were used to calculate the current R value for what we acknowledge was the better portion of the polyurethane foam; i.e., that which was still serviceable after five years. This R value is 4.8, which should be compared with a value for new insulation of R-7.1. Thus, a 33% degradation has occurred, and it raises the question, "What might the effect of this degradation be on the energy saving today?"

To answer this question it is important to consider how else the insulation might have changed. The most important change, other than the above-indicated change in the insulating capacity, is the change in mass due to absorption of moisture. To determine this mass, a full 2½-inch thick section of the insulation, one quarter of a square foot in area, was removed, placed in a waterproof wrapping, and taken to the laboratory to evaluate. At the laboratory, the sample weighed 346 grams. It was then dried in an oven and weighed repeatedly until its weight became constant, at 40 grams. The moisture removed from the sample was 306 grams, corresponding to 2.68 lb/ft² of insulation.

By applying the same kind of analysis summarized in Figure 3, and accounting for the 2.68 lb/ft² of water content (at a specific heat of 1 Btu/lb°F), the temperature profile in Figure 19 at 1800 hours (or Figure 20) can be used to calculate the thermal load of the wall cross-section (including the moisture-laden insulation) for one cycle. This is just the energy stored in the wall when the steam is shut off. By comparing this to an uninsulated, bare wall, the reduction in load demand due to the insulation (five years old and moisture laden) can be determined.

The calculated annual load per thousand square feet of uninsulated wall for the typical 70°F temperature rise at the Madison location, is 91 Mcf (seven eighths the value in Figure 4 because the temperature rise is 70°F versus 80°F). For the insulated wall (in its present state),

the corresponding thermal load is 22 Mcf. The difference, 69 Mcf, multiplied by an F factor ($F_1 \times F_2 \times F_3 \times F_4$) of 2.3, is the annual saving at the burner due to the five-year-old insulation. This energy saving (oil) corresponds to 1.14 gal/ft² per year, worth about \$1.10 today. When new, this insulation was calculated to save 1.33 gal/ft² per year. Thus, the change (due to five years of service) calculated by this thermal load method is:

$$\frac{1.33 - 1.14}{1.33} = 14\%$$

which shows that the thermal load change (due to both degradation of the insulation and to moisture absorption) is at a slower rate than the change in R value. This is true for any insulation.

Perhaps the most important thing to note is that the capital cost for the complete installation was only \$0.90/ft². Compared with a first year return of \$0.60/ft², increasing steadily to a \$1.10/ft² return in the fifth year — the increase due to fuel costs increasing faster than the insulation deteriorated — it appears to have been a good investment at Ameron's Madison plant, even though much of it needed replacement after the fifth year. In any case, Ameron thought it good enough to warrant replacing it after five years, and insulating the remaining kilns.

SUPERLITE PLANT

Interest expressed at Superlite in evaluating the merit of insulating led to a study of the foamed-in-place polyurethane insulation that had served successfully in the Ameron concrete pipe kiln for several years. Figure 21 shows the spray apparatus (in the plywood box) used to apply two inches of polyurethane foam to the inside surface of eight kilns. Special precautions are required when spraying this material. Protective clothing and an independent clean air supply (Figure 22) are safety requirements that should not be ignored, particularly in enclosed spaces. It should also be noted that this material cannot be applied at all inside kilns that use Johnson burners, because of the fire hazard, and polyurethane foams cannot be used in applications where people must conduct operations regularly, unless a half-hour fire wall, or fireproof coating, is applied over it.

At the Superlite plant, kilns operate from steam supplied by central boilers, and the block are moved into and out of the kilns automatically. Therefore, this plant provided one of the best locations for testing the polyurethane material. A view of the material being applied is shown in Figure 23, and Figure 24 provides a closeup view of a freshly sprayed surface, unaffected by ultraviolet light. (Contrast this with the material after exposure to sunlight in Figure 25.)

Because the Superlite plant is one of the largest producers of block in the world, if not the largest, it presented a unique opportunity for this study. At this plant, four groups of eight kilns are served independently, and simultaneously, each group by one of four identical boilers. To make the comparison of relative efficiency, it was planned to insulate one group of eight kilns, monitor the energy expended at the boiler, and compare this with eight uninsulated kilns by monitoring the energy expended at the corresponding boiler. As a measure of energy expended, it was considered more accurate for purposes of comparing kiln performance to meter

Fig. 21. Spray apparatus used to spray polyurethane foam inside eight kilns at the Superlite plant.

Fig. 22. A view of the spray gun and safety equipment that is required for spraying polyurethane foam.

Fig. 23. Spraying polyurethane foam on vertical surface.

Fig. 24. Closeup view of surface of freshly sprayed polyurethane foam.

Fig. 25. View of the inside of the Ameron pipe kiln showing polyurethane foam after reaction with sunlight.

the boiler water evaporated to steam. The reason is that the steam demand is directly related to the thermal load at the kilns, which eliminates different boiler efficiencies as another parameter to consider.

A direct comparison of the metered boiler-water supply lines was not valid, however, because substantially different masses of block were cured in the two groups of kilns in the period monitored after the insulation was installed. The dependence of kiln efficiency on total mass within the kiln is, of course, the reason for development of the kiln-mass isolation concept in the first place. To account for variable efficiency with different masses of green block, a regression analysis was conducted.

The relationship found to provide the best fit to these data was a power curve (of the form $y = ax^b$). Figure 26 is a plot that relates pounds of steam required, per ton of product, to the output per curing cycle (expressed in mass units, M, per period, t, for proprietary reasons). For the insulated kilns there are six datum, and the regression has a correlation coefficient of 0.80. This means the probability is one in sixty that the relationship drawn is not appropriate. For the uninsulated kilns the regression curve has a correlation coefficient of 0.53, and the corresponding probability is one in six that the relationship indicated is inappropriate. (To be convincing, the odds should be less favorable for a chance relationship, perhaps somewhere around one in seventy). A curve fit to these data is not meaningful, so another means is required to engender confidence in a comparison. The means was provided by data available, on a monthly basis, from a prior year, 1978.

The 1978 data comprised total plant output tonnage versus metered gas usage. A regression using all twelve months of the data did not provide the measure of confidence sought, however. On further examination it was noted that in the summer months the data appeared to be scattered at random, probably because only half the boilers are necessary, and switching boilers (hence, efficiencies) is a possible cause. In the winter all the boilers are used each month, and the data may be expected to be more consistent.

Fig. 26. Curing energy dependence on green block load for kilns at Superlite plant.

When a power curve was fit to the winter month data by regression analysis (Figure 27), the curve had a correlation coefficient of 94%, which corresponds to a probability around one in a thousand that the curve drawn is inappropriate. By using a conversion factor, the data of Figure 27 were also placed in the same units as data in Figure 26. Simply by multiplying the metered gas consumption per pound (Btu/lb) by 1.18, the energy demand at the boiler can be determined in pounds of steam per ton of product. The corresponding curve is plotted in Figure 27. If this upper curve were plotted in Figure 26, it would show an energy demand much higher than all but one of the datum on the figure, indicating other improvements than kiln insulation have taken place at the Superlite plant since 1978. The major point in making the comparison is to confirm that the improvements at the Superlite plant in the interim (which includes the insulation) are substantial in the range of 2.0 to 3.0 M/t units.

Because a regression curve to account for variation of efficiency in the uninsulated kiln (with mass cured) cannot be developed with sufficient confidence at this point, the comparison will be made using just those four datum in Figure 26 in the vicinity of 2.0 to 2.6 M/t. This is in the range where the majority of the production occurs anyway. The mean is 2.2 M/t for the data selected, and the corresponding mean energy demand is 150 lb of steam per ton of product (127.7 Btu/lb). The ordinate at M/t = 2.2 for the curve representing the insulated kiln is 92 lb of steam per ton of product (78.3 Btu/lb). Thus, the saving due to the polyurethane foam is:

$$\frac{127.7 - 78.3}{127.7} = 38.7\%$$

whereas the predicted value was about 39%. The 38.7% saving corresponds to an annual saving of \$1.13/ft² for an option that cost \$1.12/ft², installed, and required only one day per kiln to implement. The short payback and the rapid installation time are extremely attractive, the latter because there is little production time lost in a retrofit. No estimate was made of the return on investment because of the uncertainty surrounding life expectancy of this insulation.

Fig. 27. Superlite plant curing energy dependence on green block load two years before insulating.

Expected Life (Superlite Plant)

Because the assessment of the Ameron pipe kiln had indicated gradual deterioration of the insulation over five years (see, for example, Figures 28 and 29), it was expected that similar deterioration would eventually be observed in the Superlite kilns. The process was observed to start in one kiln when a stuck steam valve produced the effect seen in Figure 30 on the first curing day following the installation. In a matter of months, blistering, cracking, and delaminating were all observed in most of the kilns. Figures 30 and 31 provide views of this behavior. The greatest damage occurs at the ceiling, where temperatures remain the highest.

A recent assessment of the current effectiveness of the insulation indicated it had dropped only $2\% \pm \frac{1}{2}\%$, on average, to $98\% \pm \frac{1}{2}\%$ of its original effectiveness. This much change is scarcely of concern, excepting it occurred in six months, and the question of rate of deterioration is very important. Though the question is not easily answered, the deterioration is obviously much faster than in the pipe kiln. In an attempt to learn something of the cause, SSI conducted some small-scale experiments in the laboratory in which the material was subjected to heat without moisture for an hour at successively higher temperatures, each following a cooling to ambient. For the laboratory tests, dry heat was applied to raise the temperature, in steps, to peaks of 140°F, 160°F, 180°F, 200°F, and 212°F. No threshold effects were apparent (but the tests were short, and time dependence would alter this). When steam was used instead of dry heat, some defects (of the same type found in the kilns) were observed to occur after only one hour at 200°F. These are shown in Figure 32. Unfortunately, funds were not available under this contract to study coatings as a means to control the deterioration, but the additional study of the deterioration process, just described, suggests adding yet another constraint to the use of uncoated material. Those plants that cure above the 160°F curing temperature typical of the Ameron plant may find an accelerated deterioration of this material.

Fig. 28. View of blistered insulation in the Ameron pipe kiln.

Fig. 29. View of pipe kiln insulation at Ameron plant after removing a portion, indicating the delamination due to blistering.

A. Blisters that formed at 212°F in the Superlite kiln.

B. Expansion cracks that formed where overlapping is feathered to make a smooth joint.

Fig. 30. Examples of insulation defects observed after one day.

A. Blisters typically form on the ceiling; expansion cracks at spray overlap locations.

B. Closeup of expansion cracks that form along overlapping points.

Fig. 31. Typical defects after six months.

A. Delamination between layers due to blistering.

B. Delamination between layers due to feathering to a thin layer at overlap.

Fig. 32. Defects produced in one-hour laboratory tests conducted with steam at temperature of 200°F.

Section 4

SUMMARY OF EVALUATION STUDIES

The studies described above, and the data presented, suggest that FOAMGLAS[®] insulation will survive with a minimum of deterioration and perform in any of the various kiln environments likely to be encountered. Because of the constraints on the sprayed-in-place polyurethane foam, it will have limited use for some time — that is, it cannot be applied in any kiln that uses Johnson burners and should be restricted to kilns that have automated loading and unloading systems until an economic fireproof coating is developed for it. In addition, to be assured of a four to five year service life, it should not be used in kilns where peak curing temperatures exceed 160°F. Some of the observed difficulty with delamination at higher temperatures may also be overcome with coatings, but there is no known program planned to develop this.

From an economic standpoint, the polyurethane foam has two major benefits. It can be applied in one day so that a kiln is out of production for only one curing cycle, and it has a total cost-in-place that is half that for FOAMGLAS[®] insulation, when both are applied by an outside contractor. However, the specialized equipment required for applying polyurethane foam practically ensures that it must be applied by (a limited number of) outside contractors, whereas the FOAMGLAS[®] insulation can be applied by anyone. Note that for those limited cases where polyurethane foam can be used, the payback period can be half that of FOAMGLAS[®] insulation when the latter is contractor installed. But, the life expectancy is half as long as well, so that there is no investment advantage other than the lower first cost. Note also that FOAMGLAS[®] insulation was found capable of delivering substantial energy and dollar savings even when applied in one of the more efficient plants; i.e., one

that uses about half the energy for hydration found to be the national average, according to Ref. 2.

To realize the dollar benefits from insulating, it will often be necessary to examine very carefully whether an adjustment might be required in operational procedures, timers, controllers. But, once the technical and mechanical aspects are resolved, the real key to the decision process lies in quantifying the economic risk. The more the economic risk can be reduced at the level of the individual decision maker, the better the chance for action. (A corollary might well be, the faster the economic risks are reduced and/or eliminated, the faster the end-user will take action.) To help the end-user with the problem of assessing the expected saving from implementing in his plant, and to provide relationships between expected service life, anticipated saving, and return on — or quality of — investment, the following section was developed.

Section 5

ECONOMIC AND RISK ASPECTS

Clearly, if there were neither cost nor risk involved, but only reward, then it would be difficult to imagine a reason for not implementing the kiln-mass isolation concept. But there are both costs and risk, as well as reward, to consider, and some means is needed to relate them, practically, so that effective incentives to take action not only can, but will, be established, and at the least cost. As a beginning, it seems necessary to develop some kind of model with which to visualize the end-user decision process. Logically, as real uncertainties are identified and eliminated, action should follow.

As a result of the DOE demonstrations of the kiln-mass isolation concept, it is believed the uncertainties involving the questions of technological and economic feasibility have been removed. This conclusion is based on the observation that the concept has been shown to work and be cost beneficial at five plants representing different types and climates and including one that was twice as efficient as the average at the start. The question of implementing turns, generally, on the economic consequences at each individual plant. Here, the salient factors of primary interest are familiar. The first and major requirement for arriving at a positive decision is that the necessary capital be available. Thereafter, investment analysis will depend on option life expectancy, rental rates on capital, and payback period. These are defined more specifically so that their interrelationship can be formulated graphically for easier visualization. The elements are:

1. The annual energy saving, R , in dollars per year.
2. The capital cost of the opportunity, S .

3. The cost represented by rental of S at an interest rate, I, or else the rate of return the user requires to influence him to invest his capital.
4. The payback period, P, required to recover (out of R) both the capital costs, S, and a sum equal to the rental cost on S, or the opportunity cost incurred by tying up S.
5. The life expectancy, T, (assignment of which requires engineering estimates until additional data define it more precisely).

An important factor is the reliability with which the parameters R, S, P, I, and T can be established.

SSI has developed the means to make fairly accurate predictions of energy consumption related to R, both before and after insulating. (Note that R rises with rising energy rates, hence it is ultraconservative to consider R fixed at today's value.) The procedure for determining the value of R has been described in earlier sections, but is somewhat complicated. A simpler, conservative procedure for estimating R has been developed under contract with Pittsburgh Corning Corporation (Ref. 3). This procedure has been condensed to a table that relates three kiln structural elements to savings per square foot that can be achieved with two inches of FOAMGLAS[®] insulation for different temperatures (in 5°F increments above ambient) typically using in curing.

These relationships are shown in Table 10. Savings from applying FOAMGLAS[®] insulation to more complex configurations can be calculated from these. For example, the kiln ceiling at one plant was a 4-inch slab over 4-inch wide by 8-inch deep concrete beams on 36-inch centers with two rows of 8-inch-by-8-inch-by-16-inch hollow-core block between beams. Some examples of the use of Table 10 are presented in Table 11, including the saving per square foot for the latter complex roof configuration (see Case III in Table 11). The Table 10 values have been made conservative so that actual savings will always be somewhat greater than calculated.

TABLE 10: DOLLAR VALUE OF ANNUAL GAS SAVING PER SQUARE FOOT*

Peak Kiln Temperature Above Ambient (ΔT in $^{\circ}F$)	8-in. Hollow Core (dollars/ft ²)	6-in. Slab (dollars/ft ²)	8-in. Hollow Core Infilled with 150 lb Concrete (dollars/ft ²)
80	0.32	0.80	0.96
85	0.34	0.85	1.02
90	0.36	0.90	1.08
95	0.38	0.95	1.14
100	0.40	1.00	1.20
105	0.42	1.05	1.26
110	0.44	1.10	1.32
115	0.46	1.15	1.38
120	0.48	1.20	1.44
125	0.50	1.25	1.50
130	0.52	1.30	1.56
135	0.54	1.35	1.62
140	0.56	1.40	1.68
145	0.58	1.45	1.74

* Assumes 2-in. layer of FOAMGLAS[®] insulation applied (insulation must be applied with no gaps), and 25¢/therm for gas. For any other price per therm, P, multiply the figure obtained from the table by P/25¢. For oil, multiply the figure obtained from the table by the price per gallon divided by 36¢.

TABLE 11: EXAMPLES OF GAS SAVING ASSESSMENTS

<p>CASE I</p> <p>Hydration Only</p> <p>Curing Temp Peak: 160°F</p> <p>Average Ambient Temp: 50°F</p> <p>Peak Temp Rise: 110°F</p>	<p>7-in. Concrete Roof Slab; 8-in. Hollow-Core Block Walls</p> <p><u>7-in. Roof Slab:</u></p> <p>Enter @ 110°F to column 2 (6-in. slab) and multiply by 7/6: \$1.28 per ft²</p> <p><u>8-in. Hollow Core Walls:</u></p> <p>Enter @ 110°F to column 1: 44¢ per ft²</p>
<p>CASE II</p> <p>Hydration and Drying</p> <p>Drying Temp Peak: 220°F</p> <p>Average Ambient Temp: 75°F</p> <p>Peak Temp Rise: 145°F</p>	<p>6-in. Concrete Roof Slab, Infilled 8-in. Block Walls</p> <p><u>6-in. Roof Slab:</u></p> <p>Enter @ 145°F to column 2: \$1.45 per ft²</p> <p><u>8-in. Hollow-Core Wall Infilled with 150 lb concrete:</u></p> <p>Enter @ 145°F to column 3: \$1.74 per ft²</p>
<p>CASE III</p> <p>Hydration Only</p> <p>Curing Temp Peak: 180°F</p> <p>Average Ambient Temp: 45°F</p> <p>Peak Temp Rise: 135°F</p>	<p>Slab and Beam Roof with 2 ea 8-in.-by-8-in.-by-16-in. Hollow Core Block Between Beams; Hollow-Core Walls</p> <p><u>4-in. Roof Slab over 4-in.-by 8-in. beams on 36-in. centers, with 2 ea hollow-core block between beams (32 in.):</u></p> <p>Slab — Enter @ 135°F to column 2 and multiply by 4"/6": \$0.90 per ft²</p> <p>Beam — Go to column 2 and multiply by (8"/6") x (4"/36"): \$0.20 per ft²</p> <p>Block — Go to column 1 and multiply by 32"/36": \$0.48 per ft²</p> <p>Total \$1.58 per ft²</p> <p><u>8-in. Hollow-Core Walls</u></p> <p>Enter @ 135°F to column 1: 54¢ per ft²</p>

Note: With material costs running around \$1.00/ft², payback ranges from 7 months to 2½ years on wall insulation and 7½ to 9½ months on ceiling insulation for these three examples of gas-fired plants. Payback would be twice as fast with oil-fired systems; i.e., ranging from 3½ months to 13½ months.

Note that the tables were developed based on a gas price of 25¢/therm (or \$2.50/Mcf). Thus, for some other gas price, P, simply multiply the Table 10 values by $P/25¢$. Because a therm is 100,000 Btu, and a gallon of oil has about 140,000 Btu, if oil is the fuel, simply multiply the Table 10 values by 0.7 times the price per gallon divided by 25¢ — or $P/36¢$.

S can be established by obtaining bid prices before implementing. Provided no change orders are made, this should be about as reliable as one can ever expect. One difficulty, here, is that there is no known infrastructure of installers doing this kind of work.

"I" should always be the rate of return the user requires to influence him to invest his capital. This is because, on purely investment grounds, there is no justification for accepting a return that is less than what can be obtained in his business. A possible (and promising) exception to this would be if a special pool of funds were set up (see "Recommendations", Ref. 1), at commercial rates of interest, that could be used only for proven energy conservation options. This would immediately overcome the problem of capital availability, and commercial lending rates would apply for "I".

The payback, P, is computed from I and R, and there are many alternatives. From a business standpoint, failure to consider cost of debt service and taxes is the most common error and grievance (Ref. 4). With the advent of programmable calculators, computation based on discounted cash flow after taxes is a simple exercise. (This method, assuming a tax rate of 50% and a five-year depreciation period, was used to calculate the payback period at the Blocklite plant.)

The appropriate value to use for T will not be available until a number of installations have been in place long enough to establish the service life. The best value at present is only an estimate. From past experience and laboratory studies, ten years seems likely to be a conservative estimate for FOAMGLAS[®] insulation, but we don't really know. Examination after two years suggests but a fraction of the service life is gone.

The crux of the matter of uncertainty is a definite risk in not knowing some of the parameters from among R , P , I , and T , accurately. It is the impact of this on the decision process that needs to be made more explicit. The quantities R , P , I , and T just defined can be used to provide the graphical summary (Figure 33) in terms of an "option effectiveness", F , which is a measure of the annual cost of an energy saving option relative to the cost of current practice. An F equal to 1.0 corresponds to an energy saving option with annual costs the same as current costs. The lower the value of F , the more effective is the option and the lower the cost relative to current annual energy expense.

Thus, the product, FR , represents an annual cost that must be allocated by the end-user to gain the benefit, R , the value of the energy that is no longer used, once the option is implemented. (F is simply the ratio of the present value of two annuities with equal annual payment, at an interest rate, I , for the periods P and T . S is the present value of the annuity with the shorter period, P , if the annual payment is R .)

The relationships in Figure 33 lead to some interesting observations when used as a tool for analyzing the decision process. Not surprisingly, Figure 33 shows that the interest rate, I , is relatively unimportant for short payback periods (see the one-year and two-year families of curves); the curves drawn for different interest rates are fairly close together. To simplify the task of making a comparative analysis, the curves for other payback periods were drawn for a commercial rate, $I = 12\%$. Once P is calculated from S , R , and I , the significant variables boil down to the life expectancy, T , and the payback period, P , and the ratio between them.

With the graphic analysis of Figure 33, the impact of some of the uncertainties become more apparent. Suppose that a 50% error occurred in estimating the life expectancy of the insulation. For example, suppose the five-year life expectancy of polyurethane foam in the pipe kiln were projected as the life expectancy estimated for polyurethane foam in a

Fig. 33. Cost of energy bought under an alternative option as a function of option life expectancy and payback period.

concrete block kiln, and then it turned out to have a service life of just two and a half years. Using the after tax payback period calculated for the five-year-life polyurethane foam at the Superlite plant (20 months) gives an $F = 0.41$, so that, for the fuel saved, the cost corresponds to a price that is 41% of the cost of the fuel that would otherwise have been consumed. If T should be two and a half years, then $F = 0.73$ (probably still acceptable), but if the actual service life, $T =$ two years, $F = 0.92$, and this is unlikely to be worthy of management attention for the reason that the time spent is more likely to produce greater profit elsewhere. (Note that employee care and treatment is also a factor in life expectancy.)

The threshold for management interest is probably somewhere between the two dashed lines marked $T/P = 2$ and $T/P = 4$, depending on the extent of the individual end-user's knowledge about technical and economic aspects, and evidence in the form of performance data. The more the uncertainty, the closer the threshold for response will be to $T/P = 4$, and the more clear-cut the evidence from performance data, the closer the threshold will approach $T/P = 2$. Though it provides some insight, Figure 33 depicts only part of the risk/reward relationship. An important aspect involves an overall techno-economic analysis in which the impact is evaluated of both tax policy and the investment-at-risk, on industry attitudes and response.

To examine the question of how risks (and rewards) are allocated on an economic basis, the tax laws must be taken into account. The economic assessment was made based on the assumption that the entire block industry made the insulation investment and that the Federal corporation tax was 50%. The capital cost for the insulation investment was taken as \$30 million, and the corresponding annual saving (income) was taken as \$20 million. These figures represent the middle ground of estimates for in-house versus contractor installation, and the appropriate mixture of natural gas and oil according to Ref. 2. Using these figures, calculations were made of the annual cash flows accruing to the insulation manufacturers and the installers, the financial institutions, the block industry, and the U.S. Treasury. This was done twice, once assuming a five-year write-off, and again assuming a one-year write-off, for the entire investment.

Tables 12 and 13 show the yearly allocations to all beneficiaries for five years for these two write-off periods. (Risks are negative numbers and benefits are positive numbers.) In these tables, a discount rate of 12% annually was applied to industry and to Treasury borrowing rates. Moreover, it was also assumed that manufacturers' and installers' profits were 12% before taxes, and that the 550 man-years of jobs created (350 man-years of installation and 200 man-years of insulation manufacturing) generated income, taxed at a 12% rate, for the Internal Revenue Service. Use of a single interest rate throughout simplified the calculations. The only thing that is unrealistic in these assumptions is that using the same borrowing rate (12%) for the Treasury as for industry operates to make the Treasury's share look relatively smaller than it actually is.

For each one of the five years, the figures were converted to present value at the end of Year One, so that direct comparisons of relative economic risks and/or benefit could be made on a common basis. Note particularly the relative sizes of the investment "at risk" (the negative numbers) in the five-year write-off as compared with the one-year write-off; with the one-year write-off, benefits to industry commence in the second year instead of in the third year as occurs with the five-year write-off. An interesting question is what the impact on industry implementations and Treasury revenues would be if the economic risks and benefits were designed to be somewhat more equitable throughout the investment, either as in Table 13, or better yet, with total recovery of cost allowed the first year.

Perhaps the simplest and most enlightening way to look at the problem is to concentrate solely on "incentive cost" versus "opportunity cost".* For every year the government passes up its "50% collective share" of a potential (industry) energy conservation saving, the present value of all future revenues (see the last figure of the last column of Table 12) must be discounted another year (i.e., another 12%). Thus, if the delay in

* Incentive cost here represents tax revenues lost by allowing fast write-offs, opportunity cost represents those lost by not allowing them.

TABLE 12: YEARLY RISK/BENEFIT ALLOCATION FOR FIVE-YEAR WRITE-OFF
(all figures in millions of dollars)

INSULATION MFRS & INSTALLERS					FINANCIAL INDUSTRY						BLOCK INDUSTRY									U.S. TREASURY		
Year End	Gross Sales	Gross Profit	Tax	Net Profit	Loans Outstanding	Gross Profit	Tax	Net Profit At Year End	Discounted to Year 1	Cum Present Value 1)	Outlay	Gross Income	Depr	Loan Int	Gross Taxable	Tax 2)	Net After Tax	Depr Plus Net	Yr End Cum. Risk or Benefit 1)	Year Net	Year 1 Present Value	Yr End Cum. Risk or Benefit 1)
1	30	3.6	2.8 ³⁾	1.8	30	3.6	1.8	1.8	1.8	1.8	30	20	6	3.6	13.4	5.2	5.2	11.2	-18.8	9.8	9.8	9.8
2					18.8	2.26	1.13	1.13	1.01	2.81		20	6	2.26	11.74	5.87	5.87	11.87	- 6.9	7.0	6.25	16.05
3					6.93	0.83	0.41	0.41	0.33	3.14		20	6	0.83	13.17	6.59	6.59	12.59	4.51	7.0	5.58	21.63
4												20	6	0	14.0	7.0	7.0	13.0	13.77	7.0	4.98	26.61
5												20	6	0	14.0	7.0	7.0	13.0	22.03	7.0	4.45	31.06
Cum. Benefit				1.8						3.14									22.03			31.06

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TABLE 13: YEARLY RISK/BENEFIT ALLOCATION FOR ONE-YEAR WRITE-OFF
(all figures in millions of dollars)

INSULATION MFRS & INSTALLERS					FINANCIAL INDUSTRY						BLOCK INDUSTRY									U.S. TREASURY		
Year End	Gross Sales	Gross Profit	Tax	Net Profit	Loans Outstanding	Gross Profit	Tax	Net Profit At Year End	Discounted to Year 1	Cum Present Value 1)	Outlay	Gross Income	Depr	Loan Int	Gross Taxable	Tax 2)	Net After Tax	Depr Plus Net	Yr End Cum. Risk or Benefit 1)	Year Net	Year 1 Present Value	Yr End Cum. Risk or Benefit 1)
1	30	3.6	2.8 ³⁾	1.8	30	3.5	1.8	1.8	1.8	1.8	30	20	30	3.6	0	-6.8	-6.8		-6.8	-2.2	-2.2	-2.2
2					6.8	0.82	0.41	0.41	0.37	2.17		20		0.82	19.18	9.59	9.59		2.49	10.0	—	6.96
3												20			20	10	10		10.46	10.0	7.97	14.93
4												20			20	10	10		17.58	10.0	7.12	22.58
5												20			20	10	10		23.94	10.0	6.36	28.41
Cum. Benefit				1.8						2.17									23.94			28.41*

- 1) To facilitate comparisons, values are cumulative through the year of entry with each yearly positive contribution (or positive residual after debt payment) discounted at 12% per year to the end of year one before summing.
 - 2) Ignores state corporation tax, which may increase this column 10% and decrease industry benefit 10%.
 - 3) Includes income tax on wages of \$8 million, but does not count benefit of creating 550 man-years of work.
- * This amount is more than the corresponding value in Table 12, discounted one year.

implementing such an option amounts to just two years, the Table 12 value of 31.06 would be discounted 12% for two years (to 24.76), an opportunity cost of 6.3 million dollars to tax revenues. This very nearly equals what it would cost (out of tax revenues) if industry were allowed to recover its total costs in the first year. (Note that four years have already passed since this energy conservation concept was first suggested, two years since it was demonstrated, and less than 0.4% of the market has implemented.)

Should the delay in implementing be just one year, the opportunity cost (i.e., loss of tax revenue) will exceed the cost of allowing a first year write-off because it will discount the cumulative tax revenue figure of 31.06 in Table 12 to 27.73, while the first year write-off will produce cumulative tax revenues that exceed this; i.e., 28.41 (see Table 13). Moreover, if the investment were to have a ten-year life, the elimination of a two-year delay through a fast write-off incentive would actually result in a 6% increase in the discounted cumulative value of tax revenues over that produced under the alternative of letting normal market forces take their course. These points are made because the real purpose of government would seem to be to change the normal market forces creatively, so that events will happen that are better than if they were left to chance.

Aside from the fact that a policy to allow a single year total-cost recovery would likely increase Treasury revenues far above current policy, this creative alternative (as opposed to using life expectancy as the basis for a write-off period) would deliver many additional, less tangible benefits as well. These include, for example, benefits such as accelerating the creation of 550 man-years of work — with attendant benefits of a reduction in joblessness and welfare payments; increased profits for insulation manufacturers (and more jobs as a result); fewer foreign imports, which enables U.S. dollars to be kept at home (hence, fewer U.S. assets sold abroad). Quite simply, dollars invested in so-called "incentives to motivate" industry to implement an option that is generally cost beneficial (but individually risky) are guaranteed to generate far more Treasury

dollars than spent.*

As a final concept to promote every possible avenue that could accelerate energy conservation, the best approach is to drive it at all levels via the profit motive. Thus, if just 10% of the dollar revenue that the Treasury realizes out of implemented conservation opportunities were allocated to the DOE to develop and verify additional profitable conservation opportunities, the entire effort might possibly become one of the largest financial successes in history. With this approach, energy conservation in industry has the potential to produce savings that would enable the DOE (if appropriate tax incentives were developed for industry) to outperform the economic feat of the Federal National Mortgage Association, under Mr. Roger Lapin (Ref. 5). Considering the current international problems affecting energy-producing nations, this reward-sharing concept might be worth trying.

* "Incentives to motivate" seems a misnomer. No businessman is going to need motivation, except for poor risks. Eliminate, or reduce, the economic risk to reasonable bounds and response may prove dramatic.

Section 6

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to clarify some of the questions about insulating kilns that were raised by members of the block industry. Answers were developed and conclusions are given below. The intent has been to supply information to industry to help promote more implementations of the kiln-mass isolation concept demonstrated in the earlier DOE program. Because there are now 28 kilns known to be insulated (10 under DOE support) promotional progress is indicated; and, additional progress is expected.

FOAMGLAS[®] Insulation Results

From the study just completed it has been concluded that FOAMGLAS[®] insulation, when properly installed, will perform just as well in kilns that use Johnson burners as in those that use central boilers. Moreover, this insulation will stand 270°F in drying cycles and can be cost beneficial even in one of the more efficient automated kilns.

Service life has not been established conclusively, but from measurements made after one and a half years in service, it appears the estimated ten-year life expectancy is reasonable. FOAMGLAS[®] insulation can be installed by virtually anyone, but care must be taken to mount the insulation properly; bonding agents other than those recommended can seriously damage the insulation. An adjustment to the curing cycle is required to realize the saving because the temperature will rise faster when the kiln is insulated. The adjustment requires monitoring the temperature rise to find how much shorter to set the timing cycle. Where temperature controllers are used, the saving should be realized automatically so long as the curing cycle called for is the same in the insulated kilns as it was

when they were uninsulated.

Polyurethane Foam (CPR 480) Results

The polyurethane foam that was tested (CPR 480) was found to be less expensive to install than FOAMGLAS[®] insulation. However, the overall return on investment was found to be essentially the same as for FOAMGLAS[®] insulation because of a shorter life expectancy. Polyurethane will have limited application in block kilns because of its inherent fire hazard, which precludes use where there are open flames (e.g., Johnson burners) or where there is routine traffic by humans. The latter indicates its use is further restricted to plants where kilns are loaded by automated equipment (about 10% to 20% of the plants visited). In the instances where this material can be used, life expectancy will be shortened, and the economic benefit reduced, wherever kiln temperatures exceed 160°F. It is possible that a suitable coating could correct all these deficiencies, but the only fireproof coating found with a specification that made it plausible to test has an installed cost, itself, that exceeds that of contractor installed FOAMGLAS[®] insulation. Table 14 summarizes the major features of the two insulations.

Economics, Risk, and Promotion

The major deterrent to widespread implementation is more probably economic risk rather than any remaining technical uncertainty, with the possible exception of life expectancy. To get the latter question answered conclusively will require development of statistical data and the passage of time. A prerequisite to obtaining the required statistical data is the insulation of a statistically significant "cross-section" of kilns. The whole process could likely be accelerated by a more equitable distribution of risks and rewards.

By integrating the concept of opportunity cost (at the Treasury) with an analysis of the risk (to the industry that would implement the option), a generic solution relevant to accelerating the implementation of any conservation option with widespread applicability has been proposed;

TABLE 14: INSULATION COMPARATIVE PERFORMANCES

Insulation Material	FOAMGLAS [®] Insulation	CPR 480 Polyurethane
Manufacturer	Pittsburgh Corning Corporation	The Upjohn Company CPR Division
Service Temperature Limit in Steam Kilns	300°F+	160°F
Estimated Service Life in Steam Kilns	10 years	5 years
Fire Safety	No restrictions	No open flames, No human traffic, without fireproof coat
Installation Costs: per 2,000 sq ft kiln:		
Man-Hours	100 - 120	6 - 8
Cost/sq ft (Contractor installation)	\$2.20 - \$3.50	\$1.00 - \$1.60
Cost/sq ft (In-house installation)	\$1.50 - \$2.50 (including labor at \$10 to \$15 per hour)	n.a. (requires professional installation)
Installation Precaution:		
Mounting	Use only recommended mastics	Must have warm, dry surfaces
Labor	Unskilled	Skilled
Fireproofing	Unnecessary	Costs \$2.50/sq ft when required

i.e., a first year write-off. This proposed approach will eliminate the major economic risk to industry and has the potential to deliver more tax revenue than can be expected if normal market forces are allowed to take their course. Moreover, allocation of a fraction of these treasury revenues to the DOE has the potential to deliver repeated successes at an accelerated pace.

For the kilns insulated to date, the indicated annual saving has ranged from 600 Mcf to 1,000 Mcf. Actual savings have been less because some plants have failed to make the proper adjustments in the curing cycle. This oversight could cause the potential savings to be lost in one third of the kilns (but this would decrease with time and peer discussion). Assuming 500 Mcf are saved on average, currently, at the 28 insulated kilns, the cumulative annual saving is 14,000 Mcf (2,400 bbl of oil equivalent) each year. This annual saving corresponds to about 0.4% of the market potential. Thus, with a saturated market (in the block industry) and proper adjustments to the curing cycles, the potential is an annual saving of 1,000,000 bbl of oil equivalent. Including concrete pipe curing will increase this substantially.

Recommendation

The potential for a saturated market will close on 100% as the apparent risk to the individual implementer approaches zero. The latter can come about in many ways, but it can be made to occur fastest with a creative tax policy such as described in Section 5, and it is probable that, if implemented, this path will create more tax revenues than any reasonable alternative including leaving the process to occur spontaneously.

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