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AN ENERGY AUDIT OF THREE ENERGY-CONSERVING DEVICES
IN A STEEL INDUSTRY DEMONSTRATION PROGRAM: TASK III:
GTE HIGH TEMPERATURE RECUPERATION

By
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June 1983

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Pacific Northwest Laboratory
Richland, Washington

U. S. DEPARTMENT OF ENERGY

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AN ENERGY AUDIT OF THREE ENERGY-CONSERVING
DEVICES IN A STEEL INDUSTRY DEMONSTRATION
PROGRAM: TASK III: GTE HIGH TEMPERATURE
RECUPERATION

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EXECUTIVE SUMMARY

As part of its effort to encourage industry to conserve fuel, the Office of Industrial Programs of the Department of Energy has undertaken a program to demonstrate to industry the benefits of installing various energy-conserving devices and equipment. This report presents results on one of those systems, a high-temperature ceramic recuperator designed and manufactured by Sylvania Chemical and Metallurgical Division, GTE Products Corporation of Towanda, Pennsylvania. The ceramic cross-flow recuperator unit recovers waste heat from the hot combustion gases and delivers preheated air to high-temperature burners of various manufacture.

Of the 38 host site installations included in the program, sufficient operating data were obtained from 28 sites to evaluate the benefits in terms of energy and economic savings that can be achieved. Performance and cost data are analyzed and presented in this report for those 28 installations, which covered a variety of applications, sizes, and industry types. Except for 5 sites where unusual operating or data-collection problems were encountered, the improvements in performance of the recuperated furnaces equalled or exceeded estimates; the average of the total fuel savings for these 23 sites was 44.0 percent, some portion of which resulted from furnace improvements other than recuperation.

Payback times were calculated for both total costs and for recuperator-related costs, using a cumulative annual after-tax cash flow method which includes tax investment credits, estimates of general and fuel-price inflation, and maintenance costs. Average payback times ranged from 2.3 years based on recuperator-related costs to 3.1 years based on total costs. The median payback time in either case is between two and three years. It should be noted that production levels generally were lower than normal during the 1981 and 1982 period when these results were obtained. Low production levels result in reduced efficiency, lower total fuel savings and consequently longer payback times than would be developed under normal business conditions.

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FINAL REPORT

on

AN ENERGY AUDIT OF THREE ENERGY-CONSERVING DEVICES IN A STEEL-INDUSTRY DEMONSTRATION PROGRAM

Task III: GTE High Temperature Recuperator

by

A. O. Hoffman, H. W. Lownie, and F. C. Holden

BACKGROUND AND OBJECTIVES

Based upon surveys of industrial energy consumption several years ago, the annual consumption of natural gas and fuel oil by selected metals and nonmetals producing segments of the U. S. economy was estimated at over 2 quads. Because a major fraction of that total energy is used in furnaces for various industrial processes, the savings that could be introduced by more efficient use of furnace fuels are substantial.

The Office of Industrial Programs (OIP) of the Department of Energy (DOE) decided that its encouragement of the development and commercialization of various energy-conserving systems could have a significant beneficial effect on the conservation of energy in the industrial sector. As a result of that decision, an agreement was made for joint funding with the GTE Products Corporation of the initial demonstration of GTE's compact high-temperature recuperator. The results of that demonstration program showed the technical and economic feasibility of using ceramic heat recuperators for heat recovery in industrial processes.

In the present program, the initial demonstration program was expanded to provide comparisons of equipment in a number of process industries with the same or similar equipment fitted with the GTE ceramic recuperator system. The program plan included 38 host site installations containing a total of 175 recuperator units.

The agreements between each host site and GTE included a commitment on the part of the host site to install and operate the equipment over a suitable time period; to provide a baseline furnace for comparison purposes; and to collect and furnish data on fuel consumption, product throughput, and costs to a third party for analysis, evaluation, and reporting.

Early in 1980, OIP arranged for Battelle's Pacific Northwest Laboratories (PNL) to be the third party responsible for coordinating the receipt, analysis, and reporting of data provided by the host sites, as well as for similar data to be developed from several other energy-conserving processes and systems. PNL designated Battelle's Columbus Laboratories (BCL) to perform the analyses and reporting on the GTE high-temperature recuperator systems.

Although originally intended as a program to be conducted over a 12-month time period, various delays resulted in the need to extend the time of performance to the present. This report describes the results obtained through December, 1982, on 28 of the 38 host sites. Performance data were not available on the other 10 sites in time for inclusion in this report.

DESCRIPTION OF CONVENTIONAL PROCESSES AND EQUIPMENT

The industrial processes selected as suitable candidates for this demonstration are diverse, but have in common the requirement for process heat at relatively high temperature (1600 F and above) and in quantities large enough to justify the capital expenditures needed for heat recovery systems. The most common fuel is natural gas, with #2 (and in one instance #4) fuel oil used in a smaller number of installations. Most of the host sites are in the primary metals or fabrication industries, where the energy is used to heat metals to modify properties (annealing, heat treatment), to permit hot working (forging, rolling), or to produce molten metal for casting. For each of these applications, the useful output is a reasonably direct function of the amount of metal heated and the temperature to which it is heated. Other applications include calcining, metal reduction, die heating, and ladle heating.

Most of the applications examined in this program involved batch heating; that is, a given weight of material is loaded into the furnace, heated to temperature over some time period, and then removed. Cycle times can range from short to long (a few hours to several days), and the number of cycles per week will vary according to both the cycle time and the overall business level.

Continuous processing is involved in a few of the host site operations; in these cases the furnace is operated continuously and is shut down only for annual repair and maintenance.

Much of the operating data was generated during 1981 and 1982, a period of difficult business climate in many of the industries represented in this program. As a result, many production schedules have been reduced during the evaluation period to fewer total hours and fewer shifts than originally planned. Reduced production levels generally lead to reduced overall efficiency, as well as to lower total fuel savings and consequent longer payback times.

Furnaces

The industrial furnaces included in this program are of many types and sizes, ranging from small single-burner aluminum pot melters to very large box, carbottom and rotary furnaces. Despite the variety of equipment involved, the typical furnace consists of an insulated enclosure; one or more burners firing into the enclosure; suitable flues arranged to exhaust the combustion products from the enclosure; means for loading and unloading the furnace with the material to be heated; and controls for regulating temperature within the furnace. Additional furnace controls, which can be of several levels of sophistication, may be employed to regulate the air:fuel ratio, both at high- and low-firing rates; the pressure within the furnace enclosure; and to ensure that safe combustion of fuel takes place. Many of the older furnaces were equipped with only rudimentary controls, a deficiency that usually is corrected when recuperators are added.

A simple schematic diagram for a typical industrial furnace is illustrated in Figure 1. The energy is supplied by the fuel, usually natural gas or fuel oil. The useful energy output is the heat added to the product, and the remaining energy supplied is lost to the surroundings. Depending upon the temperature at which the furnace is operated, the largest heat loss usually is the sensible heat contained in the combustion gases exhausted from the furnace. The remaining principal losses are by radiation from furnace openings, and by conduction of heat through the furnace walls. For a furnace run intermittently, as in many batch operations, the heat stored in the refractory during heat-up eventually is lost to the surroundings when the furnace is cooled.

The efficiency with which the heating value of the fuel is converted into useful heat in the product being heated is typically low (e.g., 10 percent or less) for much of the equipment currently used. The low thermal efficiency results primarily from the following:

- Loss of sensible heat in combustion gases that are exhausted at high temperature to the atmosphere
- Furnace losses through radiation and conduction of heat from the furnace enclosure
- Poor control of the combustion process
- Operating procedures and scheduling that lead to low utilization of furnace capacity.

Loss of heat in combustion gases can be reduced by recuperation, extracting a portion of the waste heat and returning it to the furnace as preheated combustion air. Furnace losses can be lowered by improving the insulation of the furnace cavity, and by blocking openings wherever possible. Better control of the combustion process typically involves the addition of fuel:air ratio and pressure controls, as well as by closer attention by the operators. The low utilization of furnace capacity is a particularly pervasive problem, and one that frequently is beyond the complete control of the operator. For example, a furnace often is designed to heat the largest load foreseen, whereas most production loads are far below that maximum. It

$$\begin{aligned} \text{Energy Input} &= \text{Useful Energy Output} \\ \text{(Fuel to Burners)} &\quad \text{(Heat Added to Product)} \\ &+ \\ &\text{Stack Losses} \\ &\quad \text{(Sensible Heat in Flue Gases)} \\ &+ \\ &\text{Furnace Losses} \\ &\quad \text{(Conduction, Radiation, Storage)} \end{aligned}$$

FIGURE 1. SCHEMATIC DIAGRAM OF AN INDUSTRIAL FURNACE

seldom is practical for production reasons to size the furnace near the mean load. Similarly, although efficiency is greater when the furnace is running two or three shifts a day, business conditions may dictate single shift operations.

In this program, the rebuilding of a baseline furnace usually included improvements that addressed the first three energy losses listed above--recuperation, improvements in furnace insulation, and combustion controls. The fourth item is more related to operating practice and business conditions than to technical factors, and thus may not have been improved. In fact, some recuperated designs increased the effectiveness of heating such that the improved furnace was even more under-utilized than the original.

DESCRIPTION OF GTE RECUPERATORS AND FURNACE INSTALLATIONS

GTE Recuperator

The heart of the GTE recuperator system is a cross-flow ceramic heat exchanger, illustrated in Figure 2. The ceramic core is mounted in a refractory lined steel frame such that the hot exhaust gases flow through the rectangular passages in one direction and the combustion air through the matrix at right angles to the exhaust gas flow (Figure 3). Heat is transferred through the 0.050-inch walls from the hot exhaust gases to the incoming combustion air. The exhaust gases typically flow directly through the matrix, whereas the combustion air typically flows through a triple pass pattern.

The ceramic core is made from cordierite, a magnesium-aluminum-silicate ceramic that is reported to withstand temperatures up to about 2500 F with good resistance to thermal shock. The units are approximately 1-foot cubes with a capacity of about 1 million Btu/hour; actually three sizes currently are available with nominal capacities of 0.6, 1.0, and 1.5 million Btu/hour, and all three sizes have been utilized in this program.

FIGURE 2. GTE CROSSFLOW CERAMIC HEAT EXCHANGER

FIGURE 3. GTE RECUPERATOR UNIT MOUNTED IN STEEL CASING

The compact size of the GTE recuperator makes possible a number of design alternatives. One common configuration involves mounting a number of recuperators on top of the furnace, and ducting the combustion air either directly or through headers to the burners. This requires insulation of the ducting to avoid excessive heat losses. Many of the more recent installations involve close coupling the recuperator to the burner, which essentially results in a self-recuperative burner unit. A number of burner manufacturers have designed such packages and are offering them to the market. Photographs of three typical installations illustrate their general layout and appearance (Figures 4, 5, and 6).

Site Installations

The 38 host sites finally selected for inclusion in this program are listed in Table 1, which shows the type of furnace, nominal operating temperature, the number of recuperators installed, the unrecuperated thermal input, and the type of fuel normally used. The first installation (McInnes Steel) was in operation late in 1980; the others have come into operation during 1981 and 1982 except for a few expected to commence operations early in 1983. In most of the plants where a dual fuel capability is shown, natural gas is the fuel actually being used.

In most cases, the recuperated furnace was a retrofit to a unit already in the plant. The amount of rebuilding and modification to the furnace, in addition to adding recuperators and high-temperature burners, varied substantially; actually, these ranged from construction of a completely new furnace to the addition of only recuperators and burners. These variations introduced difficulties in the allocation of costs, and efforts have been made to distinguish between total costs and recuperator-related costs in the analyses of payback.

To aid in the analysis of furnace performance, the 38 host sites were classified according to furnace type, and the numbers and sizes of recuperators listed for each, as shown in Table 2. A plot showing the relationship between the number of recuperators installed and the

FIGURE 4. SLOT FORGE REHEAT FURNACE (SITE 38), 4 ECLIPSE BURNERS, 4 GTE R600 TPX RECUPERATORS

FIGURE 5. BOX STEEL FORGE REHEAT FURNACE (SITE 37), 4 NORTH AMERICAN BURNERS, 4 GTE R1500 TPX RECUPERATORS

FIGURE 6. STEEL FORGE REHEAT ROTARY HEARTH FURNACE (SITE 36), 8 SELAS DNS BURNERS, 8 GTE R1500 TPX RECUPERATORS

TABLE 1. GENERAL DESCRIPTION OF HOST SITE INSTALLATIONS

No.	Host Site	Location	Furnace Type	Furnace Temp. °F	No. of Recup.	Unrecup. Thermal Input MM BTU/Hr.	Fuel Type
1	McInnes Steel	Corry, PA	Forge Reheat, Steel, Box	2,250	4	6	G/O
2	Lebanon Steel	Lebanon, PA	Carbottom Heat Treat Steel	1,800	6	9	G/O
3	Aican	Oswego, NY	Ladle Preheater - Aluminum	2,000	1	1	G
4	X-Tek	Cincinnati	Retort Heat Treat - Steel	1,950	12	7	G/O
5	Ajax X-Ray	Sayre, PA	Aluminum Pot Melter	2,050	1	1	O
6	GTE Towanda #9	Towanda, PA	Tube	1,600	10	2.5	G
7	Hammond & Irving	Auburn, NY	Forge Reheat, Steel, Box	2,200	4	4	G/O
8	Bay City Forge	Erie, PA	Forge Reheat, Steel, Box	2,250	8	12	G/O
9	Monroe Forge	Rochester, NY	Forge Reheat, Steel, Box	2,150	2	3	O
10	Special Metals	New Hartford, NY	Steel Box Heat Treat	1,800 ⁽¹⁾	6	8	G/O
11	Special Metals	New Hartford, NY	Rollg. Mill, Preht., Stl, Box	2,100	4	4	G/O
12	Harnischfeger	Milwaukee, WI	Forge Reheat, Steel	2,250	4	6	G
13	GTE Towanda #21 Moly	Towanda, PA	Tube	2,150	7	4.0	G/O
14	GTE Towanda #16	Towanda, PA	Tube	1,650	3	2.5	G/O
15	GTE Towanda #13 Tube	Towanda, PA	Tube	1,600	3	2.0	G/O
16	GTE Towanda #1 Calciner	Towanda, PA	Rotary Calciner	1,750	3	2.5	G/O
17	GTE Towanda #3 Calciner	Towanda, PA	Rotary Calciner	1,800	3	2.5	G/O
18	Kentucky Forge	Madisonville, KY	Slot Forge	2,500	2	2	G
19	Schmidt	Portland, OR	Slot Forge, Steel	2,500	2	4	G/O
20	Crescent Tool	Jamestown, NY	Slot Forge	2,200	2	2	G
21	Pfizer Company	Canaan, CT	Vacuum Retort Furnace	2,200	5	3	O
22	Howmet Turbine	Dover, NJ	Investment Die Reheat, Tunnel	2,000	3	3	G
23	Howmet Turbine	Muskeegan, MI	Investment Die Reheat, Tunnel	2,000	3	3	G
24	National Forge	Warren, PA	Stl. Forge - Carbottom Heat Tr	2,300	8	10	G/O
25	Bucyrus Erie	Milwaukee, WI	Carbottom Heat Treat	1,700	12	4	G
26	Timet	Toronto, OH	Forge Reheat, Titanium, Box	2,100	8	7	G
27	McWilliams	Rockaway, NJ	Steel Forge Reheat, Box	2,000	3	5	G/O
28	Altech	Dunkirk, NY	Rolling Mill Reheat	2,250	6	9	G/O
29	Crucible Steel	Syracuse, NY	Forge Reheat, Steel, Box	2,250	2	6	G/O
30	Buffalo Metal Casting	Buffalo, NY	Aluminum Pot Melter	2,050	1	1.5	O
31	Standard Steel	Burnham, PA	Forge Reheat, Steel, Box	2,200	6	8	G/O
32	National Forge	Erie, PA	Ladle Preheater, Steel	2,200	4	6	G/O
33	Ladish Company	Cynthiana, KY	Steel Forge Reheat	2,250	8	5	G/O
34	Pratt & Whitney	Hartford, CT	Box Heat Treat, Steel	2,100	4	3	G
35	Anax Specialty Metals	Florham Park, NJ	Steel Forge Reheat, Box	2,250	5	7	G/O
36	Bethlehem Steel	Bethlehem, PA	Steel Forge Reheat, Roty Hrth	2,300	8	8	G/O
37	Cape Ann Forge	Gloucester, MA	Steel Forge Reheat, Box	2,250	4	6	G/O ⁽²⁾
38	Stanley Spring (TRW)	Harrisburg, PA	Forge Reheat, Steel Box	1,900	4	3	G/O
					175		

G - Natural Gas

O - Light Oil (#2)

(1) Annealing at 2,150 F, homogenizing at 1800 F.

(2) Fuel normally used is #4 fuel oil.

TABLE 2. GTE RECUPERATOR DESIGN DATA BY TYPE OF FURNACE AND SITE

Recuperator Sizes: S = 0.6 million Btu/hr
M = 1.0 million Btu/hr
L = 1.5 million Btu/hr

A. BOX FORGE FURNACES						B. SLOT FORGE FURNACES					
No. Recuperators					Unrecup. Input, MM Btu/hr	No. Recuperators					Unrecup. Input, MM Btu/hr
Site	S	M	L	Total		Site	S	M	L	Total	
1	0	0	4	4	6	18	2	0	0	2	2
7	0	0	4	4	4	19	0	0	2	2	4
8	0	0	8	8	12	20	0	0	2	2	2
9	0	0	2	2	3						
12	0	0	4	4	6	Total	2	0	4	6	8
26	8	0	0	8	7						
27	0	3	0	3	5						
29	0	0	2	2	6						
31	0	0	6	6	8						
33	8	0	0	8	5						
35	0	5	0	5	7						
36	0	0	8	8	8						
37	0	0	4	4	6						
Total	16	8	42	66	83						
No. furnaces in group:					13	No. furnaces in group:					3
Avg. No. recuperators/furnace:					5.2	Avg. No. recuperators/furnace:					2.0
Avg. unrecup. input,					6.4	Avg. unrecup. input,					
MM 8tu/hr/fce:						MM 8tu/hr/fce:					2.7
Avg. unrecup. input,					1.2	Avg. unrecup. input,					
MM 8tu/hr/recup.:						MM 8tu/hr/recup.:					1.3
Furnace temperature, F:						Furnace temperature, F:					
Range:					2000-2300	Range:					2200-2500
Average:					2210	Average:					2400

(Continued)

TABLE 2. (Continued)

C. HEAT TREAT FURNACES						D. TUBE FURNACES					
No. Recuperators					Unrecup. Input, MM Btu/hr	No. Recuperators					Unrecup. Input, MM Btu/hr
Site	S	M	L	Total		Site	S	M	L	Total	
2	0	0	6	6	9 (car)	6	10	0	0	10	2.5
4	6	0	0	6	7 (retort)	13	7	0	0	7	4.0
10	0	0	6	6	8 (box)	14	0	2	1	3	2.5
24	0	0	8	8	10 (car)	15	0	2	1	3	2.0
25	12	0	0	12	4 (car)	Total	17	4	2	23	11.0
34	4	0	0	4	3 (box)						
38	4	0	0	4	3 (box)						
Total	26	0	20	46	44						
No. furnaces in group:					7	No. furnaces in group:					4
Avg. No. recuperators/furnace:					6.6	Avg. No. recuperators/furnace:					5.8
Avg. unrecup. input, MM Btu/hr/fce:					6.3	Avg. unrecup. input, MM Btu/hr/fce:					2.8
Avg. unrecup. input, MM Btu/hr/recup.:					1.0	Avg. unrecup. input, MM Btu/hr/recup.:					0.5
Furnace temperature, F:						Furnace temperature, F:					
Range:					1700-2300	Range:					1600-2150
Average:					1960	Average:					1750

E. DIE-REHEAT FURNACES						F. ROLL-PREHEAT FURNACES					
No. Recuperators					Unrecup. Input MM Btu/hr	No. Recuperators					Unrecup. Input, MM Btu/hr
Site	S	M	L	Total		Site	S	M	L	Total	
22	0	2	1	3	3	11	0	0	4	4	4
23	0	2	1	3	3	28	0	0	6	6	9
Total	0	4	2	6	6	Total	0	0	10	10	13
No. furnaces in group:					2	No. furnaces in group:					2
Avg. No. recuperators/furnace:					3.0	Avg. No. recuperators/furnace:					5.0
Avg. unrecup. input, MM Btu/hr/fce:					3.0	Avg. unrecup. input, MM Btu/hr/fce:					6.5
Avg. unrecup. input, MM Btu/hr/recup.:					1.0	Avg. unrecup. input, MM Btu/hr/recup.:					1.3
Furnace Temperature, F:						Furnace Temperature, F:					
Range:					2000-2000	Range:					2100-2250
Average:					2000	Average:					2175

TABLE 2. (Continued)

G. ALUMINUM POT MELTERS						H. LADLE HEATERS					
No. Recuperators					Unrecup. Input, MM Btu/hr	No. Recuperators					Unrecup. Input, MM Btu/hr
Site	S	M	L	Total		Site	S	M	L	Total	
5	1	0	0	1	1.0	3	1	0	0	1	1 (Al)
30	1	0	0	1	1.5	32	0	0	4	4	6 (Steel)
Total	2	0	0	2	2.5	Total	1	0	4	5	7
No. furnaces in group:					2	No. furnaces in group:					2
Avg. No. recuperators/furnace:					1.0	Avg. No. recuperators/furnace:					2.5
Avg. unrecup. input, MM Btu/hr/fce:					1.2	Avg. unrecup. input, MM Btu/hr/fce:					3.5
Avg. unrecup. input, MM Btu/hr/recup.:					1.2	Avg. unrecup. input, MM Btu/hr/recup.:					1.4
Furnace temperature, F:						Furnace temperature, F:					
Range:					2050-2050	Range:					2000-2200
Average:					2050	Average:					2100
I. ROTARY CALCINERS						J. VACUUM RETORT					
No. Recuperators					Unrecup. Input, MM Btu/hr	No. Recuperators					Unrecup. Input, MM Btu/hr
Site	S	M	L	Total		Site	S	M	L	Total	
16	0	2	1	3	2.5	21	5	0	0	5	3
17	3	0	0	3	2.5						
Total	3	2	1	6	5.0						
No. furnaces in group:					2	No. furnaces in group:					1
Avg. No. recuperators/furnace:					3.0	Avg. No. recuperators/furnace:					5.0
Avg. unrecup. input, MM Btu/hr/fce:					2.5	Avg. unrecup. input, MM Btu/hr/fce:					3.0
Avg. unrecup. input, MM Btu/hr/recup.:					0.8	Avg. unrecup. input, MM Btu/hr/recup.:					0.6
Furnace temperature, F:						Furnace temperature, F:					
Range:					1750-1800	Range:					2200
Average:					1775	Average:					2200

unrecuperated thermal input (Figure 7) shows the general trend lines for the 38 installations. The majority fall within the lines bounded by 0.5 and 2.0 million Btu/hour per recuperator. The two sites lying above the band might be construed as somewhat over designed, whereas the one below might be under-designed. It has been noted, however, that the latter unit actually is operated well below its nominal thermal input capacity.

METHODS FOR DATA COLLECTION AND ANALYSIS

With few exceptions, each of the 38 host sites was visited by BCL personnel for an on-site inspection of the equipment, the instrumentation, and the operating procedure. The objectives of the program were discussed with the operating staff, and arrangements were made for the periodic collection and transmittal of data to Battelle. These visits were followed up by telephone calls and return visits in some instances to resolve problems and answer questions. A substantially high degree of cooperation was obtained from the host site personnel during these interactions. In many cases, the visits were coordinated with GTE staff or with the equipment installers to ensure better communication.

At each site, information was requested on

- Fuel consumption data as a function of product throughput for both the baseline and the recuperated furnaces
- Financial data, including purchase and installation costs, fuel costs, and information on maintenance and repair costs as experienced.

Other items of information requested included details of the process variables, instrumentation, and operational scheduling procedures.

Methods for Analysis of Fuel Economy

A key element in this program is the assessment of furnace performance by comparing one unit with another in the same plant. This makes it possible to eliminate a number of site-specific variables that otherwise would be difficult to evaluate and nearly impossible to control. It also

FIGURE 7. RELATIONSHIP OF NUMBER OF RECUPERATORS TO UNRECUPERATED THERMAL INPUT PER FURNACE

reduces the data requirements for the host site to a realistic and manageable level. In contrast, the information that would be required for a full heat balance test program would involve substantially more instrumentation and deviations from normal production procedures that were beyond the scope of this program.

The comparison may be made on either a "before-and-after" or a "side-by-side" basis; in a few instances it was possible to obtain both. In the first method, performance data were collected and analyzed for the original or baseline furnace before the installation of the GTE recuperator system. After the retrofit, which usually included furnace improvements in addition to the recuperators and burners, the furnace was monitored and its performance was compared with that of the original. In the second approach, a GTE-equipped furnace was operated along with a comparison furnace with operating data being collected simultaneously on both. In either case, it was important that operating procedures, scheduling, and utilization of the comparison units be kept as similar as possible to provide a useful comparison.

It also was necessary to choose the basis for comparison from among a number of valid ways in which this might be done. For example, one basis would be to monitor fuel consumption only during working periods where product throughput is at or near rated capacity. This would be expected to yield the best fuel economy of which the furnace is capable. The basis selected for this program involved operations as they actually occurred in the plant, including fuel used for furnace idling, cooling and reheating overnight or weekends, operational delays, and small furnace loads. Although the absolute performance results are lower than those of which the equipment is capable, they are more nearly representative of actual production experience. However, because business conditions were poor during much of the time period when the comparisons were made, production levels frequently were substantially lower than those considered to be "normal" for the plant involved.

Analysis of Furnace Performance Data

The comparative performance data requirements for furnaces with and without recuperation will vary according to the specific process involved. In addition, the ability and willingness of each host site to

collect operating data affects the depth of analysis that can be applied. Where possible, furnace performance curves have been developed in terms of specific energy consumption as a function of product throughput. The energy saved by furnace improvements then is expressed as the percentage difference taken at the mean throughput value.

In a number of situations, the variety of materials and heating temperatures was such that the scatter of data points around the performance curve was unacceptably great, and a valid trend line could not be developed. In such cases, the comparison was made for average values alone of energy used and product heated. In still other instances, no reliable information could be obtained on product throughput; the only available data were for fuel consumption. The implicit assumption that must be made then is that the average product throughput remains constant. This also is the case for the two ladle heater installations, where no "product" is being heated.

A second important point is that the comparison made between two furnaces reflects not only the addition of recuperation, but any other modifications that may have been added. The percent fuel savings that are demonstrated thus are the result of recuperation plus other furnace improvements; e.g., improved insulation, combustion controls, etc. As a result, it is not uncommon to show improvements in total fuel efficiency of 50 to 60 percent, of which only a part is the direct result of recuperation--typically 30 to 40 percent. The fuel savings attributable to recuperation alone can be estimated, but operating data were not sufficient to provide actual values.

This introduces the problem of determining financial payback times that are consistent with reported costs for the recuperation alone. Although consistency can be achieved by relating total performance improvement with total costs, it is not fair to compare the total cost of a completely new furnace with that of a retrofit. Attempts to relate recuperation-related costs with fuel savings due only to recuperation are open to question; it not only is difficult to establish exactly what costs are directly related only to recuperation, but the fuel savings from recuperation alone are estimates, rather than measured values.

Procedure for Data Analysis

The raw data obtained from the host sites were furnished to Battelle in various forms. The most common form was a log sheet identifying the furnace and listing dates and times of operation; fuel meter readings; operating temperatures; and product weights. In many instances daily fuel used, corrected for meter pressure and temperature, was included, and some host sites routinely compute the specific energy consumed in terms of Btu's per pound of material heated.

Wherever possible, the raw data were converted into data pairs corresponding to convenient time intervals; daily values were most common. The two basic pieces of information are

- (1) Product throughput (x), 1000 lbs/day, and
- (2) Specific Energy Consumption (z), 1000 Btu/lb.

For situations where all the product is the same material and all, or nearly all heated to the same temperature, the specific energy consumption is a valid measure of thermal efficiency. This is the case for most forging plants and aluminum melters. For plants where large varieties of materials are heated to different temperatures, care must be taken to account for the different amounts of heat required, or to select only data on comparable materials and temperatures for comparisons.

Values of z and x were fitted to an exponential curve of the form $z = Ax^n$ by a least-squares regression analysis. This is conveniently displayed on a logarithmic (log-log) plot of z and x as a straight line with a slope of n.

It may also be noted that the total energy consumption (per unit of time) is equal to the product of throughput and specific energy consumption. This can be expressed as follows:

$$\begin{aligned} \text{Total Energy Consumption } y &= xz \text{ (} 10^6 \text{ Btu/day), or} \\ y &= Ax^{n+1}. \end{aligned}$$

This also appears as a straight line on a logarithmic plot of y versus x, and can be derived from the same basic data.

The logarithmic plots of Specific Energy Consumption versus Throughput typically have negative slopes of about 40° from the horizontal. If this slope becomes 45° ($n=-1$), it can be shown that fuel consumption is independent of throughput. This follows from the equation $y = Ax^{n+1}$ given above; if $n = -1$, $y = Ax^0 = A$ and energy consumption is thus independent of x . This is sometimes useful in assessing the degree to which the furnace is being utilized. If the data yield a performance line with a slope of nearly -1, it generally will be found that the furnace either is over-designed or under-utilized.

This analysis of furnace performance can be done manually by constructing a best-fit straight line through the data points, or by regression analysis using either a programmable calculator* or a computer. The computer can be programmed to produce the performance curves as well as to store the data cumulatively. An example of such a computer-generated log-log plot is shown in Figure 8.

The comparison between the recuperated and unrecuperated furnaces is made by plotting both performance lines on the same graph, and comparing Specific Energy Consumption values at a common throughput. The common throughput (x value) usually is taken at a round number near the mean values for the two furnace performance lines. On the plots included in this report, the mean values are designated by triangles and the common throughput value is designated by vertical arrows. The percent fuel savings indicated is expressed as:

$$\text{Percent Fuel Savings} = \left(\frac{z_U - z_R}{z_U} \right) \times 100 \quad ,$$

where

z_U = Specific Energy Consumption of
Unrecuperated Furnace, 1000 Btu/lb

z_R = Specific Energy Consumption of
Recuperated Furnace, 1000 Btu/lb.

* The program used here for the TI-59 calculator is presented in Figure 9.

FIGURE 8. EXAMPLE OF COMPUTER-GENERATED PERFORMANCE CURVE

Step 1. Insert Program

(2nd) (CP) (LRN) (2nd) (Pgm) (1) (SBR) (CLR) (2nd) (Lb1) (A)
 (2nd) (log)(x $\rightleftharpoons$ t) (R/S) (2nd) (Lb1) (B) (2nd) (log) (2nd) (Σ +) (R/S) (RST) (LRN)

Step 2. Insert Data Pairs

(x_n) (A) (z_n) (B) (Repeat as Required)

Step 3. Extract Results

(2nd) ($\bar{x}$) (INV) (2nd) (log)	$\Rightarrow$	$\bar{z}$ (mean value of z)
(x $\rightleftharpoons$ t) (INV) (2nd) (log)	$\Rightarrow$	$\bar{x}$ (mean value of x)
(2nd) (Op) (12) (INV) (2nd) (log)	$\Rightarrow$	z Intercept (value of z at x=1)
(x $\rightleftharpoons$ t)	$\Rightarrow$	Slope
(2nd) (Op) (13)	$\Rightarrow$	Correlation Coefficient

x = 1000 lbs/day
 z = 1000 Btu/lb

FIGURE 9. PROGRAM USED FOR REGRESSION ANALYSIS ON TI-59 CALCULATOR

If the two furnace performance lines are parallel, the percent fuel savings will be independent of product throughput. More generally, fuel savings will vary somewhat over the range of throughputs.

For those situations where the data were not of sufficient quality or quantity to develop performance curves, it was possible in some instances to provide comparisons using only mean values of fuel consumption. This necessarily was the case for installations where no provision was made for measuring product throughput or, as for the ladle heater, where no real product was involved. In one or two installations there was a large variety of materials being heated and frequent changes in furnace temperature. Even though fuel meters were read between each furnace loading, the thermal inertia was so great that no clear relationship could be developed between useful energy output (product heated) and energy input (fuel used).

DISCUSSION OF RESULTS

Performance data for those installations where sufficient information was generated are summarized in Table 3; the individual performance curves are presented in Appendix B. The parameters listed in Table 3 are expressed as terms of the exponential equations described previously:

$$z = Ax^n, \quad \text{and}$$

$$y = Ax^{n+1} \quad \text{where}$$

z = Specific Energy Consumption, 1000 Btu/lb

y = Total Energy Consumption, 10^6 Btu/day

x = Product Throughput, 1000 lb/day.

The $\bar{y}$ and $\bar{z}$ values are mean values of those terms taken at the mean product throughput ($\bar{x}$), designated by triangles in the plots. For comparison of the recuperated and unrecuperated furnaces, an average daily loading was

TABLE 3. SUMMARY OF FURNACE PERFORMANCE DATA

Site No.	Host Site	Recuperated Furnace					Unrecuperated Furnace				
		A	n	$\bar{x}$	$\bar{y}$	$\bar{z}$	A	n	$\bar{x}$	$\bar{y}$	$\bar{z}$
1	McInnes Steel	28.2	-0.822	11.9	43.8	3.68	58.8	-0.757	15.5	114.5	7.41
2	Lebanon Steel	--	--	17.4	22.8	1.31	--	--	18.2	27.4	1.51
3	Alcan	--	--	--	3.1	--	--	--	--	4.8	--
4	X-Tek	11.3	-0.758	17.4	22.6	1.30	24.4	-0.698	11.8	51.4	4.38
5	Ajax X-Ray	--	--	0.9	3.1	3.41	--	--	0.9	4.8	5.33
6	GTE	--	--	--	--	--	--	--	--	--	--
7	Hammond & Irving	30.8	-0.728	13.4	62.2	4.65	33.3	-0.585	15.4	103.7	6.70
8	Bay City Forge	85.2	-0.996	41.0	86.5	2.11	--	--	34.9	5.6	193.70
9	Monroe Forge	9.1	-0.583	3.5	15.3	4.33	19.3	-0.785	6.1	28.5	4.67
10	Special Metals	--	--	34.3	49.4	1.44	--	--	33.1	82.8	2.50
11	Special Metals	13.0	-0.931	5.8	14.7	2.52	16.2	-0.814	5.1	22.0	4.29
12	Harnischfeger	--	--	--	--	--	--	--	--	--	--
13	GTE	--	--	--	--	--	--	--	--	--	--
14	GTE	14.8	-0.719	1.4	16.4	11.44	30.4	-0.795	1.3	32.1	24.34
15	GTE	21.9	-0.662	2.1	28.1	13.36	41.3	-0.710	2.2	51.8	23.78
16	GTE	--	--	1.8	34.5	19.50	--	--	4.9	22.7	4.60
17	GTE	--	--	--	--	--	--	--	--	--	--
18	Kentucky Forge	6.6(1)	-0.924(1)	2.1(1)	7.0(1)	3.33	8.2(1)	-0.899(1)	3.8(1)	9.4(1)	2.46
19	Schmitt Steel	14.7	-0.832	3.2	17.9	5.55	22.5	-0.765	6.5	35.0	5.35
20	Crescent Tool	8.2(1)	-0.769(1)	1.6(1)	9.1(1)	5.80	19.3(1)	-0.989(1)	1.3(1)	19.2(1)	15.25
21	Pfizer	--	--	--	50.6	--	--	--	--	72.0	--
22	Howmet	20.2(1)	-0.949(1)	3.9(1)	21.7(1)	5.61	25.5(1)	-0.974(1)	4.4(1)	26.5	6.03
23	Howmet	--	--	--	--	--	--	--	--	--	--
24	National Forge	224.9(2)	-0.850(2)	329.8(2)	537.3(2)	1.63	564.3(2)	-0.907(2)	433.4(2)	990.7(2)	2.29
25	Bucyrus-Erie	21.3	-0.680	46.7	72.9	1.56	63.2	-0.940	38.2	78.6	2.06
26	Timet	41.4	-0.850	9.1	57.7	6.34	53.7	-0.769	4.5	75.9	17.00
27	McWilliams Forge	--	--	--	15.0	--	--	--	--	32.9	--
28	Altech	10.7	-0.761	10.3	18.7	1.82	16.4	-0.887	10.5	21.3	2.03
29	Crucible	20.3	-0.886	4.9	24.3	4.97	28.9	-0.877	5.5	6.5	35.63
30	Buffalo Metal Cast.	5.6	-0.743	0.6	4.8	8.44	8.7	-0.609	0.6	6.9	12.51
31	Standard Steel	--	--	--	--	--	--	--	--	--	--
32	National Forge	--	--	--	--	--	--	--	--	--	--
33	Ladish	--	--	--	--	--	--	--	--	--	--
34	Pratt & Whitney	--	--	--	--	--	--	--	--	--	--
35	Amax	--	--	--	--	--	--	--	--	--	--
36	Bethlehem Steel	20.1	-0.650	22.5	59.6	2.65	69.6	-0.799	11.8	114.3	9.92
37	Cape Ann Forge	13.7	-0.699	11.0	28.2	2.57	36.1	-0.838	9.1	51.7	5.68
38	Stanley Spring	4.2	-0.743	28.2	21.7	0.77	35.3	-0.836	27.8	60.9	2.19

* Furnace performance is expressed by the equations:

$z = Ax^n$ and $y = Ax^{n+1}$, where $y = xz$ and

x = product throughput, 1000 lbs/day

y = total energy consumption, 10^6 Btu/day

z = specific energy consumption, 1000 Btu/lb

A = coefficient, 1000 Btu/lb

n = exponent

$\bar{x}$, $\bar{y}$, and $\bar{z}$ are mean values of x , y , and z .

(1) Data reported by shift rather than daily.

(2) Data reported weekly rather than daily.

selected at a typical value of x near $\bar{x}_R$ and $\bar{x}_U$. This value is indicated by the vertical arrows on the plots. The percent fuel savings were calculated at this average loading.

The results of these calculations are presented in Table 4, along with the other items of information that were used in the computations of cost recovery. The estimation of operating days has been complicated by the adverse business conditions during 1982. Many plants have been forced to shut down for extended periods, and others have reduced operations from two or three shifts to one. These reduced operations result in similarly reduced annual savings, which in turn increase payback times beyond those originally calculated. As business conditions improve, the calculations can be modified accordingly to revise estimated payback times.

An overview of the percent fuel savings measured in the program is presented in Figure 10, which includes theoretical fuel savings curves as a basis for comparison. Of the 28 sites for which data are shown, 10 are within the expected range (for air preheat temperatures ranging between 800 F and 1200 F); 13 are above the expected range; and 5 are below the expected range. Of those 5 with fuel savings lower than expected, various operating problems with the rebuilt furnaces account for their apparent poor performance during the data collection period. For example, in one instance (Site No. 18) the two furnaces were used to heat forging stock of different sizes, so that a true comparison could not be made.

The furnaces showing improvements in fuel economy above the range expected in some cases reflect the improvements made to the furnace during retrofit in addition to recuperation.

The calculations of payback time were made on two bases, the first being total installation cost and the second based upon costs directly related to recuperation. In both instances, the annual fuel savings used is the total value and reflects not only the savings from recuperation but those from other improvements. In general, payback times based on total costs will overstate the time to return the investment on recuperation, whereas the calculation based on only recuperator-related costs will understate the payback time. The difference between the two becomes most

TABLE 4. SUMMARY OF FUEL ECONOMY DATA

Host Site	Site No.	Average Product Throughput, 1000 lb/Day	Average Total Energy Consumption, 10 ⁶ Btu/Day (Unrecuperated)	Percent Fuel Savings	Total Energy Saved, 10 ⁶ Btu/Day	Total Energy Saved, 10 ⁶ Btu/Year	Fuel Cost, \$10 ⁶ Btu	Estimated Operating Day/Year	Total Installed Cost, \$1000	Recuperator-Related Costs, \$1000	Estimated Fuel Savings (1st Year), \$1000	Simple Payback on Total Cost, Years	Simple Payback on Recup. Related Cost, Years	After Tax Payback on Total Cost, Years	After Tax Payback on Recup. Related Cost, Years
McInnes Steel	1	15.0	113.6	59.8	67.9	16,980	5.43	250	99.46	61.32	92.17	1.1	0.7	1.5	1.0
Lebanon Steel	2	18.0	27.2	13.1	3.6	1,800	4.85	250	113.00	75.00	8.74	12.9	8.6	13.3	8.4
Alcan	3	--	14.4	36.0	5.2	1,250	4.90	240	14.80	14.80	6.12	2.4	2.4	2.8	2.8
X-tek	4	15.0	55.4	60.7	33.6	8,400	5.34	250	116.83	116.83	44.86	2.6	2.6	3.0	3.0
Ajax X-Ray	5	0.9	4.8	37.1	1.7	433	7.97	250	7.22	7.22	3.45	2.1	2.1	2.5	2.5
GTE Towanda #9	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hammond & Irving	7	15.0	102.6	37.4	38.4	9,600	4.40	250	66.64	66.64	42.24	1.6	1.6	2.0	2.0
Bay City Forge	8	40.0	186.0	53.5	99.5	14,930	5.50	150	251.30	108.47	82.09	3.1	1.3	3.3	1.7
Monroe Forge	9	5.0	27.3	35.2	9.6	2,880	7.83	300	41.14	41.14	22.55	1.8	1.8	2.3	2.3
Special Metals	10	14.0	82.8	42.4	35.1	8,420	5.50	240	103.00	96.30	46.31	2.2	2.1	2.6	2.5
Special Metals	11	5.5	22.3	34.2	7.6	5,470	5.50	240	67.30	67.30	30.10	2.2	2.2	2.6	2.6
Harnischfeger	12	--	--	--	--	--	--	--	145.65	110.00	--	--	--	--	--
GTE Towanda #21 Moly	13	--	--	--	--	--	--	--	97.47	53.80	--	--	--	--	--
GTE Towanda #16	14	1.4	32.6	50.1	16.3	5,480	5.38	336	53.34	53.34	29.50	1.8	1.8	2.2	2.2
GTE Towanda #13 Tube	15	2.2	51.6	45.1	23.3	7,820	5.38	336	37.19	37.19	42.10	0.9	0.9	1.2	1.2
GTE Towanda #1 Calciner	16	3.0	35.1	38.5	11.1	4,540	5.38	336	41.61	41.61	24.40	1.7	1.7	2.1	2.1
GTE Towanda #3 Calciner	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Kentucky Forge	18	3.0 ⁽¹⁾	9.2 ⁽¹⁾	21.5	2.0 ⁽¹⁾	1,000	3.44	250	49.00	49.00	3.44	14.2	14.2	14.6	14.6
Schmitt Steel	19	5.0 ⁽¹⁾	32.9 ⁽¹⁾	41.2	13.6 ⁽¹⁾	3,400	5.55	250	95.99	57.22	18.87	5.1	3.0	4.7	3.3
Crescent Tool	20	1.5 ⁽¹⁾	19.3 ⁽¹⁾	53.6	10.3 ⁽¹⁾	5,150	5.81	250	38.27	38.27	29.92	1.3	1.3	1.7	1.7
Pfizer Company	21	--	72.0 ⁽¹⁾	29.7	21.4 ⁽¹⁾	7,810	7.68	365	123.55	76.55	59.99	2.1	1.3	2.5	1.7
Howmet Turbine	22	4.0 ⁽¹⁾	26.4 ⁽¹⁾	17.9	4.7 ⁽¹⁾	3,525	5.54	250	93.20	62.39	19.53	4.8	3.2	4.5	3.4
Howmet Turbine	23	--	--	--	--	--	--	--	111.51	80.76	--	--	--	--	--
National Forge	24	400.0 ⁽²⁾	983.4 ⁽²⁾	43.7	429.7 ⁽²⁾	21,490	5.29	50 ⁽²⁾	675.32	149.44	113.66	5.9	1.3	5.4	1.7
Bucyrus Erie	25	40.0	78.8	11.9	9.4	2,350	5.50	250	244.71	114.23	12.93	18.9	8.8	18.7	8.7
Timet	26	7.0	84.2	34.1	28.7	8,610	5.29	300	134.40	108.40	45.55	3.0	2.4	3.2	2.8
McWilliams	27	--	32.9 ⁽¹⁾	54.3	17.9 ⁽¹⁾	4,480	4.43	250	73.20	41.04	19.82	3.7	2.1	3.8	2.5
Altech	28	10.0 ⁽¹⁾	21.2 ⁽¹⁾	12.5	2.7 ⁽¹⁾	1,350	5.50	250	136.58	126.09	7.43	18.4	17.0	18.2	17.1
Crucible Steel	29	5.0	35.2	30.7	10.8	2,700	4.44	250	101.99	41.79	12.00	8.5	3.5	8.3	3.6
Buffalo Metal Casting	30	0.6	7.1	31.5	4.4	1,100	7.68	250	17.91	16.53	8.45	2.1	2.0	2.5	2.4
Standard Steel	31	--	--	--	--	--	--	--	--	--	--	--	--	--	--
National Forge	32	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ladish Company	33	--	--	50.0 ⁽³⁾	--	--	--	--	188.43	77.53	--	--	--	--	--
Pratt & Whitney	34	--	--	--	--	--	--	--	54.13	54.13	--	--	--	--	--
Amex Specialty Metals	35	--	--	45.9 ⁽³⁾	--	--	--	--	152.17	138.07	--	--	--	--	--
Bethlehem Steel	36	20.0	127.2	55.0	70.0	17,500	5.50	250	293.39	216.61	96.25	3.0	2.3	3.3	2.6
Cape Ann Forge	37	10.0	52.5	44.4	23.3	5,830	5.55	250	129.21	96.70	32.33	4.0	3.0	4.0	3.3
Stanley Spring (TRWO)	38	30.0	61.6	63.7	39.2	9,810	5.54	250	97.64	43.31	54.29	1.8	0.8	2.2	1.1

* Furnace performance is expressed by the equations:

 $z = Ax^n$ and $y = Ax^{n+1}$, where $y = xz$ and x = product throughput, 1000 lbs/day y = total energy consumption, 10⁶Btu/day z = specific energy consumption, 1000 Btu/lb x , y , and z are mean values of x , y , and z .

(1) Data reported by shift rather than daily.

(2) Data reported weekly rather than daily.

(3) Preliminary performance data.

FIGURE 10. FUEL SAVINGS AS A FUNCTION OF NOMINAL FURNACE TEMPERATURE

significant in situations where a large complete new furnace installation is involved, and where the recuperator-related portion of that is relatively small (e.g., Site 24).

Payback calculations were made using both simple and after-tax discounted methods. In the former, the total cost is divided by the first-year fuel savings to give an estimated payback time. The more realistic procedure (as described in Appendix A) was used for the second computation.

GENERAL CONCLUSIONS

The diversity of host site operations and the adverse business circumstances encountered during much of the time span of this program make it somewhat difficult to draw general conclusions. Nevertheless, the following statements represent Battelle's opinions based upon the findings of this study:

- The GTE recuperator system has been successfully demonstrated in a wide variety of industrial furnace applications
- The improvements in fuel economy demonstrated, measured under production conditions, equalled or exceeded projections except for a few isolated cases. Those exceptions are attributed to unique operational difficulties or to incomplete data.
- Payback times may be calculated on a number of different bases. One involves crediting all of the fuel savings against all of the costs; this method is reasonable for the furnace user who is more interested in totals and less concerned with how much of that total is the result of recuperation alone.

A second approach is to credit only the fuel savings attributed to the recuperation addition against the recuperator-related costs. This

method requires some judgment both in deciding what costs should be considered recuperator related, and what fraction of the total fuel savings is properly credited to the recuperator. The latter is difficult to measure on most industrial installations, because it requires a substantial amount of additional instrumentation along with the effort needed to collect the additional data. In this program, it was not possible to obtain that information, although reasonable estimates are possible. This approach is preferred by GTE, for the following reasons. Most of the furnaces that were built or rebuilt on this program were units which the users already had decided to upgrade, with or without recuperation. Thus, the additional costs to be justified in terms of payback are only those directly related to recuperation; the non-recuperator costs would have been incurred in either case.

The difference between these two approaches will be most significant where there is a large difference between total and recuperator-related costs. For example, the new furnace at National Forge (Site 24) involved a total cost of \$675,000 as compared with recuperator-related costs estimated at \$159,000. If the full fuel savings of \$114,000 for the first year is credited in each case, the simple payback time drops from 6 to 1.4 years when only the recuperator-related costs are considered.

- No substantive data were generated on maintenance costs during this program. In a few cases, operating problems unrelated to the recuperator resulted in excessive temperatures and destruction of the ceramic units; otherwise no failures were reported during normal operations.

APPENDIX A

METHOD FOR FINANCIAL ANALYSES

The method selected for financial analyses is payback period based on cumulative annual after-tax cash flow. The method is the same as that used in the companion "Task I. Hague Forge Furnaces" report, but several inputs have been revised because of changes in depreciation allowances and changes in expected rates of inflation occurring since the companion work was issued.

Why a Payback Method?

Contacts with industrial companies show that most use some form of payback calculation to provide an indication of economic worth of a proposed project. A recent and continuing series of articles in Energy User News has been directed toward determining the basis on which various companies evaluate economic potential of proposed new energy-conserving investments. This series also indicates that payback calculations are by far the most common method in use by industrial companies, both large and small.

Although payback period is the most common method for evaluating economic worth of new equipment, it suffers from limitations that are widely recognized by financial analysts. Therefore, a search was made through a number of reports and documents issued by DOE and its contractors during the past several years. The object of the search was to determine whether any other method had been used to any substantial degree to overcome the limitations of the payback method. Although the search disclosed occasional discussion of more sophisticated methods, there has been little use of them in a quantitative way.

After consideration of the pros and cons of each of the methods that might be employed for project purposes, the ultimate decision to use a payback method was based on the fact that the resulting parameter (payback

period in years) is most readily understood by operating and engineering personnel employed in industrial plants and by manufacturers of equipment. Although some of the other methods may be "better" from the viewpoint of a financial analyst, they are less understandable to the intended audience for this project.

Payback Period

Payback period is the ratio of the initial capital investment divided by some measure of annual savings. Relatively sophisticated payback methods, such as the one selected for this project, determine savings from accounts that include depreciation, operating costs, taxes, and tax credits. The payback period, therefore, is a measure of the number of years required to recover the initial cash investment.

Disadvantages of payback methods in general include (1) they fail to consider cash flows beyond the payback period, (2) they ignore the magnitude and timing of cash flows during the payback period, and (3) the results can be deceptive if erroneously interpreted to be a measure of profitability. The payback method is not an adequate indicator of financial risk. Payback period is most appropriately considered to be a constraint that must be satisfied, rather than a profitability measure to be maximized.

The payback method that has been selected is based on recovery of full capital cost, using fuel saving as an important device for recovery of cost. There is a fuel saving when (1) an existing furnace is retrofitted with energy-conservation equipment, or (2) a new furnace replaces an old furnace that is fully depreciated. However, when an increase in capacity is involved, there may be no identifiable fuel saving (because there is no basis for comparison). With no recovery of cost via fuel saving, computed payback period will be longer than when a fuel saving is involved. But there still will be a payback period, because original cost will be recovered through tax credits and expensing of depreciation.

For an evaluation among several alternatives (such as a comparison of a new furnace with recuperation to a new furnace without recuperation, both involving an increase in capacity within a shop), other methods of

financial analysis (such as internal rate of return) are more useful than payback analysis.

The calculations necessary to determine payback period on an after-tax cash-flow basis sometimes are truncated by plant people. Their "simple" payback analysis is made by dividing original investment by estimated annual before-tax saving in fuel cost. This short cut is taken for convenience or because of lack of information or uncertainty about values to assign and methods to handle depreciation, operating costs, taxes, tax credits, and inflation. Therefore, these factors vital to rational analysis often simply are ignored. Agreement between the after-tax cash-flow method and the "simple" method may be close under some sets of conditions, but is strictly fortuitous in the general case.

Average Rate of Return

Average rate of return is an accounting method. It determines the ratio of annual book earnings to average net investment. The method is little used in the literature on energy conservation, and aside from its simplicity, has little to recommend it for the present purposes. It is based on accounting income, not cash flow. As with payback period, it ignores the time value of money and fails to consider the present value of cash inflows and outflows.

Internal Rate of Return

Internal rate of return is a discounted cash-flow method that considers the magnitude and timing of expected cash flows in each period of a project's life. The method recognizes the time value of money.

The internal rate of return is the discount rate that equates the present value of expected cash outflows with the present value of expected cash inflows. Because of the discounting feature, the method has intuitive appeal, and is widely recommended in financial texts. In actual use, however, the method appears to be reserved to financial

personnel, making final judgments or doing capital budgeting. The method requires an assumption about future discount rates, information not usually available to plant or engineering personnel, and viewed today even by expert financial analysts as speculative. The calculation involves either iterative trial and error using present-value tables or the use of a computer program. Use of the calculated internal rate of return requires that the user have information on the required rate of return or hurdle rate for the particular company.

A few years ago, Battelle-Columbus in a study and report for DOE about energy conservation in the steel industry evaluated the economic worth of a number of alternatives using the internal rate of return as the measure. The resulting rates involved numbers different from what people expected to see. Confusion about the meaning of the numbers as given in the draft report was so extensive and elicited so many questions that the method and its results were deleted from the final report. Although theoretically sounder than other methods, lack of understanding of the theory by the readers and users of the report destroyed practical significance for the plant-oriented engineering-oriented audience.

The after-tax cash-flow payback method selected for this project generates the quantitative information necessary to calculate internal rate of return, but stops short of making the speculative assumptions necessary for the calculation of rate of return.

Present Value

Present value is a method by which all cash flows, in and out, are discounted to present value using a required rate of return. It is a variant of internal rate of return, and has similar advantages and disadvantages. An additional disadvantage surfaces--it is necessary to know or assume a required rate of return. This is usually an assumption. Our experience with metal-producing and fabricating firms suggests that even the largest are uncertain about the value of the "required" rate. The method seems to have low applicability for the present purposes.

Unquantified Considerations

Although payback and other forms of analysis of economic worth deal with selected variables in a quantitative manner, the methods customarily ignore other considerations that can play a determining role in the company's decisionmaking process. Therefore, payback analysis is only one of the factors that is taken into consideration by companies when deciding whether or not to install a new item of equipment. Although payback analysis can be standardized to permit comparison among sites, other factors can have overriding importance in any particular shop. Among the unquantified factors often considered in addition to payback analysis are the following:

- Change in product quality
- Change in productivity
- Change in space requirements
- Change in operating practices
- Change in type of personnel needed
- Change in insurance rates or safety requirements
- Change in downtime cost.

Method for Payback Analysis

The general form of the selected method is:

$$\text{Payback period, years} = \frac{\text{Cash investment}}{\text{After-tax net cash flow}}$$

The annual net cash flow can change from year to year because of changes in such factors as investment credits and escalating costs of energy and general inflation. It is necessary, therefore, to make separate calculations of annual after-tax net cash flow for each year until the cumulative total of annual net cash flows equals the initial cash investment. From this, the payback period is calculated in terms of the required number of years.

Input data that must be specified for each calculation include the following:

- Total installed furnace cost
- Estimated useful life
- Estimated salvage value (when applicable)
- Investment tax credit
- Energy-savings tax credit
- Assumed applicable tax rate
- Assumed general inflation rate
- Estimated energy cost in Year 1
- Assumed energy-cost inflation rate
- Annual energy savings
- Annual maintenance cost increment.

From these, computation develops the following for each year:

- Projected energy cost (escalated)
- Fuel-cost savings (escalated)
- Incremental maintenance cost (escalated)
- Net cost savings
- Depreciation
- Effect on pre-tax profit
- Effect on after-tax profit
- Total tax credits
- After-tax cash flow
- Cumulative after-tax cash flow.

The computation is continued for sufficient years until the cumulative after-tax cash flow equals the total installed furnace cost.

Comments regarding the derivation and handling of each of these factors follow. Numbers in circles refer to items used in the computation. The method is described in sufficient detail that readers may make adjustments or modifications for their own purposes.

Total Initial Installed Furnace Cost ①

Total installed capital cost (equipment plus freight and installation) can be relatively easy to determine when a single outside contractor provides all the equipment and labor. In the more usual situation, however, several parties are involved. Often, in the early stages of commercialization of new equipment, as in this project, some equipment is sold at discounted or promotional prices, or developmental subsidies are granted to the buyer. The influence of a discount or subsidy needs to be considered, so that the resulting payback period does not mislead other prospective users who may be required to pay full list price.

In the case of retrofits of existing equipment, the furnace is often modified at the same time that recuperative equipment is retrofitted. The resulting change in performance is an integration of both the modification and the retrofitting, plus, perhaps, other changes in conditions of operation. Total installed capital cost for the modification plus the retrofit overstates the cost of the retrofit. Installed capital cost for only the recuperator components understates the size of the investment needed to obtain the desired result. In such situations, two or more payback analyses can be made, each based on a different interpretation of total installed capital cost.

Estimated Useful Life ②

This is the life used in the calculation of annual depreciation. Current Federal tax codes permit process equipment of the type under consideration to be written off (depreciated) at an accelerated rate (described later) over a period as short as 5 years. Because accelerated depreciation and short write-off periods maximize cash flow in early years, it is assumed that companies generally will use the 5-year accelerated schedule. This assumption incorporates another assumption--that the equipment will have a useful life of at least 5 years. Because the recuperators under consideration have had a maximum of only about 2 years of service, the validity of the assumption about a 5-year minimum life is still to be determined.

Estimated Salvage Value (3)

Estimated salvage value of the equipment is a proper deduction against original cost in those situations where depreciation is calculated by the straight-line or sum-of-the-years-digits methods. For methods of accelerated depreciation (as used for this project), the consideration of salvage value is neither needed nor appropriate. If there eventually is some income from sale of residual parts, it is credited to profit on sale of equipment.

Investment Tax Credit (4)

It is presumed that buyers of recuperators will apply for and qualify for the existing 10 percent tax credit on new equipment. When the original capital cost includes both new equipment (such as a recuperator), and modification of an existing furnace (which may not qualify for a tax credit), judgment must be used to select a value for the estimated tax credit (which is subject to audit by IRS).

Energy Savings Tax Credit (5)

Currently, certain specific types of energy-conserving equipment (including recuperators) qualify for an energy saving tax credit of 10 percent of installed cost. However, IRS has been very strict in limiting this credit to the specifically legislated items. It is by no means certain that in any individual case involving a new furnace or a retrofit package of several items that the entire cost of the furnace or package will be allowed by IRS as the basis for an energy-saving tax credit. The general subject is currently under active consideration by congressional groups. For the present purposes, it is assumed that an energy tax credit of 10 percent will be allowed on all or most of the equipment under study. An effect of this assumption is to shorten the calculated payback period.

Assumed Applicable Tax Rate (6)

It is assumed that the equipment is installed in a profit-making enterprise taxed at an effective rate of 46 percent for IRS purposes.

Assumed General Inflation Rate (7)

The rate of general inflation is taken as 7.5 percent annually.

Estimated Energy Cost in Year 1 (8)

Because each installation under consideration is already in operation, the current shop cost for energy is known or can be estimated.

Assumed Energy Cost Inflation Rate (9)

For extrapolation of current energy costs to future years, the increase in cost is taken to be 15 percent annually.

Annual Energy Savings (10)

Annual energy savings credited to new equipment or to retrofits are determined for each situation from data reported for each site. Because annual energy savings are strongly influenced by the conditions and number of hours of operation of the equipment per year, at some sites it is appropriate to calculate several options for payback analysis, each based on a different annual energy savings.

Annual Maintenance Cost Increment (11)

In all cases under study, the equipment involved in the recuperated furnace is more complex than the baseline equipment or the furnace prior to retrofit. Therefore, it is presumed that the new equipment will entail higher costs for maintenance and replacement parts. In those

situations where actual incremental costs are not specifically known, this item for Year 1 is taken to be 10 percent of the original capital cost, and for future years is escalated at the general inflation rate.

Year Number (12)

The year prior to actual start-up of the equipment is defined as Year 0. The first year of operation is Year 1. These are not necessarily calendar years.

Projected Energy Cost (13)

This is the expected cost of energy expressed in dollars per million Btu (\$/MMBtu). It is determined from the following relationship:

$$(13) = (8) \left[1 + \frac{(9)}{100} \right]^{[(12)-1]}$$

Fuel Cost Savings (14)

Annual savings in fuel cost is given by:

$$(14) = (10) \times (13) .$$

Incremental Maintenance Cost (15)

$$(15) = (11) \left[1 + \frac{(7)}{100} \right]^{[(12)-1]} .$$

Net Cost Savings (16)

Annual net cost saving is determined as annual fuel cost savings less annual incremental maintenance cost:

$$(16) = (14) - (15) .$$

Annual Cash Investment (17)

Cash investment in Year 0 is taken to be equal to Total Initial Installed Furnace Cost (1). If additional cash investment is made in any subsequent year, it is included in the calculation for the appropriate year.

Depreciation (18)

The Tax Code of 1981 now allows depreciation of process equipment over 5 years using the 150 percent declining balance method, switching to straight line when that becomes advantageous. Only half of the formula amount is allowed in the first year. The resulting accelerated schedule allowed by the current tax code is as follows:

<u>Year</u>	<u>% of original investment</u>
1	15
2	22
3	21
4	21
5	21
6 and over	0

It is assumed that most companies will maximize cash flow by using this accelerated schedule for tax purposes, even though a longer write-off period may be used for book or accounting purposes.

Effect on Pre-Tax Profit (19)

Annual pre-tax cash-flow effects is determined as:

$$(19) = (16) - (18) .$$

Effect on After-Tax Profit (20)

Annual after-tax profit for each year is calculated as

$$(20) = (19) \left[1 - \frac{(6)}{100} \right]$$

Total Tax Credits (21)

Tax credits, taken in Year 1, are:

$$(21) = (4) + (5) .$$

Annual After-Tax Cash Flow (22)

For each year,

$$(22) = (18) + (20) + (21) - (17) .$$

Cumulative After-Tax Cash Flow (23)

This is the cumulative sum of annual after-tax cash flows (22). The cumulative sum in Year 0 is negative in the amount of the investment (17), and decreases annually. The payback period is determined when the cumulative sum reaches zero. Because this usually occurs between two years, the fractional year is determined by interpolation. For example, assume that the cumulative sum (23) is -\$28,000 at the end of Year 2 and +\$38,000 at the end of Year 3. The fractional year is $\frac{\$28,000}{\$28,000 + \$38,000} = 0.4$, and the payback period is 2.4 years.

Three Methods to Solve for Payback Period

Payback period by the cumulative annual after-tax cash-flow method described here may be determined in three ways:

- By manual calculation using the formulas given in this Appendix. Although some of the formulas appear at first glance to be complicated, actually they can be handled rapidly with a simple pocket calculator
- By use of a programmed computer. For this project, payback periods were calculated using a program stored in a Hewlett Packard 34C personal (pocket) computer. Solution time for each situation averaged less than 30 seconds

- By graphical solution, as described below.

Figure A-1 is convenient for determining First-Year Fuel Saving (in dollars) from Unrecuperated Input (in MM Btu per year) and First-Year Fuel Price (in dollars per MM Btu) when either of the following is known or can be estimated:

- Saving (because of recuperation) in percentage of Unrecuperated Input, or
- Saving in MM Btu per year.

Figure A-2 permits Payback Period (in years) to be determined from:

- First-Year Fuel Saving (in dollars), which is determined from Figure A-1 or by calculation, and
- Total Installed Cost (in dollars).

Above 5 years payback time, the slope and shape of the capital-cost curves, in Figure A-2, change because depreciation is no longer contributing to cash flow.

FIGURE A-1. GRAPHICAL DETERMINATION OF FIRST-YEAR FUEL SAVING FROM RECUPERATION

FIGURE A-2. GRAPHICAL DETERMINATION OF PAYBACK PERIOD FOR RECUPERATION EQUIPMENT

FIGURE A-2. GRAPHICAL DETERMINATION OF PAYBACK PERIOD FOR INVESTMENT

HOST SITE NO. 1

McInnes Steel Company
Corry, Pennsylvania 16407
Mr. Dave Dearborn (814) 665-8251

Brief Description:	McInnes Steel Company forges, heat treats, and machines a wide range of alloys to produce parts for a broad variety of industries.
Furnace Type:	Front opening, box furnace used to preheat steels to 2250 F for forging.
Furnace Equipment:	The rebuilt test furnace was equipped with four high-temperature burners designed to burn natural gas or No. 2 oil. Maximum firing rate is 6 MM Btu/hour. Four ceramic recuperators were roof-mounted and the furnace was equipped with combustion and furnace pressure controls.
Fuel and Metering:	This plant uses natural gas fuel and the gas metering was done with both a turbine meter and an orifice meter that is part of the MARC control system. [This installation was completed early in 1981 before the availability of calibrated positive-displacement meters.]
Operating Procedure:	This furnace is normally in production operation for 2 shifts per day with a furnace heating time of 6,600 hours per year. Ingots, blooms, and billets are heated (and often reheated) for forging.
Testing Procedure:	At this host site, both a before-and-after and a side-by-side data collection period were used.
Performance Information:	On a before-and-after basis, the rebuilt and retrofitted test furnace averaged a natural gas savings of 59.8 percent. The variation in specific fuel usage versus throughput of steel is shown in the following graph. This percentage was for the combined contributions of the recuperator and all other furnace modifications at this site.
Cost Information:	The total cost of the rebuild/retrofit at this site was \$99,461. An overall savings of 59.8 percent is equivalent to a savings of 67,900 MM Btu/day at an average daily loading of 15,000 pounds of steel. Natural gas costs this plant \$5.43 per million Btu. The average annual savings over 250 working days is \$92,170. The recuperator-related cost was estimated at \$61,320.

FIGURE B-1. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, McINNES STEEL (HOST SITE NO. 1)

HOST SITE NO. 2

Lebanon Steel Foundry
P. O. Box 390
Lebanon, Pennsylvania 17042
Mr. David Hitz (717) 273-1611

Brief Description:	Lebanon Steel is an integrated foundry producing stainless and alloy steel castings. They normally work about 15 shifts per week.
Furnace Type:	Carbottom annealing furnace with six R1500 recuperators, top mounted. Preheated air is manifolded and ducted to two Hauck dual-fuel (gas and #2 oil) burners. Recuperated furnace (#2), and comparison furnace (#4) are fiber lined.
Furnace Equipment:	Furnace originally equipped with mass-flow combustion controls, but no pressure control. Air ducts are not insulated, so that preheat at burners is low (~600 F).
Fuel Metering:	Natural gas with an assumed gross heating value of 1000 Btu/SCF, meter factor is 2.02.
Operating Procedure:	Loads are estimated. Most anneals are done at 1650-1750 for 3-4 hours; some alloy anneals are done at higher temperatures.
Testing Procedure:	This is a side-by-side comparison, for which furnace data are estimated. Fuel economy was based upon comparisons of specific energy conserved (Btu/lb) for anneals at 1650 F and at 1725/1750 F for the two furnaces. No performance curves were generated.
Performance Information:	The recuperated furnace showed an average improvement in fuel economy of 13.1 percent at an estimated loading (per anneal) of 18,000 lbs. During period of data collection, typical usage was two anneals per day, and estimated annual usage is 250 days per year, for an estimated annual fuel savings of 1800 MM Btu/year.
Cost Information:	Total cost of the installation was given as \$113,000; costs directly related to the recuperation were estimated at \$75,000. Natural gas price was \$4.85/MM Btu at the time of evaluation. The calculated annual savings in fuel cost were \$8,740.

HOST SITE NO. 3

Alcan Sheet and Plate
Division of Alcan Aluminum Corporation
Lake Road North
Oswego, New York 13126
Mr. Carl J. Sunser (315) 342-0121

Brief Description:	Alcan Corporation is a major producer of aluminum and aluminum products.
Furnace Type:	A gas-fired pot (ladle) preheater. Ladles are used to transport liquid aluminum.
Furnace Equipment:	A cover-mounted, high-temperature burner close coupled to a single ceramic recuperator.
Fuel and Metering:	This plant uses natural gas fuel and the gas metering is with a certified positive-displacement meter.
Operating Procedure:	The burner is reported in operation 5,744 hours per year. The top operating temperature is 1,500 F.
Testing Procedure:	At this host site, a before-and-after comparison was completed; i.e., a fuel-consumption comparison was made on the use of the cover before and after retrofit of the new burner and recuperator system.
Performance Information:	Detailed fuel consumption data measured over 8-hour heating cycles indicated that the use of a recuperator with combustion controls resulted in a 36 percent savings in natural gas consumption. The unrecuperated ladle heater consumed 5.77 therms per operating hour and the recuperated ladle heater consumed 3.70 therms per hour.
Cost Information:	The total cost of this retrofit was \$14,801 and this was all recuperated-related. The cost of natural gas at this plant is \$4.90 per million Btu. The overall savings in energy averaged 5.2 MM Btu/day (240 days) of operation per year. For 5,744 hours, the annual savings is \$6,120.

HOST SITE NO. 4

X-Tek Company
11451 Reading Road
Sharonville, Ohio 45242
Mr. Richard Warren (513) 242-1111

Brief Description:	X-Tek is a producer of machines and heat-treated steel parts for the steel industry. A large amount of their production is the manufacture of rolling mill rolls for steel companies (up to 50 tons in weight).
Furnace Type:	A controlled atmosphere, top opening, retort furnace. The furnace is 10.5 feet in diameter and is 20 feet tall. The furnace has an interior Inconel shell within which the gas composition is controlled for neutral heat treatment or gas carburizing. Steel mill rolls are supported vertically within the interior chamber and this chamber is heated by 12 burners "stair stepped" along the horizontal and vertical dimensions of the furnace. These burners heat the furnace space between the furnace lining and the Inconel shell.
Furnace Equipment:	This furnace was retrofitted with 12 ceramic recuperators each close coupled to a high-temperature burner. The control system installed is an L & N microcomputer. Furnace pressure controls were installed.
Fuel and Metering:	Natural gas fuel and positive displacement metering.
Operating Procedure:	This furnace is in operation about 5,000 hours per year and usually is operated on either a 1600 F heat-treat cycle or an 1800 F carburizing cycle. The furnace load can vary in weight from 6 to 50 tons. The minimum cycle time is about 12 hours, but it is not unusual to have a 100-hour heat-treat cycle on a large steel mill roll.
Testing Procedure:	This comparison was made in the before-and-after mode. Weight and fuel consumption data were collected prior to and following the retrofit of recuperators, burners and new controls. The burners that were replaced were "excess air" manual control burners.

Performance Information:

The average loading of this retort furnace is 15,000 pounds per cycle, and approximately 15,000 pounds per day. Prior to the retrofit, the furnace used 3,700 Btu per pound of steel heated. Following the retrofit the specific fuel consumption dropped to 1,450 Btu/lb for a fuel-savings of 60.7 percent at the same average loading per day.

Cost Information:

The cost of the retrofit was \$116,830. X-tek is in operation 250 days per year. The average daily load in this furnace is 15,000 pounds per day. Overall, the savings were 2,245 Btu per pound of steel heated. Natural gas costs this plant \$5.34 per million Btu and the annual savings is \$44,860.

FIGURE B-2. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, X-TEK (HOST SITE NO. 4)

HOST SITE NO. 5

Ajax X-Ray Company
Sayre, Pennsylvania 18840
Mr. Bill McCreary (717) 888-6605

Brief Description	Ajax X-Ray is a small foundry casting small aluminum and bronze parts.
Furnace Type:	An oil-fired, pot-melting furnace for aluminum. The melting pot is a 300-pound capacity silicon carbide crucible sealed within a refractory lined chamber that is 3 feet in diameter and 4 feet high. The surface of the crucible is heated to melt the aluminum charge in the crucible. After melting, molten aluminum is ladled from this furnace over the range of 1250 to 1400 F.
Furnace Equipment:	This furnace was equipped with one ceramic recuperator in the flue exhaust. This recuperator was close coupled to a single high-temperature, dual-fuel burner. Combustion controls were added but furnace-pressure controls were not required.
Fuel and Metering:	No. 2 fuel oil. Rotary meters.
Operating Procedure:	This plant is normally in operation 1 shift per day, 250 days/year. The first pot load of aluminum is melted prior to the start of the shift and new charges are then melted depending upon demand.
Testing Procedure:	The performance of the test furnace was compared directly with an unrecuperated furnace of the same size.
Performance Information:	In comparison with an unrecuperated furnace, the test furnace indicated a fuel savings of 37.1 percent over an average amount 900 pounds of aluminum melted per day. The specific energy consumed at 900 lbs per day was 5,330 Btu/lb for the unrecuperated furnace and 3,410 Btu/lb for the recuperated furnace.
Cost Information:	The total cost of the retrofit was \$7,221. No. 2 fuel oil costs this plant \$1.10/gallon or about \$7.97/MM Btu. The annual savings at an average melting rate of 900 lbs/day and operating at 250 days per year is \$3,450.

HOST SITE NO. 6

GTE Products Corporation
Towanda, Pennsylvania 18848
#9 Tube Furnace

No operating data.

HOST SITE NO. 7

Hammond & Irving Company
254 North Street
Auburn, New York 13021
Mr. Robert Gallagher (315) 253-6265

Brief Description: Hammond & Irving produces a variety of steel ring forgings and housing for bearings.

Furnace Type: A front opening, box furnace used to preheat steel to 2200 F.

Furnace Equipment: Furnace was equipped with four dual-fuel high temperature burners coupled to four ceramic recuperators. Included in the retrofit were combustion and furnace pressure controls. The maximum thermal input is 7 MM Btu/hour, compared with 12.8 MM Btu/hour before retrofitting.

Fuel and Metering: This host site is using natural gas rated at 1032 Btu/SCF. Gas metering is accomplished using a positive-displacement meter.

Operating Procedure: Normal operation is 250 days per year. In a 24-hour day, the weight of steel heated is in the range of 7,000 to 21,000 pounds. The operating temperature is a consistent 2,200 F.

Testing Procedure: This host site used a before-and-after comparison. Gas consumption and daily furnace load weights were recorded prior to the installation of new burners, recuperators and controls.

Performance Information: Over a period of 6 months of operation of the recuperated furnace, it was found that the average overall fuel savings was 37.4 percent. The data obtained are summarized on the following graph. The mean weight of steel heated per day is 15,000 pounds. The indicated average savings is 38.4 million Btu per operating day.

Cost Information: The total cost of the retrofit was \$66,643. The cost of natural gas to this plant during the test period was \$4.40/million Btu. A savings of 38.4 million Btu/working day is equivalent to an annual saving of \$42,240 for a fuel cost of \$4.40/MM Btu.

FIGURE B-3. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, HAMMOND AND IRVING (HOST SITE NO. 7)

HOST SITE NO. 8

Bay City Forge, Zurn Industries
1802 Cranberry Street
Erie, Pennsylvania 16502
Mr. Burt Peterson (814) 456-2088

Brief Description:	Bay City Forge is a relatively small (5,000 tons per year) open die forging plant, producing a variety of shapes ranging from 500 to 16,000 pounds. Although normal operations were at about 3400 hours per year, they have reduced operating time drastically in 1982.
Furnace Type:	Forge-reheat box furnaces used to heat billets to 2250-2300 F.
Furnace Equipment:	The recuperated unit is a new furnace equipped with 8 GTE R1500 TPX top mounted recuperators and 8 North American 6825-6X dual-fuel burners. The furnace was fiber lined. Comparison furnaces are similar except with 10 burners, no recuperation.
Fuel and Metering:	Positive displacement gas meters, natural gas fuel.
Operating Procedure:	Side-by-side comparison, with furnace loads averaging 30,000-50,000 pounds. Long heating cycles. Current operations at about three days every other week.
Testing Procedure:	Side-by-side comparison of nearly identical furnaces except for recuperation and pressure control on recuperated furnace. Limited data (15 heats on recuperated furnace, 6 heats on unrecuperated furnace).
Performance Information:	Based upon average throughputs of 40,000 lbs per day, fuel savings of recuperated furnace were indicated at 53.5 percent as compared with the unrecuperated furnace. Daily energy savings are 99.5 MM Btu.
Cost Information:	Total cost of the furnace was \$251,300, of which \$108,470 was estimated to be directly related to recuperation. For gas priced at an assumed \$5.50/MM Btu, and 150 days per year operation, the annual savings are \$82,090.

FIGURE B-4. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, BAY CITY FORGE (HOST SITE NO. 8)

HOST SITE NO. 9

Monroe Forging, Inc.
Division of Amtel Metals, Inc.
McKee Road
Rochester, New York 14603
Mr. Ralph Brower

Brief Description:	Monroe Forging specializes in rolling rings (12 to 78-inches in diameter) of titanium, stainless and high temperature alloys for jet engine builders.
Furnace Type:	Front opening, box furnace used to heat metals and alloys in the range of 1650 to 2200 F. The majority of heats are at about 2000 F. The furnace interior measures 99 x 99 x 36 inches high.
Furnace Equipment:	The test furnace and the comparison furnace were rebuilt and both were equipped with an interior overlay of ceramic fiber insulation in the roof and the upper half of the walls. The test furnace was retrofitted with two ceramic recuperators, four high-temperature oil burners and combustion and furnace-pressure controls.
Fuel and Metering:	No. 2 fuel with standard oil meters on each furnace.
Operating Procedure:	The furnaces at this plant are normally in operation for 14 or more hours per day and about 300 days per year. Billets in the range of 150 to 160 pounds are heated on the day shift and heat treatment of product is completed on the second shift.
Testing Procedure:	Direct side-by-side comparison of a relined unrecuperated furnace with a relined recuperated furnace of the same size.
Performance Information:	Monroe's average furnace load per day is 5,000 pounds. The unrecuperated furnace averaged 5,500 Btu/pound while the recuperated furnace averaged 3,565 Btu per pound. The indicated saving of 1,935 Btu/pound is a 35.2 percent fuel saving.
Cost Information:	The cost of the retrofit was \$41,139. No. 2 fuel oil costs this plant \$1.08/gallon, or \$7.83/MM Btu. For a 300 day-per-year production rate, the annual savings in fuel costs is \$22,550.

FIGURE B-5. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, MONROE FORGING (HOST SITE NO. 9)

HOST SITE NO. 10

Special Metals Corporation
An Allegheny Ludlum Industries Affiliate
New Hartford, New York 13413
Mr. J. W. Haggerty (315) 798-2900

Brief Description:	Special Metals Corporation specializes in the production of wrought superalloys for the investment casting industry.
Furnace Type:	A front loading, large box furnace (110-in wide x 168-in long x 72-in high) used for annealing and heat treatment.
Furnace Equipment:	This furnace was equipped with six 1.5 MM Btu/hour high temperature burners and six, roof-mounted ceramic recuperators. Also included were combustion and furnace-pressure controls.
Fuel and Metering:	This furnace is fired with natural gas. The gas meter is a positive displacement type.
Operating Procedure:	Under normal business conditions, this furnace is in operation 15 shifts per week. The furnace charges range from 10 to 25 tons of superalloy ingots that are heated in the range of 1800 to 2150 F. Ingots can be up to 10 tons in weight and heating cycles range from 48 to 60 hours.
Testing Procedure:	For comparison purposes, data were collected from a side-by-side operation using the recuperated furnace and a nearby unrecuperated furnace of the same size.
Performance Information:	The fuel economy of the two furnaces was compared for loads ranging from 25,000 to 40,000 pounds. The data were not sufficient to develop performance curves, but an average fuel savings of 42.4 percent for the recuperated furnace was calculated at an average loading of 34,000 pounds.
Cost Information:	The cost of the retrofit installation was given as \$103,000. Assuming 240 days of operating per year, a fuel cost of \$5.50/MM Btu, and daily fuel savings at 35.1 MM Btu, the annual savings are \$46,310.

HOST SITE NO. 11

Special Metals Corporation
An Allegheny Ludlum Industries Affiliate
New Hartford, New York 13413
Mr. J. W. Haggerty (315) 798-2900

Brief Description:	Special Metals Corporation specializes in the production of wrought superalloys for the investment casting industry.
Furnace Type:	A front loading box furnace used to preheat small superalloy billets prior to rolling.
Furnace Equipment:	This furnace was equipped with 4 high-temperature burners, four ceramic recuperators, and combustion and furnace pressure controls.
Fuel and Metering:	This furnace is fired with natural gas. The gas is metered with a rotary turbine meter.
Operating Procedure:	Under normal business conditions, this furnace is in operation 15 shifts per week heating about 15,000 pounds of billets (within the range of 1600 to 2100 F) every 10 hours.
Testing Procedure:	This comparison was made between No. 1 and No. 2 cog ovens in a side-by-side mode of operation. Fuel consumption is based upon direct meter readings assuming a meter factor of 1.0 and a gross heating value of 1000 Btu/SCF for natural gas.
Performance Information:	At an average throughput of 5,500 pounds per shift, the fuel savings were 34.2 percent. At three shifts per day, the energy saved is 7.6 MM Btu/day. Performance curves are shown in the attached graph.
Cost Information:	The installed cost of the retrofit was \$67,300, all of which was related to recuperation. The annual savings assuming 240 days of operation and with natural gas priced at \$5.50/MM Btu is \$30,100.

FIGURE B-6. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, SPECIAL METALS (HOST SITE NO. 11)

B-19

HOST SITE NO. 12

Harnischfeger
4400 W. National Avenue
Milwaukee, Wisconsin
Mr. Kim Able (414) 671-4400

No data available.

B-20

HOST SITE NO. 13

GTE Products Corporation
Towanda, Pennsylvania 18848
Mr. Tim Brunelli (717) 265-2121

Molybdenum Reduction Tube Furnace

(No operating data available)

HOST SITE NO. 14

GTE Products Corporation
Towanda, Pennsylvania 18848
Mr. Chris Kronenwetter (717) 265-2121

Brief Description:	The Chemical and Metallurgical Division of GTE Products Corporation produces a variety of chemical, metallurgical, and ceramic products. Operations are continuous, and employ about 1600.
Furnace Type:	This installation is a tube furnace used to reduce tungsten oxide powder to tungsten metal. It is gas fired and operated continuously (3 shifts). The furnace is divided into three zones for temperature control, and operates at a nominal temperature of 1650 F.
Furnace Equipment:	The retrofit included three recuperators mounted on top of the furnace, one R1500 TPX and two R1000 TPX sizes, supplying preheated air through insulated ducts to six Hauck burners in each zone. The furnace is equipped with combustion and pressure controls. The comparison furnace is similar, except without recuperation.
Fuel and Metering:	The fuel for these furnaces is natural gas. Fuel consumed during operations is measured with a positive displacement meter.
Operating Procedure:	Normal production is continuous except for the summer holiday period. The estimated operating time is 8,064 hours per year.
Testing Procedure:	This side-by-side comparison was made by monitoring daily fuel consumption and throughput.
Performance Information:	The performance of the recuperated furnace was compared with that of the unrecuperated furnace at an average throughput of 1400 lbs/day. The performance curves are presented graphically. The specific energy consumption was reduced by 50.1 percent for a daily energy savings of 16.32 MM Btu.
Cost Information:	The total installed cost for the retrofit was \$53,340, all of which was attributed to the recuperation. At the current natural gas cost of \$5.38/MM Btu, the annual savings are \$29,500.

FIGURE B-7. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, GTE (HOST SITE NO. 14)

HOST SITE NO. 15

GTE Products Corporation
Towanda, Pennsylvania 18848
Mr. Chris Kronenwetter (717) 265-2121

Brief Description:	The Chemical and Metallurgical Division of GTE Products Corporation produces a variety of chemical, metallurgical, and ceramic products. Operations are continuous, and employ about 1600
Furnace Type:	This installation is a natural gas fueled tube furnace used for the production of tungsten in a continuous mode. It employs 10 Hauck burners arranged in three heating zones. It operates at a nominal temperature of 1600 F.
Furnace Equipment:	The furnace was retrofitted with three top-mounted R1000 TPX recuperators, one for each heating zone. The preheated air is carried to the 10 Hauck burners by insulated ducts. Both furnaces are equipped with combustion and pressure controls.
Fuel and Metering:	Fuel is natural gas, and fuel consumption is measured with positive displacement meters.
Operating Procedure:	Both furnaces are run continuously for an estimated total of 8,064 hours per year (336 days). Daily measurements of product weight and fuel consumption were made.
Testing Procedure:	This side-by-side installation was evaluated by comparing specific energy consumption of each furnace at a single average level of product throughput.
Performance Information:	The comparison made at an average daily throughput of 2150 lb/day showed a fuel savings of 45.1 percent for the recuperated furnace when compared with the similar unrecuperated unit. Performance curves are plotted in the following graph.
Cost Information:	The total installed cost of the retrofit was \$37,190, all of which was allocated to recuperation. For a daily savings of 23.29 MM Btu, a current gas price of \$5.38/MM Btu, the annual fuel savings are \$42,100.

FIGURE B-8. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, GTE (HOST SITE NO. 15)

HOST SITE NO. 16

GTE Products Corporation
Towanda, Pennsylvania 18848
Mr. Jack Burwick (717) 265-2121

Brief Description: The Chemical and Metallurgical Division of GTE Products Corporation produces a variety of chemical, metallurgical, and ceramic products. Operations are continuous, and employ about 1600.

Furnace Type: This installation is on a rotary calciner furnace operated at a nominal temperature of 1750 F. The furnace is operated in a continuous mode and is used to reclaim scrap materials.

Furnace Equipment: Three recuperators, one R1500 TPX and two R1000 TPX, were installed on top of the furnace, with the larger unit (R1500) on the first zone. Preheated air was carried in insulated ducts to North American dual-fuel burners, two in each zone for a total of six. The recuperated furnace is equipped with combustion and pressure controls.

Fuel and Metering: These units are fired with natural gas. Fuel consumption is measured with positive displacement meters.

Operating Procedure: This calciner, both before and after retrofit, was operated continuously for an estimated 8,064 hours per year.

Testing Procedure: In this before-and-after comparison, the product throughput and fuel consumed were measured over six month periods. Performance curves were developed as shown in the following graphs.

Performance Information: Average throughputs were increased substantially after the recuperation was added (from about 1700 to 4800 pounds per day). The comparison was made at an intermediate throughput of 3,000 pounds per day, where a fuel savings of 38.5 percent was calculated.

Cost Information: The total installed cost of this retrofit was \$41,610; all of this was attributed to recuperation. With an average daily savings of 13.5 MM Btu/day, operation for 336 days per year, and a fuel cost of \$5.38/MM Btu, the annual saving is \$24,400.

FIGURE B-9. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, GTE (HOST SITE NO. 16)

HOST SITE NO. 17

GTE Products Corporation
Towanda, Pennsylvania 18848
Mr. William Fulkerson (717) 265-2121

(No operating data available)

HOST SITE NO. 18

Kentucky Forge
Madisonville, Kentucky 42451
Mr. Ed Smith (502) 821-4868

Brief Description:	Kentucky Forge is a small (15 employees) impression die forge shop producing mining tool parts.
Furnace Type:	Slot Forge Furnace used to heat steel bars in the range of 5/8 to 1-3/4-inch in diameter. Furnace temperature is 2400 F.
Furnace Equipment:	The test furnace was retrofitted with two R600 recuperators and two high-temperature Eclipse burners. Maximum firing rate is 2 MM Btu/hour. Combustion controls on both furnaces.
Fuel and Metering:	Natural gas fuel, positive displacement meters.
Operating Procedure:	Steel bar ends are heated and forged sequentially. Operation normally is 2-8 hour shifts, 5 days per week.
Testing Procedure:	Side-by-side comparison of a recuperated and unrecuperated slot furnace. The comparison is not exact because different sized rods are heated in the two furnaces.
Performance Information:	The average fuel saving for the recuperated furnace was 21.5 percent. The average production rate was 3,000 pounds per shift (250 days per year) and the indicated average fuel saving was 2.0 MM Btu/shift.
Cost Information:	The total cost of the retrofit of the test furnace was \$49,006. The indicated yearly saving at the test furnace is 1000 MM Btu/year. Natural gas at this plant cost \$3.44/MM Btu (this was early in 1982) which results in a yearly savings of \$3,440 for two shift operation.

FIGURE B-10. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, KENTUCKY FORGE (HOST SITE NO. 18)

HOST SITE NO. 19

Schmitt Steel, Inc.
2765 NW Nicolai Street
Portland, Oregon 97210
Mr. Van D. Kleckner (503) 222-3641

Brief Description:	Schmitt Steel produces steel forgings in the range of 5 to 50 pounds. This plant has 10 forge furnaces and employs about 50 workers.
Furnace Type:	Slot forge furnace. Test furnace size is 28 x 37 x 115 inches. The furnace operates at 2400 F.
Furnace Equipment:	The test furnace was equipped with two R1500 TPX recuperators and two Eclipse high-temperature burners. Combustion controls were installed.
Fuel and Metering:	Natural gas fuel. Positive displacement meters.
Operating Procedure:	Schmitt Steel operates on one-shift for about 2,000 hours per year. Steel bars are heated as required to supply the forging shop.
Testing Procedure:	At this host site the comparison involves side-by-side operation of the recuperated furnace with an unrecuperated furnace of similar size.
Performance Information:	At an average furnace throughput of 5,000 pounds per day, the energy saved on the recuperated furnace was 13.6 MM Btu/day, or 41.2 percent compared with the unrecuperated furnace.
Cost Information:	The capital cost of the entire rebuild and retrofit was \$95,985, of which \$57,220 was recuperator related. Natural gas fuel costs this plant \$5.55/million Btu. At a savings of 41.2 percent on 5,000 pounds per day for 250 days per year, the annual savings is \$18,870.

FIGURE B-11. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, SCHMITT STEEL (HOST SITE NO. 19)

HOST SITE NO. 20

Crescent Tool Company
245 Harrison Road
Jamestown, New York 14701
Mr. Richard Radspinner (716) 487-1926

Brief Description:	Crescent Tool manufactures forged hand tools.
Furnace Type:	Small slot-forge furnace (32 x 54-inch interior) operating at 2400 F.
Furnace Equipment:	The rebuilt test furnace was modified to pass the flue gas out each end through recuperators. The furnace was equipped with two R1500 TPX recuperators and two high-temperature North American burners.
Fuel and Metering:	Natural gas fuel. Both the test furnace and the comparison furnace were equipped with Sprage 1000 positive-displacement gas meters.
Operating Procedure:	The slot furnaces at this location are used to heat 1-inch steel bars prior to forging. During these tests, the furnaces were started at 5 a.m. and shut off or idled at 3 p.m. Normal operations are 3 shifts. Operation is 250 days/year or 2500 hours/year.
Testing Procedure:	Side-by-side of a recuperated and an unrecuperated furnace of the same size and capacity in the same shop.
Performance Information:	At an average throughput of 1,500 pounds per shift, the fuel savings were calculated at 53.6 percent, which amounts to an energy saving of 10.3 MM Btu/shift.
Cost Information:	The total cost of the retrofit was \$38,270, all of which was related to the addition of recuperation. Based upon 250 days of operation per year, 2 shifts per day, and fuel costing \$5.81/MM Btu, the annual savings are \$29,920.

FIGURE B-12. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, CRESCENT TOOL (HOST SITE NO. 20)

HOST SITE NO. 21

Pfizer Minerals Pigment and Metals Division
Daisy Hill Road
Canaan, Connecticut 06018
Mr. Dave Dudeck (203) 824-5437

Brief Description:	At this location Pfizer produces calcium metal in a retort process.
Furnace Type:	Box furnaces with multiple, fixed-position, horizontal retorts.
Furnace Equipment:	Each furnace is equipped with five, side-mounted oil burners. The recuperated furnace was retrofitted with five high-temperature burners and five ceramic recuperators. The test furnace was also equipped with furnace-pressure control.
Fuel and Metering:	Each furnace has a totalizing oil meter. No. 2 oil is used for firing.
Operating Procedure:	This plant is organized on a 24-hour cycle and the plant is in operation 365 days per year. A 24-hour cycle consists of a short unload and unload period (with the retorts remaining in the furnace) followed by heating and holding the retorts at 2215 F.
Testing Procedure:	Testing consisted of a before-and-after comparison of a recuperated and unrecuperated furnace of the same size; however, no records of actual charge weights were available so that the comparison was made on fuel usage alone.
Performance Information:	Over a six-month test period, it was determined that the oil consumption at the recuperated furnace averaged 14.6 gallons per hour (over a 24-hour period) as compared with 20.8 gallons per hour for the unrecuperated furnace. The indicated savings is 29.7 percent.
Cost Information:	The capital cost of the retrofitted recuperation system on the furnace was \$123,550 of which \$76,550 is recuperator related. The indicated annual savings for the recuperated furnace is \$59,990 based upon No. 2 fuel oil at \$7.68/MM Btu.

HOST SITE NO. 22

Howmet Turbine Components Corporation
Austenal Dover Division
Roy Street
Dover, New Jersey 07801
Mr. Ed Laux (201) 361-0300

Brief Description:	This division of Howmet is a major producer of investment castings for gas turbines used in military and commercial aircraft engines.
Furnace Type:	Pusher-type, tunnel furnace for preheating investment casting molds (ceramic) to 2250 F. This preheat furnace is 23-inches wide by 30-inches high by 23-feet long. Casting molds are loaded onto metal support trays and trays are loaded into one end of the furnace through a guillotine door. The trays and molds pass through 3 zones in the furnace and are removed from the furnace at 2250 F.
Furnace Equipment:	The test furnace was retrofitted with three (one R1500 and two R1000) roof-mounted ceramic recuperators (one for each zone). The preheated air from these recuperators is ducted to 15 high-temperature burners mounted in the lower side of the furnace. This furnace was also equipped with combustion, temperature, and furnace-pressure controls.
Fuel and Metering:	Natural gas fuel. Positive displacement meters.
Operating Procedure:	At the time of Battelle's visit, the preheat furnaces were in operation for two 10-hour shifts, four days per week. Normal operation is 8,000 hours per year or 7 days per week. When not in operation, the furnace is idled at 1600 F.
Testing Procedure:	Direct side-by-side comparison of an unrecuperated furnace and a recuperated furnace of the same size.
Performance Information:	At a mean furnace loading of 4,000 pounds per day, the indicated fuel saving was 17.9 percent. The specific energy usage dropped from 6,700 Btu/pound to 5,500 Btu/pound for a 1,200 Btu/pound saving. Note: Fuel savings of 30 percent have been reported for this installation after burner adjustments were corrected.

HOST SITE NO. 22 (Continued)

Cost Information:

The capital cost of the retrofit was \$93,203, of which \$62,387 was the installed cost of the recuperator related items. For the level of production during which data were obtained, the average throughput level was 4,000 lb/day, and total annual savings would be low (\$6,500). For more normal operations (3 shifts rather than 1), the annual savings would be \$19,500. This would be increased to \$32,680 annual savings at the improved performance (30 percent). Natural gas costs this plant \$5.54 per million Btu.

FIGURE B-13. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, HOWMET-DOVER (HOST SITE NO. 22)

HOST SITE NO. 23

Howmet Turbine Components Corporation
Whitehall, Michigan 49461
Mr. John Mastee (616) 894-7644

(No operating data available)

HOST SITE NO. 24

National Forge Company
Forge Division
Front Street
Irving, Pennsylvania 16329
Mr. Tom Faust (814) 563-7422

Brief Description: National Forge Company is one of the largest forge shops in the country in terms of volume and size of steel ingots that are forged. They employ about 1,250 people.

Furnace Type: Car-bottom heating furnace for large steel ingots. Hearth size is 12 x 25 feet, and capacity is about 200,000 pounds.

Furnace Equipment: The test furnace was equipped with 8 top-mounted R1500 ceramic recuperators and 8 North American high-temperature burners. Also included were electronic combustion and furnace pressure controls. The furnace was built to be a state-of-the-art furnace. This included (a) fiber lining on roof, sides and door, (b) special door seals, and (c) special car-bottom seals.

Fuel and Metering: Natural gas fuel. Rotary gas meters on all furnaces. Computer recording/readout of hourly fuel and temperature readings.

Operating Procedure: This plant is normally in operation 7,200 hours per year. The heating furnaces are loaded heavily and heating time is a total of 24 to 30 hours. The maximum temperature is 2300 F.

Testing Procedure: Direct side-by-side comparison of furnaces of the same size that are also equipped with combustion controls to maintain 10 percent excess air to the burners. Data were reported weekly rather than daily.

Performance Information: At an average weekly furnace loading of 400,000 pounds the rebuilt, recuperated furnace used 43.7 percent less fuel than the comparison furnace. The energy input to the recuperated furnace averaged 1,383 Btu per pound as compared with 2,458 Btu per pound for the unrecuperated furnace. Integration of the hourly hot-air temperature readings by National Forge Engineering indicated that the fuel savings attributable to the recuperators alone was about 33 percent.

Cost Information:

The capital cost of the rebuild and retrofit was \$675,318. Natural gas costs this plant \$5.29 per million Btu's. The annual saving in fuel cost at the 43.7 percent overall improvement is \$113,660. The capital cost of the recuperator-related retrofit was \$149,440.

FIGURE B-14. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, NATIONAL FORGE (HOST SITE NO. 24)

HOST SITE NO. 25

Bucyrus Erie Corporation
S. Milwaukee, Wisconsin 53172
Mr. John Grimm (414) 768-4000

Brief Description:	This Bucyrus Erie plant manufactures heavy equipment for the earth-moving industry.
Furnace Type:	A car-bottom, heat-treat furnace in which the cars loaded with steel castings move through the furnace. The end doors are opened about once each hour for moving in loaded car and for removing a car that has been process. The furnace has three heating zones with the hottest zone being maintained at 1650 F.
Furnace Equipment:	The test furnace was equipped with 12 R600 TPX recuperators close coupled to 12 high-temperature Eclipse burners. This furnace was equipped with combustion controls but furnace-pressure controls were not installed to avoid upsetting temperature uniformity in the 3 zones in the furnace.
Fuel and Metering:	Natural gas fuel. Positive displacement meters.
Operating Procedure:	In a normal economy, these furnaces would be in operation 18 shifts per week or 7,200 hours per year. Current production levels average 40,000 pounds per day. Empty cars are sometimes run through the furnace as spacers when product levels are low.
Testing Procedure:	Before-and-after comparison of a furnace that was retrofitted with recuperators.
Performance Information:	Although preliminary tests by the furnace installer after recuperation showed an improvement in fuel economy of 44 percent, operating data did not confirm that level of improvement. For an average daily throughput of 40,000 pounds per day, the measured fuel savings was 11.9 percent. The performance curves are presented in the graphs attached. This lower-than-expected performance has been attributed to the high fraction of time during which the furnace operates at low fire where high excess air and cold air infiltration are evident.
Cost Information:	The total installed cost of this retrofit was \$244,710. Assuming normal operation at 250 days per year and a fuel cost of \$5.50/MM Btu, the annual savings are \$12,930.

FIGURE B-15. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, BUCYRUS ERIE (HOST SITE NO. 25)

HOST SITE NO. 26

Timet, Incorporated
A Division of Allegheny International
100 Titanium Way
Toronto, Ohio 43964
Mr. Thad Kucherawy (614) 537-1571

Brief Description:	Timet is a major producer of wrought titanium products.
Furnace Type:	Box forge furnace. Operating temperatures range from 1750 to 2100 F.
Furnace Equipment:	The test furnace was equipped with eight R600 ceramic recuperators and eight North American high-temperature burners. Electronic controls were installed for combustion control and furnace control. The comparison furnace is a similar unit without recuperation.
Fuel and Metering:	Natural gas fuel. Positive displacement meters.
Operating Procedure:	Normally the furnaces are in operation 18 shifts per week (7,200 hours per year). Bars and ingots of titanium and titanium alloys are machine charged and discharged. Furnaces are used for heat treatment and for preheating titanium for a cogging mill.
Testing Procedure:	Side-by-side comparison of a recuperated and an unrecuperated furnace of the same size.
Performance Information:	Overall, the energy savings at the recuperated furnace was 4,100 Btu/pound of titanium heated for a saving percentage of 34.1 percent. The mean daily furnace loading was 7,000 pounds. The performance curves shown in the attached graph were based upon runs at a variety of temperatures.
Cost Information:	The total cost of this installation was \$134,401, of which \$108,400 was recuperator related. Fuel costs were given a \$5.29/MM Btu at this site. The annual fuel savings are projected at \$45,550 for 300 days' operation per year.

FIGURE B-16. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, TIMET (HOST SITE NO. 26)

HOST SITE NO. 27

McWilliams Forge Company
Franklin Avenue
Rockaway, New Jersey 07866
Mr. Gordon Hayes (201) 626-0200

Brief Description:	This medium-sized plant produces steel, stainless steel, superalloy, and titanium forgings.
Furnace Type:	Front opening, box furnace used to heat forging billets in the range of 1625 to 2200 F (depending upon the type of material).
Furnace Equipment:	Rebuild and retrofit of the test furnace included installation of a new burner wall and door seals, three high-temperature Selas burners each equipped with a close-coupled R1000 ceramic recuperator. Also installed were combustion controls and furnace pressure controls.
Fuel and Metering:	Natural gas fuel and positive-displacement meters.
Operating Procedure:	Single shift operation, 250 days per year. Furnaces are fired at 4 a.m. and shut down at 3 p.m.
Testing Procedure:	Side-by-side comparison with an unrecuperated furnace equipped with inspirating burners, an on-off type combustion control, and no pressure control.
Performance Information:	At this host site, it was not possible to obtain records of the weights (and temperature) of the daily furnace loads in either the recuperated or unrecuperated furnace. Based upon the assumptions that both furnaces were loaded and heated in a similar manner, the indicated fuel saving for the rebuilt furnace was 54.3 percent. No performance curves were generated.
Cost Information:	The total cost of the rebuild and retrofit of the test furnace was \$73,200, of which \$41,000 was related to the recuperator addition. McWilliams Forge reported natural gas at 1,015 Btu/SCF at a cost of \$4.43/MM Btu. The calculated annual saving was \$19,820 based upon 250 operating days per year.

HOST SITE NO. 28

Altech Specialty Steel Corporation
Willowbrook Avenue
Dunkirk, New York 14048
Mr Thomas E. Lahey (716) 366-1000

Brief Description:	A large company producing specialty steel and titanium products.
Furnace Type:	Box reheat furnace (8 x 16 x 3.5 feet) used to heat billets of various materials to temperatures from 1700 to 2350 F for hot rolling.
Furnace Equipment:	Retrofit was done by mounting six R1500 TPX recuperators on top of an existing furnace, and providing preheated air through insulated ducts to six top-mounted North American dual-fuel burners. Comparison furnace essentially identical but without recuperation. Combustion and pressure controls on both furnaces.
Fuel and Metering:	Natural gas is principal fuel. Positive displacement meters are used to measure fuel consumption.
Operating Procedure:	Normal operations are two shifts per day, with average loads of 15,000 pounds per shift. The average throughput during the test period, however, was about 10,000 pounds per shift.
Testing Procedure:	The comparison is on a side-by-side basis between the recuperated furnace and a similar unrecuperated unit. Daily readings are taken of weights heated and fuel used.
Performance Information:	Performance curves for the two furnaces were developed as shown in the following graph. At a common throughput of 10,000 pounds per shift, the indicated fuel saving is 12.5 percent.
Cost Information:	The total installed cost of the retrofit was \$136,580, of which \$126,086 was recuperator related. Assuming two-shift operations, 250 operating days per year, and a fuel cost of \$5.50/MM Btu, the indicated annual savings are \$7,430 for 10,000 pound per shift loads.

FIGURE B-17. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, ALTECH (HOST SITE NO. 28)

HOST SITE NO. 29

Crucible Steel Company
Syracuse, New York 13201
Mr. Levi Thomas (315) 487-4111

Brief Description: Crucible Steel is a producer of specialty steels and alloys. In the department where the recuperated furnace is located, Crucible Steel operates a small rolling mill for special alloy orders.

Furnace Type: Conventional box heating furnace. Furnace interior is 12 x 7 x 3 feet high. Steel is heated in the range of 1800 to 2100 F.

Furnace Equipment: The test furnace was equipped with two North American high-temperature dual-fuel burners, two R1500 TPX ceramic recuperators and combustion and furnace-pressure controls.

Fuel and Metering: Natural gas fuel. Positive displacement meters.

Operating Procedure: Two-shift operation (normally), 5 days per week. Early lightoff of furnace. A typical first furnace load is 2,000 to 3,000 pounds of 150-pound billets. Furnaces are unloaded piece by piece for mill feeding and are refilled with cold billets as the hot billets are removed. The furnace doors are opened and closed about 80 times per shift.

Testing Procedure: Side-by-side comparison of a recuperated and an unrecuperated furnace of the same general size and loading. Fuel usage was based upon total consumption, including that used for furnace idling between mill runs.

Performance Information: The average daily throughput during the test period was 5,000 pounds. At that rate, the fuel saving was 30.7 percent based on totals. If only the fuel used during the time metal is being heated is considered, the fuel saving is 38.3 percent. Performance is shown graphically in the attached plot.

Cost Information: The complete cost of the retrofit was \$101,990, of which recuperator-related costs were identified as \$41,790. For 250 days per year of operation and natural gas at \$4.44/MM Btu, the projected annual savings from recuperation are \$12,000.

FIGURE B-18. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, CRUCIBLE STEEL (HOST SITE NO. 29)

HOST SITE NO. 30

Buffalo Metal Castings
1875 Elmwood Avenue
Buffalo, New York 14207
Mr. James E. Sloan (716) 874-6211

Brief Description:	Buffalo Metal Castings is a small (40 employees) nonferrous foundry producing mainly brass and aluminum castings.
Furnace Type:	The test furnace is a 600-pound oil-fired aluminum pot furnace.
Furnace Equipment:	The retrofitted furnace was equipped with one R1000 TPX ceramic recuperator close coupled to a North American dual fuel burner. Combustion controls, but no pressure controls, were installed. A similar unrecuperated pot furnace was used for comparison.
Fuel and Metering:	This installation burns No. 2 fuel oil. Fuel consumption is measured by a rotary meter.
Operating Procedure:	Single shift operation is usual, typically with 1200 pounds of aluminum melted per shift (two melts). For most of the period during which test data were obtained (1982), one melt per day was usual.
Testing Procedure:	Side-by-side comparison of recuperated and unrecuperated melting furnaces, with daily records of weight of aluminum melted and fuel consumed.
Performance Information:	At an average production level of 600 pounds, the fuel saved by the recuperator-equipped furnace is 31.5 percent. Performance curves for the recuperated and unrecuperated units are presented.
Cost Information:	The total retrofit cost \$17,910 of which \$16,530 is identified as recuperator related. For 250 days per year operation, two melts per day (1,200 pounds), and fuel oil at \$7.68/MM Btu, the projected annual savings are \$8,450.

FIGURE B-19. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, BUFFALO METAL CASTINGS (HOST SITE NO. 30)

HOST SITE NO. 31

Standard Steel Company
Burnham, Pennsylvania 17009
Mr. Gary L. Zook (717) 248-4911

Brief Description: A gas-fired box furnace used to heat steel ingots for forging and forge reheating.

(No operating data available)

HOST SITE NO. 32

National Forge Company
1341 West 16th Street
Erie, Pennsylvania 16512
Mr. Tom Ebert (814) 452-2300

Brief Description: This installation will be on a 100-ton ladle
heater

(No operating data available)

HOST SITE NO. 33

Ladish Company
Cynthiana, Kentucky
John S. Koniar (414) 747-3070 (Cudahy, Wisconsin)

Brief Description:

Heat-treat box furnace. No operating data available, but preliminary performance measurements by Ladish indicate a 50 percent improvement in fuel economy.

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HOST SITE NO. 34

Pratt and Whitney Aircraft Company
400 Main Street
East Hartford, Connecticut 06108
Mr. Lloyd Curtin (203) 565-3348

Brief Description: Heat-treat box furnace.

(No operating data available)

HOST SITE NO. 35

Amax Specialty Metals Corporation
1875 McCarter Highway
Florham Park, New Jersey 07932
Mr. Tom Abagliano (201) 377-6398

Brief Description: Box furnace used to heat slabs and shapes for hot rolling.

(No operating data available; however,
preliminary test information indicates
fuel savings of 45.9 percent)

HOST SITE NO. 36

Bethlehem Steel Corporation
701 East 3rd Street
Bethlehem, Pennsylvania 18016
Mr. E. R. Hittinger (215) 694-2592

Brief Description: The recuperated furnace is located within a large steel manufacturing plant, in a forging shop.

Furnace Type: One of five rotary hearth steel-heating furnaces. The furnace is circular and the hearth rotates slowly on tracks. The loading of cold steel and the unloading of heated steel are accomplished at the same location. Steel is heated to 2350 F.

Furnace Equipment: This rotary furnace was relined with rammed refractory in roof and walls and this refractory was covered with ceramic fiber modules. The furnace was equipped with eight Selas high-temperature burners, eight R1500 TPX ceramic recuperators and furnace pressure and combustion controls.

Fuel and Metering: Natural gas firing (1,008 Btu/SCF). Fuel flow metering is accomplished with an orifice meter on each of the two furnace zones.

Operating Procedure: The furnace is normally operated 2 shifts per day, five days per week. The furnace is started about 3 hours before the first shift.

Testing Procedure: Data were obtained in a before-and-after comparison. During the "before" period, the furnace was oil-fired with manual combustion controls. The "after" period followed furnace relining and retrofitting of gas burners, recuperators, and furnace pressure and combustion controls.

Performance Information: The furnace before recuperation used an average of 6,359 Btu/pound and after used an average of 2,860 Btu/pound for a 55.0 percent savings. This fuel savings is for an average furnace throughput of 20,000 pounds of steel per day.

Cost Information: The total cost of the retrofit was \$293,391, of which \$218,508 was attributed to recuperator-related additions. Fuel cost was reported as \$5.50/MM Btu. For the average daily throughput of 20,000 pounds and 250 days per year of operation, the annual fuel savings are \$96,250.

FIGURE B-20. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, BETHLEHEM STEEL (HOST SITE NO. 36)

HOST SITE NO. 37

Cape Ann Forge
Gloucester, Massachusetts 01930
Mr. Richard Hendee (617) 283-5151

Brief Description:	Cape Ann Forge Company produces large steel shafts and rolls by open-die press forging and machining.
Furnace Type:	Conventional box furnace used to preheat steel billets or ingots to 2350 F for forging.
Furnace Equipment:	The test furnace was equipped with four North American side-mounted high-temperature burners designed to burn natural gas or No. 4 fuel oil. The four R1500 TPX ceramic recuperators are close-coupled to the burners and are equipped with eductors and controls for furnace pressure control.
Fuel and Metering:	This furnace uses No. 4 fuel oil as the primary fuel with natural gas provided for a pilot flame and limited supplementary fuel. All meters are positive displacement meters.
Operating Procedure:	Normal procedure at this plant is to load steel into the furnace in the afternoon for overnight heating and forging in the morning. This plant is in operation 5 shifts per week.
Testing Procedure:	At this host site, a recuperated and unrecuperated furnace of about the same size are operated side-by-side. In addition, operating data for the test furnace prior to retrofit were provided.
Performance Information:	In both side-by-side and before-and after comparisons, the total energy savings for the recuperated furnace was 44.4 percent (2,615 Btu per pound of steel heated). This saving is taken at the mean daily furnace load of 10,000 pounds of steel.
Cost Information:	The cost of the complete rebuild/retrofit was \$129,209. The cost of the recuperator-related portion of the installation was \$96,700. This plant burns No. 4 fuel oil (146,000 Btu/gallon) costing \$0.81 per gallon or \$5.55/MM Btu. The annual savings at the overall 44.4 percent savings is \$32,330.

FIGURE B-21. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, CAFE ANN FORGE (HOST SITE NO. 37)

HOST SITE NO. 38

Stanley Spring Company
A Division of TRW
1300 N. Cameron Street
Harrisburgh, Pennsylvania 17103
Mr. Joe Killinger (717) 233-5751

Brief Description: Stanley Spring Company manufactures replacement leaf springs for auto, truck and heavy road equipment. Steel bars are heated to 1650 F and are taken from the furnace one at a time for power forming followed by oil quenching.

Furnace Type: Double-ended (two door) box furnace with a center archway that separates the furnace into two sections.

Furnace Equipment: The recuperated furnace is a new furnace equipped with: (a) fiber-lined walls and roof; (b) four Eclipse high-temperature burners (two per section); (c) four close-coupled R600 TPX ceramic recuperators; (d) furnace pressure and combustion controls; and (3) a metallic recuperator on the exhaust stack feeding preheated air to the ceramic recuperators.

Fuel and Metering: Natural gas fuel and Rockwell gas meters.

Operating Procedure: All Stanley Spring Company furnaces are in operation 15 or more shifts per week. Operators load steel bars for a furnace charge and once the bars have been heated, they are manually removed to feed the spring-forming operation.

Testing Procedure: At this host site, the side-by-side comparison was between a new, fiber-lined, recuperated furnace and an older, brick-lined unrecuperated furnace of the same size.

Performance Information: Per working day, the comparison furnaces at this host site each heat an average of 30,000 pounds of steel. At this level of operation the savings calculated for the new recuperated furnace was 63.7 percent.

Cost Information: The total cost of the new furnace was \$97,636, of which \$43,306 was attributed to the recuperator-related items. Fuel cost was \$5.54/MM Btu. Based on 250 operating days per year, the annual savings compared with the old furnace was \$54,290.

FIGURE B-22. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, STANLEY SPRING (HOST SITE NO. 38)