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

Task 1. Hague Forge Furnaces

By
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February 1983

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Battelle Columbus Laboratories
Columbus, Ohio

U. S. DEPARTMENT OF ENERGY

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OFFICE OF INDUSTRIAL PROGRAMS
DEPARTMENT OF ENERGY

BATTELLE
Columbus Laboratories

EXECUTIVE SUMMARY

As part of its effort to encourage industry to conserve fuel, the Office of Industrial Programs of the Department of Energy undertook a program to demonstrate to industry the benefits of installing particular types of energy-conserving devices and equipment. This Final Report describes one of these types of equipment and the results obtained under production conditions in commercial plants.

The equipment under consideration includes improved forge furnaces and associated heat-recovery components designed and manufactured by Hague International of South Portland, Maine. The systems are available either as complete furnace packages or as retrofits to existing forge furnaces. They are used to heat steel to about 2300 F prior to hot forging.

The energy-conserving devices include improved insulation, automatic air-fuel ratio control, and a ceramic recuperator that recovers heat from hot combustion gases and delivers preheated air to high-temperature recirculating burners.

Twelve Hague furnaces and retrofit packages were purchased and installed by eleven "host" forge shops that agreed to furnish performance data for the purpose of demonstrating the energy and economic savings that can be achieved in comparison with existing equipment.

Within each forge shop, an effort was made to make the comparison between a Hague unit and a "conventional" baseline unit as valid as possible within the normal commercial production environment.

The Hague-built units included slot, box, and pusher furnaces; retrofits were made on box, car-bottom, and rotary forge furnaces. Start-up dates were from January 1978 to March 1981.

Throughput rates for furnaces in the program ranged from a low of about 2000 to as high as 80,000 pounds of steel per day. Average specific energy consumption ranged from about 1000 Btu per pound of steel to over 10,000 Btu per pound.

Fuel savings were reported by comparing the specific energy consumption (Btu's per pound of steel heated) for each Hague furnace with that of a comparison furnace. Savings typically were in the vicinity of 50 percent; higher when compared with a poorly performing conventional furnace and lower when compared with a good quality furnace.

Economic comparisons were made using payback period based on annual after-tax cash flow. Payback periods for the Hague equipment varied from less than two years to five years or more. In addition to fuel savings, the amount of use (throughput) was highly significant in affecting payback period. In several cases, payback times were high only because the units were operated at a small fraction of their available capacity.

Attention is drawn to the significance of throughput rate in affecting fuel consumption in both conventional nonrecuperative furnaces and in Hague-equipped furnaces. Most of the forge furnaces evaluated in this program were drastically underutilized; that is, product throughput rates are much lower than the capacities of the furnaces. This low degree of utilization severely penalizes both fuel efficiency and payback time.

The average annual energy savings for each of the twelve Hague-equipped furnaces reviewed in this program is 16.5 billion Btu's, and the average daily throughput is 28,000 pounds. If that average furnace were operated 250 days per year, the annual throughput would be about 7 million pounds or 3500 tons.

It has been estimated that about 3 million tons of forgings are produced in the U. S. annually, and that about 15,000 furnaces are available in the industry. If half of that production was heated in Hague furnaces, with the average throughput involved in this program, a total of 430 units would be needed. At 1982 prices, those would cost a total of about \$86 million, would save about \$28 million annually in fuel costs, and would have a payback period of about 3 years. The total annual energy savings from this group of 430 furnaces would be about 0.007 quad.

To supplement the foregoing program on Hague furnaces under commercial production conditions, a detailed comparison was made at one site under more closely controlled conditions. The comparison was made between a Hague slot forge furnace (Model 4) and a nonrecuperative unit recently designed and built by the forge shop. The fuel saving attributable to the Hague recuperative system was about 12 percent when both furnaces were operated at about 50 percent of capacity, and about 29 percent when the furnaces were operated close to full capacity.

The following observations should be kept in mind for the individual comparisons that are made in this report:

- Comparisons on an absolute basis, such as percent thermal efficiency or Btu/lb of steel heated, should be made only for comparable operating conditions; these are most likely to be achieved within a single plant.
- Performance improvements, usually expressed in terms of percent fuel savings, clearly will depend upon the quality of the comparison furnace. High fuel savings are achieved by comparing a Hague unit against an old, inefficient furnace; savings are lower when the comparison is made against a modern "state-of-the-art" furnace.
- In retrofit installations, improvements normally are made to the original furnace in addition to the recuperator, burners, and air/fuel ratio control. These improvements also contribute to the overall performance improvement, and are included in the results reported here. In many instances, the rebuilt furnace is equivalent to a new furnace.
- Furnace scheduling and throughput are highly important factors in establishing furnace performance; these factors are commonly dictated by other production criteria and are seldom optimized for fuel economy.
- Furnace maintenance and operation varied considerably among the plants contacted, with consequent effects on furnace performance. Increased attention to maintenance and operation generally would result in efficiency improvements for both the Hague and conventional units.

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National Flame & Forge, Inc.

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FINAL REPORT

on

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PROGRAM
TASK I: HAGUE FORGE FURNACES

by

H. W. Lownie and F. C. Holden

BACKGROUND AND OBJECTIVES

In the United States, there are probably about 15,000 furnaces, more or less*, used in the steel forging industry to heat small to large pieces of steel to temperatures of about 2300 F so that the steel may be forged in dies, presses, or hammers to provide useful products. The products generically are called "steel forgings". They may individually weigh from a few ounces to 50 tons or more.

"Conventional" slot and box forging furnaces, which will be described, and which comprise the great majority of all forging furnaces in service, are simple box-like structures, usually constructed as a steel shell lined with fire brick. In many cases, they have been built by the forge shops themselves. The heating systems of such units typically include simple burners, usually fueled with natural gas, and simple manual-control valving. Because most of these furnaces were built during periods of low prices for energy, little attention was paid to thermal efficiency. Even today, the fuel costs in many forge shops represent only about 1 to 3 percent of the total value of the forgings produced.

The amount of energy theoretically required to heat 1 pound of steel to forging temperature (about 2300 F) is about 370 Btu. Actual average fuel consumption in individual conventional forging furnaces

*The number of forge furnaces in the industry is not known. Recent estimates have varied from about 8,000 to about 18,000.

appears to be mostly in the range of 3000 to 12,000 Btu/lb of steel. Some furnaces probably use as much as 15,000 Btu/lb. Since the start of this demonstration program (early in 1980), some of the forge shops included in the program have made considerable progress in designing, building, and operating improved "conventional" (nonrecuperative) forge furnaces. As a result, one shop has been able to demonstrate average fuel consumptions as low as about 1500 Btu/lb in nonrecuperative furnaces.

The majority of conventional nonrecuperative forge furnaces, many of which are old and poorly instrumented, probably consume an average of about 4500 to 8000 Btu/lb of steel (thermal efficiencies of about 4 to 8 percent). The best of the modern conventional nonrecuperative furnaces using about 1500 Btu/lb have a thermal efficiency of about 25 percent, but such furnaces are few.

As will be shown, when comparing fuel-consumption figures for different situations, recognition needs to be taken not only of differences in furnace design, condition, and characteristics (as between recuperative and nonrecuperative), but also of the degree to which the furnace is loaded relative to its capacity and the number of hours of use per day. Low degrees of use and short runs can easily triple or quadruple energy consumption per pound of steel heated, regardless of the inherent characteristics of the furnace.

About 1976, fuel costs escalated and natural gas supplies were curtailed to many industrial users. As the heat losses associated with conventional forge furnaces became better recognized, several furnace manufacturers and the Forging Industry Association (FIA), the forging industry's trade association, began to disseminate more and better information and to make available improved furnace designs aimed at higher thermal efficiency. However, although some of the more progressive forge shops took modest steps toward improved thermal efficiency, many forge shops have exhibited resistance to change.

The DOE Office of Industrial Programs (OIP) judged that its encouragement of the development and commercialization of improved forge furnaces would have a significant beneficial effect on conservation of energy in the industrial sector. OIP, therefore, undertook to support

the development and commercialization of the particular new designs and equipment of Hague International, South Portland, Maine. Hague has delivered over 20 furnaces or retrofit packages to forge shops located in the U. S., and at least one overseas. Retrofits involve the installation of selected energy-conserving equipment on an existing furnace, as differentiated from an entirely new furnace that includes the energy-conserving equipment.

In accordance with arrangements made between OIP and Hague, Hague designated twelve forge shops as "host sites" for this demonstration program.* Each host site was defined to meet the following qualifications:

- Purchase of a Hague forge furnace or retrofit package
- Continuing operation of the Hague equipment under commercial conditions
- Access to a "baseline furnace" that would serve as a reference in the same shop for comparison with the Hague equipment
- Agreement of site personnel to collect fuel-consumption and cost data on each Hague furnace (or retrofit) and baseline furnace and to furnish these data 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 forge-furnace host sites, as well as similar data to be provided by host sites concerned with several other types of energy-conserving equipment and processes. PNL designated Battelle's Columbus Laboratories to do the analysis and reporting of the performance of forge furnaces.

In this Final Report, Task 1 refers to the collection, analysis, and reporting of the results of demonstration activities under normal commercial production conditions at eleven host sites, each having at least

*One site subsequently declined to participate in the demonstration program. The remaining eleven sites include twelve furnaces provided by Hague or equipped with Hague retrofitted equipment.

one Hague-equipped furnace. Task 4 refers to a special activity initiated in late 1981 in which a Hague furnace was compared with a modern state-of-the-art nonrecuperative furnace at one site using a higher degree of control and instrumentation than was possible under normal commercial production conditions. The results of Task 4 are included in this report as Appendix C.

During the course of this work, two Interim Reports were issued and distributed to participating organizations for information and comments. The Interim Report on Task 1 was dated June 30, 1981, and the Interim Report on Task 4 was dated December 10, 1981.

DESCRIPTION OF CONVENTIONAL PROCESS AND EQUIPMENT

Regardless of type, all fuel-fired forge furnaces have the following elements:

- A refractory or refractory-lined structure to contain the heat provided by combustion, and to contain the steel while it is being heated by direct contact with the products of combustion
- A system of one or more burners, with provisions for supplying fuel and combustion air to the burners. The most common fuel is natural gas, although fuel oil is used in some shops, and several are equipped with dual-fuel capabilities. The air is usually supplied at ambient temperature to the burners
- An exhaust system. The hot products of combustion are vented to the atmosphere, thereby entailing high loss of sensible heat
- A system for loading the cold steel into the furnace and retrieving the hot steel when ready for forging.

Conventional furnaces usually, but not always, include a thermocouple or other device for measuring furnace temperature, and sometimes for controlling furnace temperature. Usually, the air-fuel ratio is adjusted by the furnace operator based on his own observation and judgment, and is accomplished by simple manual controls. Most commonly, the fuel supply to the furnace is not individually metered.

Types of Forge Furnaces

There are five major types of forge furnaces. Each is represented in the present study.

- Slot furnaces appear to be the most common type, and are among the least efficient. Their fuel consumption, as they are usually operated, appears to be in a range of 2500 to 15,000 Btu per pound of steel heated, with an average of perhaps about 5000 Btu/lb (about 7 percent fuel efficiency). They obtain their name from a horizontal slot along one side of the furnace. After the furnace is brought up to operating temperature, a number of steel billets is inserted through the slot, left for sufficient time to reach the desired temperature, and then withdrawn individually through the slot as needed at the forging hammer or press. Conventionally, new cold billets are inserted to replace heated billets that are withdrawn, so that the furnace usually contains a number of billets in different stages of heating. The slot is usually open so that substantial amounts of products of combustion and flame may escape through the slot, or external air may be drawn into the furnace. In some furnaces, the slot also serves as the flue for the combustion products.
- Box furnaces are probably the second most common type. The average fuel consumption is probably about 4000 Btu per pound of steel heated (about 10 percent efficiency), but some box furnaces are operated at extremely low efficiency (say 2 percent) to suit production conditions in the shop. Box furnaces have a door in at least one end of the furnace. Conventionally, the door is raised and lowered to permit steel billets (or other shapes) to be charged to the furnace and removed as needed. There are two major modes of operation. One mode involves charging the furnace with steel to its capacity, bringing the entire load up to forging temperature, and then withdrawing heated steel as desired, often over a period of several hours or a full shift. The second mode is analogous to operation of the slot furnace. Steel billets or forgings in process are charged individually, brought to temperature, and withdrawn, to be replaced with other billets or forgings in process. In this mode, relatively little steel may be in the furnace at any particular time.
- Car-bottom furnaces are similar in appearance to box furnaces. Whereas the box furnace has a stationary hearth on which the steel is placed, the hearth of a car-bottom furnace, and sometimes the door, is mounted on tracks so that the hearth can be withdrawn from the furnace proper to facilitate loading and unloading of large pieces of steel (up to 60 tons or more per piece) by means of an overhead crane.

- Rotary-hearth furnaces are cylindrical, with a rotating hearth (somewhat like a Lazy Susan). In contrast to the three prior types that are designed mainly for batch operation, the rotary-hearth furnaces are designed for essentially continuous operation. Steel is placed onto the hearth through a hole in the furnace wall, and is carried around the furnace on the rotating hearth that has its speed matched to the production rate at the hammers or presses. As heated steel is removed, cold steel is added to take its place. Because of the continuous mode, rotary-hearth furnaces have potential for higher efficiency than slot, box, or car-bottom furnaces, but high efficiency is by no means assured. Some appear to be operated at fuel rates as high as about 7000 Btu per pound of steel (an efficiency of about 5 percent).
- Pusher furnaces are rectangular, relatively long, relatively low in height, and may or may not have doors or radiation shields at both ends. As for rotary-hearth furnaces, they are designed for continuous operation. Steel billets are placed crossways on the hearth and in contact with each other. As each billet is added at the charging end, the charging machinery pushes the entire load toward the discharge end. After the furnace hearth is completely loaded, a billet must be removed from the discharge end of the furnace before a cold billet can be added at the charging end. As for rotary-hearth furnaces, pusher furnaces, because of their continuous mode, have potential for relatively high thermal efficiency.

Types of Operation

When analyzing the performance of different types of furnaces in different situations at different sites, it is important to recognize that the operators consider the furnaces to be a means to an end, and not an end in themselves. The operators tend to focus on production and the overall sequence of operations in the forge shop, and adapt the operation of the forge furnaces to maximize the convenience of other operations, mainly the forging presses and hammers.

The batch types of forge furnaces (slot, box, and car-bottom) that account for the greatest fraction of the total number of furnaces are characteristically capable of heating much more steel than they are called

upon to heat. This occurs for a number of reasons; for example, once a furnace and its load are brought up to temperature, most of the original load may be held in the furnace until it is convenient for the operator to remove it. A furnace may be on idle (low-fire) for much of the period that it is being operated during the day. This has a substantial influence on the average amount of energy consumed per pound of steel heated in that furnace. The thermal inefficiencies associated with the overall scheduling and mode of operation of many forge furnaces are at least as great as the thermal losses associated with the forging furnace per se.

Although there are exceptions (including many of those among the present host sites), most forge furnaces are not under close technical control. Controls and instrumentation frequently are rudimentary, and often in poor repair. Reliance is placed on the skill of the operator, whose "eye" often is judged to be superior to instrumentation. Many forge shops are essentially enlarged versions of the old village blacksmith shop. Infiltration of new relatively sophisticated equipment into this environment presents a considerable challenge.

Causes of Low Thermal Efficiency

Overall forging furnace efficiencies are low because of

- Loss of sensible heat in combustion gases that are exhausted to the atmosphere
- Radiation from openings in the furnace (as from slots and from open or ill-fitting doors)
- Conduction losses through the walls, roof, doors, and hearth
- Lack of good control of the air-fuel ratio
- Lack of good control of the furnace temperature
- Shop practices and scheduling; specifically those which lead to a low utilization of furnace capacity.

DESCRIPTION OF HAGUE EQUIPMENT

The Hague furnaces and components are designed to improve fuel efficiency by:

- Recovering sensible heat from waste combustion gases
- Minimizing radiation, conduction, and convection losses from the furnaces and their components
- Optimizing the efficiency of the fuel combustion process.

The Hague furnaces studied during this demonstration program included both complete package units, manufactured at the Hague plant in South Portland, Maine, and shipped to the host site, and retrofits to existing furnaces already in place at the host sites. In both situations, the following major components were included:

- A ceramic recuperator (CERHX[®]), designed to recover heat from the furnace exhaust gases and transfer it to the incoming combustion air. The recuperators are made in various capacities ranging from about 1.5 to 20 million Btu/hour. Combustion air passes through rows of silicon carbide tubes, designed to be capable of handling exhaust gases up to 2800 F and providing combustion air heated up to 1800 F. The first row of tubes facing direct radiation from the furnace are smooth for improved strength and resistance to thermal shock. Subsequent rows of tubes are finned (extended surfaces) to improve heat transfer. The units may be mounted with the tubes in a horizontal or vertical position. The recuperator usually is designed as a single-pass unit.
- Insulated ducting is used to carry the preheated air from the recuperator to the burners. The ceramic-lined steel ducting is fabricated in spool sections that can be assembled in the field.
- Recirculating burners (Transjet[®]), designed and manufactured by Hague, are utilized to accept combustion air preheated up to 1800 F. Stock models are available with ratings up to 4 million Btu/hour for natural gas, oil, or with dual-fuel capability (gas or oil).

- Combustion air control is provided by a unit (Oxsen) which monitors the oxygen content in the exhaust gas stream, and trims the fuel/air ratio to predetermined levels.

Among the Hague-built complete package furnaces, the slot forge furnace is one of the more common types. A typical slot-forge furnace is illustrated in Figure 1, in which the top-mounted recuperator, blower, and insulated ducting connecting the header with the burner can be seen. The slot opening is above the horizontal hearth and shielded by the four closures at the front.

Figure 2 shows a box furnace during final assembly, and Figure 3 illustrates a continuous pusher furnace design, also in final assembly.

The standard furnaces are constructed of castable refractory within a steel shell, supported by a steel box frame. Several units have had ceramic fiber linings added after delivery to the customer. The retrofit installations include the principal features of the Hague units, but represent various original designs of box, rotary, and car-bottom types.

IDENTIFICATION OF HOST SITES

Twelve host sites were identified by Hague International for inclusion in this program. One site has two Hague furnaces. Eleven of the twelve sites were visited by Battelle personnel, in most instances twice or more, and have provided data and information. The twelfth site elected not to participate in the data-gathering phase.

The participating sites are identified in Table 1, which also indicates the type of Hague equipment involved. The sites are listed in approximate order of the date of startup of the Hague equipment.

FIGURE 1. TYPICAL HAGUE SLOT FORGE FURNACE

FIGURE 2. TYPICAL HAGUE BOX FURNACE

FIGURE 3. HAGUE-BUILT PUSHER FURNACE

TABLE 1. IDENTIFICATION OF FORGE FURNACE HOST SITES,
AND NATURE OF HAGUE EQUIPMENT

(Listed in approximate order of start-up of
Hague equipment)

Site	Hague Equipment (Start-up Date)
Anderson Shumaker Company Chicago IL	Retrofit on box furnace. 4 million Btu/hr. (January 1978) (Recuperator replaced September 1978)
Scot Forge Company Clinton WI	Retrofit on box furnace. 8 million Btu/hr. (June 1978) (Rebuilt and modified August 1981)
Scot Forge Company Spring Grove IL	Retrofit on box furnace. 8 million Btu/hr. (September 1978)
Canada Forgings Welland ONT	Model 4 slot furnace. 4 million Btu/hr. (August 1979)
Earl M. Jorgensen Company Seattle WA	Retrofit on car-bottom furnace. 15 million Btu/hr. (December 1979)
W. Pat Crow Forgings, Inc. Fort Worth TX	Model 4 slot furnace. 4 million Btu/hr. (August 1980)
	Model 5 slot furnace. 4.5 million Btu/hr. (January 1981)
Reed Rock Bit Company Houston TX	Retrofit on rotary-hearth furnace. 8 million Btu/hr. (November 1980)
K. O. Forge, Inc. Houston TX	Box furnace 5 million Btu/hr. (March 1981)
National Flame & Forge, INC. Houston TX	Pusher furnace. 13 million Btu/hr. (March 1981) (Modified later to 11 million Btu/hr)
Western Forge and Flange Company Santa Clara CA	Box furnace. 4 million Btu/hr. (March, 1981)
Taylor-Wharton (Division of Harsco Easton PA	Modified Model 4 slot furnace.* 4 million Btu/hr. (March 1981)

* Usual fuel before January 1982 was oil. All others natural gas.

METHODS FOR DATA COLLECTION AND ANALYSIS

Each of the eleven host sites participating in the program was visited by Battelle technical personnel for an on-site inspection of the Hague equipment, the baseline furnace, instrumentation, and the mode of operation of the furnaces and shop. The purpose of the study was explained to host-site personnel, most of whom were anxious to cooperate because the objectives of the study correspond closely with their own interests in evaluating the performance of the new equipment.

At each host site, two types of information were requested:

- Fuel-consumption data related to the steel throughput, both for the new Hague equipment and for the baseline furnace. The purpose of such information was to serve as a basis for analysis to determine the amount of energy conservation being obtained at each site for the specific Hague equipment under the specific set of conditions existing at each site.
- Financial data concerning each installation. Among such data are costs for purchase and installation of the Hague equipment, current costs for fuel (and expectations for the future), and incremental costs of the Hague equipment for maintenance and replacement parts. Combined with fuel-consumption data, the financial data serve as a basis for computing the financial worth of the Hague equipment under the specific set of conditions existing at each site.

It is pertinent to recognize two important features of the data-collection aspects of this program:

- All fuel-consumption and financial data were provided to Battelle directly by personnel at the host site. Data from other sources, such as the manufacturer of the equipment, have not been included.
- Participation of the hosts has been voluntary. Some elected to provide data in substantial depth, even though this involved added cost to them and sometimes modification of their usual mode of operation; others had situations and circumstances that limited the data that they elected to provide.

Methods for Fuel-Consumption Analyses

A key element in this program is the assessment of fuel-consumption performance by comparing one furnace with another in the same forge shop. This makes possible the elimination of a number of site-specific variables that otherwise would be difficult to evaluate and nearly impossible to control. It also 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 greater deviations from normal production procedures than are within the scope of this program.

The comparison was made on either a "before-and-after" or a "side-by-side" basis. In the first instance, performance data were collected and analyzed on an original or baseline furnace that then was either replaced by a new Hague unit or retrofitted with Hague-built energy-conserving devices. In the second instance, the Hague unit was operated along with the old unit, with data being collected on both simultaneously. In either situation, it was intended that operating procedures be kept as similar as possible for both units so as to provide a useful comparison. Unintended deviations did occur on occasion because of the vagaries of the production process and changes in the shops' order books.

It also was necessary to choose an operating basis for comparison. There are several valid ways in which this might be done. One basis would be under conditions where the best fuel economy of each furnace is demonstrated. Generally, this involves operation at or near rated capacity of the furnaces. Another (the one selected for use here) involves operations as they actually take place in the shop, including the fuel used for furnace idling, weekend cooling and reheating, operational delays, small furnace loads, etc. Although the absolute performance values in terms of efficiency are lower than those of which either the old or new equipment is capable, the results are more nearly representative of actual plant experience.

Many of the detailed procedures of furnace operation, such as burner adjustments and furnace-pressure control, have significant effects on furnace efficiency. In some forge shops these adjustments are made

periodically by plant engineers or by other trained staff. In others, the "fine tuning" of the combustion system is left to largely untrained operators or maintenance staff. One result of the lack of close control is the circulation of air through the furnace in excess of that required for combustion. This excess air may result from incorrect adjustment of air-fuel ratio controls (where they exist) or it may be drawn into the furnace through slots or open and ill-fitting doors. Efficiency is lowered because large volumes of air must be heated and then exhausted without adding to the useful output.

In this program, procedures for furnace operation were those representing normal production practice for the particular plant. No special efforts were made to adjust or tune furnaces beyond the normal maintenance schedule for each shop.

Analysis of Forge Furnace Performance Data

The basic information generated by each host site included the amounts of fuel consumed and steel heated, each measured over an appropriate time period (e.g., daily). The data recorded typically were daily fuel-meter readings and daily totals of the numbers and sizes of work pieces heated, which then were converted to weights.

In most forge shops, the amount of steel heated per day will vary over a fairly wide range as production operations in the shop demand. That range will depend upon such factors as the size and complexity of forgings, the number of reheats required (if any), the overall level of business, the limitations and availability of staff and equipment, and any tooling changes or equipment breakdowns that may occur. For example, in one plant making large forgings, daily throughputs for a furnace ranged from a low of 4000 pounds to a high of 30,000 pounds; its average over a 6-month period was about 15,000 pounds per day.

The capacity of a forging furnace is commonly expressed in terms of the weight of steel that can be heated to forging temperature per hour. A capacity rating generally is stated by the manufacturer for a new furnace,

but for many of the older units such ratings are available only in terms of operator experience. Other indications of capacity are physical size, recuperator capacity, and total burner capacity. The relationship of actual throughput to capacity, however defined, is significant when comparisons are being made between two units. Accordingly, it was important that sufficient operating data be obtained to establish with reasonable certainty the amount of fuel consumed over the range of throughput that was encountered.

Procedure for Handling Data on Furnace Performance

The raw data obtained from forge-furnace host sites consisted of periodic (usually daily) values of energy input and steel throughput. Energy inputs typically involved differences in fuel-meter readings in cubic feet of natural gas or gallons of oil, while throughput was expressed in pounds of steel heated. Fuel use was converted to Btu's by multiplying the gross heating value of the fuel (e.g., 1000 Btu/scf) by the amount of fuel consumed, following the application of appropriate meter correction factors. For most plants, where normal forging practice involves heating all the forging stock to the same temperature, the specific energy consumption (Btu/lb) is a direct and useful measurement of efficiency. The thermal efficiency is calculated as the theoretical amount of energy required to heat the steel to temperature divided by the actual energy required. The theoretical energy required to heat steel to a given temperature or heat content, is taken from Figure C-13.

If the furnace is used to heat materials to different temperatures, or if materials with different specific heats are being heated, it is necessary to calculate thermal efficiency separately for each temperature and/or material. For these situations the specific energy consumption is not a valid basis for comparison.

Specific energy consumption and thermal efficiency (for steel heated to the same temperature) are inversely related. For example, for steel heated to 2300 F, when specific energy consumption is 4000 Btu/lb, thermal efficiency is $370/4000 = 9$ percent. When specific energy consumption is 2000 Btu/lb, thermal efficiency is $370/2000 = 18$ percent.

Typical data and units are as follows:

<u>Item</u>	<u>Units</u>	<u>Symbol</u>
● Throughput of Steel	1000 lbs/day	x
● Fuel Consumed	Standard Cubic Feet (scf)/ day (Gas) or Gallons/day (Oil)	
(Meter reading difference x Meter factor)		
● Total Energy Consumption	10^6 Btu/day	y
(scf/day or Gallons/day x Gross Heating Value of Fuel)		
● Specific Energy Consumption	1000 Btu/lb of steel	z
(Total Daily Energy Consumption ÷ Daily Throughput)		

When a sufficient quantity and quality of data become available, values of z and x are fitted to an exponential curve of the form $z = a x^n$ by a least-squares regression analysis. This yields a straight line on a logarithmic (log-log) plot of z versus x. Because $y = xz$, a corresponding relationship can be derived in the form $y = ax^{n+1}$. This also is a straight line on a logarithmic plot of y versus x. Graphs of these two quantities can be used to compare the fuel economy of two furnaces at equal levels of throughput on either a specific or total energy consumption basis. This is illustrated in the schematic figures in Figure 4, which show the form of both linear and logarithmic plots of total energy consumption, specific energy consumption, and efficiency as functions of throughput.

Method for Financial Analyses

The method selected for financial analyses is payback period based on cumulative annual after-tax cash flow. The method includes specified assumptions about useful life of the equipment, investment tax

FIGURE 4. SCHEMATIC LINEAR AND LOGARITHMIC GRAPHS OF FURNACE PERFORMANCE

credit, energy-saving tax credit, tax rate, general inflation rate, and energy-price inflation rate. Fuel savings are determined from the results of analyses of comparative fuel consumption at each site. Depreciation is calculated using the method of double declining balance.

The reasoning leading to the selection of this method for use in the present program, the bases for the various assumptions, and the specifics of the computational method are given in Appendix A--"Method for Financial Analyses".

Fuel-Metering Equipment

Until very recently, few forge shops were concerned with measuring the fuel consumption of individual furnaces. In many plants, the only available records of energy use were the monthly billings from the supplier for the entire facility. Renewed interest in energy conservation has led to an increased demand for compact, inexpensive, and accurate fuel-flow meters for installation on individual furnaces. For natural gas, the most common types are the rotary positive-displacement meter and the turbine meter, either of which can be equipped with a dial-type or digital readout system. In most instances, the cumulative reading is taken in actual cubic feet (acf). In general, this will require correction to yield standard cubic feet (scf). The correction is based upon the simple gas laws to convert to standard conditions of 60 F and 14.73 psia atmospheric pressure. Correction factors for pressure and temperature are:

$$F_p = \frac{\text{Atmospheric Pressure} + \text{Gage Pressure (psig)}}{14.73}$$

$$F_T = \frac{520}{460 + \text{Line Temperature (F)}}$$

Natural gas is usually supplied to the burners of the furnace at low pressure (about 6 to 8 inches of water column or 0.25 psig). If the meter is placed in the supply line at this low pressure, the pressure-

correction factor is small. However, at this low pressure the meter must handle a relatively large volume of gas, and must be sized accordingly. In many plants, gas is supplied at a higher pressure (25 to 30 psig) and is passed through a reducing valve to the furnace. If the meter is placed in the high-pressure line, its capacity is correspondingly increased, because it then is measuring gas at high pressure and thus of higher density. In this way, the meter can be physically smaller and correspondingly less expensive than a meter placed in the low-pressure line. It will, however, be important that the pressure be monitored and that a correction factor be applied.

In some instances, the plant operating personnel have not been made aware of the need for meter-correction factors, and reported only the meter-reading differences. This usually will lead to low apparent energy consumption values, although the comparison between two furnaces may still be valid if both meters operate at the same line pressure.

From the start of this program, data collection was hampered by a shortage of suitable metering equipment at several of the host sites. This resulted in part from increased demands for such equipment by industry generally during the 1980-81 period. In some instances, shops were using existing or reconditioned meters that were of questionable accuracy. Most of these have since been replaced.

RESULTS AND CONCLUSIONS

Specific data and results for each host site are given in Appendix B.

Energy Efficiency Comparisons

At each site, a comparison was made between the specific fuel consumption (Btu/lb of steel heated) for a baseline comparison furnace and for the Hague equipment. It should be pointed out that there are substantial differences among the quality and quantity of data from the host sites upon which the summaries shown in Table 2 are based. Those sites for which only limited operating data were available are marked with an asterisk. For these cases, insufficient data were available to prepare performance curves and the summaries are based on averages only.

TABLE 2. SUMMARY OF FUEL PERFORMANCE DATA FOR HAGUE FURNACES RELATIVE TO BASELINE EQUIPMENT

Host Site	Baseline	Typical Throughput, Lbs. Steel heated per Day	Typical Specific Energy Consumption, Btu/Lb		Typical Hague Fuel Savings		Annual Energy Savings, 10 ⁶ Btu ^(a)
			Baseline	Hague	Btu/Lb	Percent	
Anderson-Shumaker*	Old, unrecuperated box furnace	1,700	7500	8500	-	-	-
Scot Forge-Clinton	Good unrecuperated box furnace (before retrofit)	45,000	3400	2000	1400	41	15,570
Scot Forge-Spring Grove*	None available	70,000	-	1114	-	-	-
Canada Forgings	Old unrecuperated Slot furnace(s)	10,000	8200	4500	3700	45	9,250
E. M. Jorgensen*	Old unrecuperated car-bottom furnaces	80,000	3900	2230	1670	43	33,400
W. Pat Crow	Good unrecuperated box furnace (new)	10,000	2280	1608	672	29	1,680
Reed Rock Bit Company	Rotary furnace (before retrofit)	25,000	6750	3000	2750	55	17,188
K. O. Forge	Old unrecuperated box furnace	13,000	4800	2100	2700	56	8,775
National Flame & Forge*	Old unrecuperated box furnace(s)	40,000	4500	2000	2500	56	25,000
Western Forge & Flange	Old unrecuperated box furnace	7,000	5300	2400	2900	55	5,075
Taylor-Wharton*	Old unrecuperated slot furnace	10,000	5760	2880	2880	50	7,200

(a) (Daily Throughput) x (250 days/year) x (Typical Hague Fuel Savings in Btu/lb).

* Limited Operating data available.

The overall average fuel savings is about 48 percent when Hague furnaces are compared with conventional or baseline furnace equipment. This average does not include the Anderson Shumaker installation nor the Scot Forge-Spring Grove furnace. In the former, the retrofitted box furnace was reported to have used more fuel than an equivalent unrecuperated unit; however, the throughputs were not monitored and the results reported represent estimates furnished to us by Anderson Shumaker personnel without substantiating data. In the Scot Forge-Spring Grove plant, no unrecuperated furnace was available for comparison. It may be noted that the energy used (1114 Btu/lb) for the Hague furnace at that plant is the lowest of those reported, consistent with good operating practice and a high level of daily throughput (70,000 lbs/day).

The relatively low (29 percent) fuel savings for the Hague furnace at W. Pat Crow reflects the comparison with a newly-built state-of-the-art conventional unit, rather than with a typical old furnace. Again, the specific energy consumption indicated (1608 Btu/lb) is among the lower values reported in the program.

Obviously, the choice of furnaces for comparison is very important in determining energy savings. A good argument could be made for comparing the Hague furnace with the most inefficient similar furnace in the shop, i.e., the most inefficient furnace should be the next furnace to be replaced and therefore the object for comparison.

Before leaving the subject of fuel efficiency, it is reiterated that almost all forge-shop operators and management consider high thermal efficiency to be a desirable characteristic of their forge furnaces. However, thermal efficiency definitely is a priority secondary to production schedules, operator convenience, and to matching of the furnace output to the forging process. If maintenance of forging schedules requires a forge furnace to be operated inefficiently, it is operated inefficiently rather than adjusting the forging schedule. In the forge-shop scheme of things, the forge furnace is a reacting device, not a controlling device.

Maintenance Experience and Costs

Early in this program, it was recognized that the relatively sophisticated equipment involved in the Hague recuperative and control system would be likely to involve some incremental added maintenance cost when compared with baseline equipment. It was desired to quantify this added cost so as to incorporate the effect into financial (payback) analyses. Quantification proved to be elusive.

Most forge shops do not keep complete records of maintenance and repair costs on each furnace. Some keep a log of "maintenance labor hours" and some keep a log of "cost of repair parts". Few shops, if any, keep a complete record. In spite of this, management in most shops expressed strong opinions about the relative maintenance costs of different furnaces.

A semi-quantitative pattern emerged in this program. For those Hague units delivered and started up in 1978 and 1979, shop complaints about excessive maintenance costs were common. For Hague furnaces delivered and started up in 1980 and 1981, shop opinions were generally that the incremental maintenance cost was "about normal" considering the added complexity of the equipment. The pattern is understandable, because the early Hague units were in retrospect prototypes introduced to industry to meet the requirements of the acceleration program. However, many purchasers of the early units were not aware of the prototype status and believed that incremental maintenance would be moderate or low.

Hague has recently recognized this pattern. For a gas-fired slot forge furnace, excluding maintenance of hearth and hot-wall refractories, Hague retroactive estimates of historical performance involved annual maintenance and spare-parts costs in excess of \$20,000. Hague forecasts that these annual costs will drop to about \$12,000 in 1982 and to about \$5,000 in 1986.

Reported maintenance problems seemed to center mostly on the short life of the early Hague silicon-carbide recuperator tubes. Problems with recuperator tubes diminished over the 2 years of the program, although data are not complete enough to quantify the degree of improvement.

Another frequently expressed source of maintenance expense has been for components of the Hague burners, some metallic and some ceramic. Over the course of the program, Hague has made modifications and improvements in such parts. The available evidence indicates that this situation has been improved by these changes, but again complete performance history on the upgraded parts is not yet available.

Several installations of Hague-built furnaces suffered from cracking of cast refractories, whereas other installations experienced no such problems. Information about the historical performance and present status of refractory stability of Hague furnaces is too sparse to permit a general conclusion to be drawn. Several plants added ceramic fiber linings to the original Hague units, in some instances under the supervision of Hague field engineers.

Economic Comparisons

The objective of economic comparisons is to evaluate the relationship between the installed costs of Hague recuperative equipment and the value of the fuel saving attributable to the equipment. The basis for comparison was selected to be payback period based on annual after-tax cash flow. The method is described in Appendix A. Examples of its use at specific host sites are given in Appendix B.

When making payback analyses, it is important to maintain chronological consistency, especially during a period of appreciable inflation and changing tax regulations. If 1979 capital costs are used, they should not be mixed in with 1982 fuel prices. Therefore, payback analyses presented in the Interim Report (June 1981) have not been adjusted for changes in prices or regulations since that time. Payback analyses made "after the fact" are susceptible to game-playing. Therefore, the method has its greatest validity and application to analyses made before or at the time of purchase.

Calculated payback periods for Hague equipment at the host sites are summarized in Table 3. It should be recognized that each such calculation is highly individualistic to the particular site and its particular

TABLE 3. SUMMARY OF CALCULATED PAYBACK PERIODS FOR HAGUE RECUPERATIVE FURNACES AND RETROFITS RELATIVE TO BASELINE EQUIPMENT

Host Site	Hague Equipment Installed Cost, \$1000 (Year)	Typical Steel Throughput, lb/day	Payback Period, years
<u>Compared With Nonrecuperative Baseline Equipment</u>			
Reed Rock Bit	78 (1980)	25,000	1-2
National Flame & Forge	350 (1980)	40,000	2-3
Scot-Clinton	65 (1977)	45,000	2-3
Taylor-Wharton	185 (1981)	10,000	2-5
Canada Forgings	91 (1979)	10,000	4
K. O. Forge	140 (1981)	13,000	5
Western Forge & Flange	146 (1981)	7,000	5-6
W. Pat Crow	135 (1980)	10,000	Over 15 ^(a)
Anderson Shumaker	65 (1978)	1,700	_(b)

(a) Based upon comparison with a modern, state-of-the-art furnace. Payback period would have been much shorter if comparisons were made with an old furnace ready for replacement.

(b) No fuel savings indicated; inadequate operating data.

conditions. These are given in more detail for each site in Appendix B. However, two patterns can be seen:

- When the comparison is made between a Hague furnace or retrofit and a typical old unit, payback times are short (1-3 years) when the equipment is used at moderate to high levels of throughput. At low throughput levels, such as at Western Forge and Flange, total annual fuel savings are simply too low to offset the capital cost. This is despite the fact that the fuel saving are high on a percentage basis.
- When the comparison is made between a Hague furnace and a modern well-designed (but unrecuperated) unit, the annual fuel savings are relatively low, thereby extending the payback period (e.g., W. Pat Crow). In fact, there is no question of replacing this unrecuperated furnace with a Hague furnace. A more realistic situation would be the question of which of those two should be selected to replace an old and inefficient unit in that plant. Operating data were not available to make those comparisons, although reasonable estimates of performance of a typical old furnace could be made easily.

Importance of Steel Throughput Rate

The data information collected and analyzed during this program have demonstrated the importance of steel throughput in affecting energy use in forge furnaces. Each of the furnaces in this program usually is operated well below its total throughput capacity, both in terms of the weight of steel it is capable of heating in a given time, and the fraction of time it is operated. This increases specific energy use as measured in Btu's per pound of steel. The effect of utilization rate is about the same whether it occurs in an old "conventional" furnace or in a new recuperative furnace. In some situations, the installation of a new Hague furnace or retrofit has increased capacity such that the operators were able to increase throughput, and thereby improve specific energy consumption still further. An example is the Reed Rock Bit furnace, where average throughput was initially increased from about 25,000 to about 50,000 pounds per day. The corresponding values for specific energy consumption were 6700 Btu/lb

and 1700 Btu/lb (see Figure B-3) which indicates a fuel savings of nearly 75 percent. Of that total, approximately half is the result of improvements to the furnace, and the other half from the increase in throughput. For purposes of comparison in this report, we have made comparisons at a single throughput value even though average throughputs may have changed with the change in equipment.

In other installations, it has not been possible to utilize increased furnace capacity for a number of reasons. These include the lack of sufficient forging equipment to handle an increase in throughput and the depressed condition of forging order books.

Extrapolated Energy Saving

From the information on hand, it is possible to make a rough extrapolation of the potential national energy saving that would be achieved if existing "conventional" forge furnaces were replaced by Hague recuperative units on a large scale. For this extrapolation, it is assumed that the Hague units that would be installed would be equivalent in size, throughput, and energy savings to the average of the Hague furnaces included in this program.

Using the data listed in Table 2, the average of the typical daily throughputs for the Hague furnaces is about 28,000 lbs per furnace, and corresponding fuel savings were about 2350 Btu/lb. Assuming that each furnace is operated for 250 days per year, the average annual throughput is about 7 million pounds or 3500 tons per furnace.

Total U. S. annual production of forgings is estimated at about 3 million tons, of which half is assumed to be produced in facilities with such small furnaces and throughputs that they do not represent reasonable markets for improved furnace equipment. If the remaining half is produced by plants where existing furnaces could be replaced by Hague units, the estimated energy savings would be:

$$\begin{aligned} & (1.5 \times 10^6 \text{ Tons/year}) \times (2000 \text{ Lbs/Ton}) \times (2350 \text{ Btu/Lb}) \\ & = 7.05 \times 10^{12} \text{ Btu/year or } 0.007 \text{ Quad/year.} \end{aligned}$$

This compares reasonably well with the 0.01 Quad/year estimate for the national potential energy savings for forge furnaces made by Office of Industrial Programs.

The 1.5×10^6 Tons/year of production could be handled by about 430 Hague units of the average capacity shown in Table 2. Assuming a typical unit installed price at 1982 levels of \$200,000, the total investment would be about \$86 million. At an assumed fuel cost of \$4 per million Btu, the annual fuel savings for the group would total \$28 million for a payback period of about 3 years.

DETAILED EVALUATION OF HAGUE RECUPERATIVE FURNACE COMPARED WITH NONRECUPERATIVE FURNACE

To supplement the performance comparisons of Hague furnaces and equipment with conventional furnaces under production conditions, a detailed comparison was made under more controlled conditions. Trials were made at W. Pat Crow Forgings, Inc. on a Hague Model 4 slot forge furnace and on a similar unit (without recuperation) designed and built at W. Pat Crow. Two runs were made on each furnace, with loading rates estimated at 50 and 100 percent of rated capacity (from about 900 to 2100 pounds of steel per hour). Steel billets were weighed and heated to forging temperature to provide a measure of useful output, and measurements of gas used were used to compute the energy input. Corrections were made to compensate for time lost in handling billets and for unscheduled delays. Operating data are presented graphically and in tabular form in Appendix C to provide a reasonably complete record of the operating characteristics of both furnaces.

The Hague furnace was shown to be more efficient thermally than the unrecuperated furnace. Under test conditions that most closely simulated operating practice, the fuel savings ranged from about 12 to 29 percent, corresponding with throughputs estimated from 50 to 100 percent of capacity.

Although these percent fuel savings are lower than the average values of Table 2, it should be noted that the comparison here is being made with a modern state-of-the-art unrecuperated furnace rather than an old unit ready for replacement. The specific energy consumption for the Model 4 Hague furnace at W. Pat Crow was among the lowest measured in this program (1600 Btu/lb).

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 similar in principle to that described in the project working paper "Forge Furnace Economics"; December 2, 1980 (previously distributed and approved by project and OIP personnel), and to the method used by Hague International for use in their sales proposals, but differs from both in some matters of interpretation and mechanics.

Why a Payback Method?

Contacts with forging and other 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 in 1981 was directed toward determining the basis on which various companies evaluate economic potential of proposed new energy-conserving investments. These articles also indicated 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 the one most readily understood by operating and engineering personnel employed by forge shops and their suppliers 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 usually 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 fuel saving (because there is no valid 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 the 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 Hague furnace with some other new furnace, both representing 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 saving in fuel cost. This shortcut is taken 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.

There is a precedent for the use of payback as the means to evaluate economic worth of energy-conserving investments. The method was described and used in "Implementation of Energy Conservation Technology in the Steel Industry", Battelle-Columbus to Office of Industrial Programs, DOE, August 1980, Contract No. W7405-Eng-92, Task 116. The method as described there was taken from "Energy Conservation in the Steel Industry", American Iron and Steel Institute, 1976. It was selected because its use by the steel-industry trade association implied its acceptance of the method.

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:

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

Because the annual net cash flow can change from year to year because of changes in factors such as investment credits and escalating costs of energy and general inflation, it is necessary 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. Although some of the formulas given below appear at first glance to be complicated, actually they can be handled rapidly with the simplest of pocket calculators. Such calculations are facilitated by use of a worksheet such as that shown below. For repeated use, the following descriptions are sufficiently general that they can be used to program the method on a small computer.

CONVENIENT FORMAT FOR PAYBACK ANALYSIS

Site:

Average Performance Data

		Case 1	Case 2	Case 3	Case 4
A	Steel throughput lb/day				
B	Fuel use MMBtu/day				
C	Fuel use Btu/lb steel				

Financial Analysis

		Option 1	Option 2	Option 3
①	Total installed furnace cost	\$		
②	Estimated useful life	Yrs		
③	Estimated salvage value	\$		
④	Investment tax credit	\$		
⑤	Energy savings tax credit	\$		
⑥	Assumed applicable tax rate	%		
⑦	Assumed general inflation rate	%		
⑧	Estimated energy cost in Year 1	\$/MMBtu		
⑨	Assumed energy cost inflation rate	%		
⑩	Annual energy savings, MMBtu/year	MMBtu/yr		
⑪	Annual maintenance cost increment	\$		
X	Payback period	Yrs		

Payback Worksheet

Actual year		0	1	2	3	4
⑫	Year number					
⑬	Projected energy cost	\$/MMBtu				
⑭	Fuel cost savings	\$				
⑮	Incr. maintenance cost	\$				
⑯	Net cost savings	\$				
⑰	Investment	\$				
⑱	Depreciation	\$				
⑲	Effect on pre-tax profit	\$				
⑳	Effect on after-tax profit	\$				
㉑	Total tax credits	\$				
㉒	Annual after-tax cash flow	\$				
㉓	Cum. after-tax cash flow	\$				

Total Installed Furnace Cost ①

Total installed capital cost (equipment plus freight and installation) may be relatively easy to determine, especially when a new packaged furnace is under consideration. Even in this situation, however, some equipment has been sold at discounted or promotional price. The influence of the discount needs to be considered, so that the resulting payback period does not mislead other prospective users who may not receive the discount.

In the case of retrofits of existing equipment, the furnace is often modified at the same time that the Hague 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 Hague 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. IRS guidelines for process equipment in SIC 33 permit the useful life to be taken as short as 14.5 years for tax purposes. Because the shortest life permits the fastest write-off for tax purposes and maximizes cash flow, it is assumed that most companies will use 14.5 years for tax purposes, but may use a longer life for book and accounting purposes.

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), unless the estimated salvage value exceeds 10 percent of the total installed capital cost, the consideration of salvage value is neither needed nor appropriate, because the remaining value at the end of the period of useful life exceeds 10 percent of the original capital cost.

Investment Tax Credit (4)

It is presumed that buyers of Hague equipment will apply for and qualify for a 10 percent tax credit on new equipment. When the original capital cost includes both new equipment (such as a Hague retrofit package) 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)

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 10.5 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 20 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 Hague equipment 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 5 percent of the original capital cost, and for future years is escalated at the general inflation rate.

Most sites do not have adequate records to sort out the actual incremental cost of maintenance. In some situations, plants have claimed that the incremental cost has been considerably higher than the 5 percent allowed here. However, some of these higher costs have been incurred because of equipment failures while some Hague components were essentially in the development stage or because of stockpiling of spare parts. On the other hand, under the terms of a DOE/Hague maintenance-service agreement (now terminated), Hague provided some parts and maintenance to some users, so that these costs did not show up in the records of the users.

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:

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

Investment (17)

Investment is taken as total installed furnace cost (1), usually in Year 0, but the method provides for additional investment that may be made in subsequent years.

Depreciation (18)

The double-declining balance method is used to maximize cash flow in early years. This accelerated method has the effect of shortening pay-back time. Annual depreciation is double the straight-line rate. For example, the straight-line rate for a useful life of 14.5 years is $1/14.5 = 0.069$, which is applied each year to the amount of the original investment. For the double-declining balance method, the annual rate for a useful life of 14.5 years is $2/14.5 = 0.138$, which is applied each year to the undepreciated balance. A characteristic of any declining balance method is that after the last year of the assumed useful life, some undepreciated balance remains. For the double-declining balance method, the undepreciated balance is about 11 percent of the original investment. If the equipment is scrapped, salvaged, or sold at this time, the income is applied to the undepreciated balance, and the difference is taken as a profit or loss on sale of equipment. Because of this characteristic, it is not appropriate to deduct estimated salvage value in Year 1 from the amount of the original investment used as the base for figuring accelerated depreciation.

The mathematics for calculation of annual depreciation by the double declining balance method are:

$$\textcircled{18} = \left[\frac{2 \times \textcircled{17}}{\textcircled{2}} \right] \left[1 - \frac{2}{\textcircled{2}} \right] [\textcircled{12} - 1]$$

Effect on Pre-Tax Profit $\textcircled{19}$

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

$$\textcircled{19} = \textcircled{16} - \textcircled{18}$$

Effect on After-Tax Profit $\textcircled{20}$

Annual after-tax profit for each year is calculated as

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

Total Tax Credits $\textcircled{21}$

Tax credits, taken in Year 1, are:

$$\textcircled{21} = \textcircled{4} + \textcircled{5}$$

Annual After-Tax Cash Flow $\textcircled{22}$

For each year,

$$\textcircled{22} = \textcircled{18} + \textcircled{20} + \textcircled{21} - \textcircled{17}$$

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.

Consistency of Data

Within any particular calculation of payback, input data should be chronologically consistent. For example, a furnace purchased in 1980 at 1980 prices should not be evaluated on the basis of operating conditions in 1982 or on the basis of tax or accounting changes made after the furnace was purchased. Payback analysis is essentially a "before-the-fact" technique. When applied retroactively to take account of new incoming data over time, as in this study, the significance of the results decreases with time.

APPENDIX B

DESCRIPTIONS OF HOST SITES, EQUIPMENT, AND RESULTS

May 4, 1982

Forge Furnace Host Site Description

Company Name and Address: Anderson Shumaker Company
824 South Central Avenue
Chicago IL 60644

Contact and Telephone Number: David J. DeLazaro, Manager, Technical Services
James Tribble, Executive Vice President
(312) 287-0874

Brief Description of Forge Shop

Small open-die shop specializing in special alloys such as high-alloy steel, Waspalloy, Inconel, etc. with stock costing \$2 to \$18 per pound. To avoid oxidation of expensive stock, forging temperatures are low (2000 F). Furnace loads are light, with frequent door openings and turnarounds. Operation is 1 shift. During periods of normal business, ship about 1.5 million pounds per year. About 40 employees. Each of any of four forge furnaces feeds stock to any of four hammers. General impression--fuel consumption per pound of steel is high because of method of operation. Box furnaces are operated almost as slot furnaces.

Baseline Furnaces

Shop originally had four home-built aged box furnaces, but with fiber linings installed. One of these (No. 14) was retrofitted with a Hague package. It is normally used in conjunction with a 4000-pound hammer. The other three, all generally similar in size to No. 14, were candidates as baseline furnaces. They are No. 15 (6 million Btu/hr), No. 18 (6 million), and No. 11 (4 million). Data were not collected prior to April, 1981, because all baseline furnaces were unmetered. Fuel is natural gas.

Hague Equipment

Box Furnace No. 14 was retrofitted with a Hague package in January, 1978, but Hague considers the start-up date to be September 1978 when the original recuperator was replaced in its entirety. Fuel is natural gas.

The retrofit consisted of (1) recuperator, (2) four burners rated at total of 6 million Btu/hr, (3) ducting, (4) Oxsen and air/fuel ratio control, and (5) Dresser (Roots) meter. Although Hague originally rated the burners at a total of 6 million Btu/hr, and later as 4 million Btu/hr, in July 1981 forge-shop management volunteered an opinion that 2 million Btu/hr was a more realistic rating. In our opinion, this downrating by the user is probably more a function of his method of operation than an inherent characteristic of the burners.

This is the earliest of the Hague installations included in the present study. Management estimated that the initial cost was \$40,000 for the Hague retrofit package and \$25,000 for installation; a total of \$65,000.

After about 2 years of experience with this installation, Hague recommended that this furnace be converted from 4-burner to 2-burner configuration, but management deferred because of added cost and problems with the present unit.

Management does some routine maintenance on the Hague unit, but periodically has Hague come in to do overhauls. Last overhaul by Hague was in mid-1981.

Fuel

Natural gas from Peoples Gas, considered to be 1000 Btu/cubic foot. Price in January, 1981, averaged about \$3.60/million Btu. Management estimates that gas cost is 4 to 30 cents per pound of forgings. This appears to be about 2 percent of sales price of average forgings. (Both gas consumption and sales price are high.) By early 1982, gas price increased to about \$4.20/million Btu.

Metering of Fuel

Hague furnace equipped from the start with a Dresser (Roots) meter, but at that time no meters on other furnaces. Plant-supply meter of little use because it feeds several heat-treating furnaces and space-heating equipment, as well as the forging furnaces.

In March, 1981, host obtained four reconditioned Dresser meters from Peoples Gas. They were installed on the three baseline box furnaces and a heat-treating furnace.

Maintenance Experience and Costs

Management has complained about inadequate life and low reliability of Hague components (mainly recuperator tubes and burner parts), but did not provide specific costs (because their records are incomplete). Management considers unscheduled shutdowns to be a major component of actual cost. Management considers tube life of 12 months to be necessary for satisfactory performance.

Oxsen and automatic air/fuel control were disconnected some months ago. Because of frequent opening of the large door, the automatic control system was unable to function properly.

Management estimated that for the period January 1978 through August 1981 (44 months), maintenance and repair costs for the Hague components totaled about \$30,000. This averages about \$8,200 per year (annually about 13 percent of original installed cost).

Performance Data

Prior to about June 1981, performance data reported by Anderson Shumaker were incomplete, allowing no conclusions to be drawn. About that time, a full-time professional engineer was hired. He "tuned" the three "conventional" box furnaces. Fuel-limiting orifices were installed, and adjustments were made to hold the air/gas ratio to about 10/1 at all firing rates. Automatic temperature controllers were installed on each furnace to replace former manual control and temperature recording. Similar tuning was not done for the Hague installation, because it had been serviced by Hague at about this time.

In attempting to compare thermal requirements of the conventional furnaces and the Hague-equipped furnace, company personnel encountered a problem because steel throughputs for each furnace were highly variable. For example, a particular furnace would be used to heat 800 pounds of steel one day, and 3500 pounds the next day. Throughput of furnaces was determined by hammer output, not by the heating capacity of the furnaces. Therefore, management decided that comparisons among different furnaces had to be made on a basis of long-term averages.

Two box forge furnaces of similar size and judged to be in "equivalent" service averaging about 1700 pounds of steel heated per day were compared for a period representing about 8 months starting September, 1981. Results were reported as follows:

Hague-retrofitted box furnace (4000-pound hammer)	Avg. 8400 Btu/lb of steel
"Conventional" nonrecuperative box furnace (3500-pound hammer)	Avg. 7500 Btu/lb of steel

Although management regards the apparent inferior performance of the Hague-equipped furnace to be "real", they were unable to explain the reasons for it. No operating data were furnished to Battelle.

Note: Of the situations evaluated in this study, Anderson Shumaker is the only one where the specific fuel consumption of a Hague-equipped furnace was reported to be poorer than that of a

nonrecuperative furnace. Anderson Shumaker specific consumptions of fuel are relatively high, because of the method of operation of all its forge furnaces (frequent reheatings of the same steel) and the sensitive nature of the high-alloy materials being heated.

Indicated Payback Period

No payback time could be calculated, because Hague-equipped furnace reportedly had higher specific fuel consumption than the non-recuperated baseline "conventional" furnace.

May 5, 1982

Forge Furnace Host Site Description

Company Name and Address: Scot Forge Company
Atlas Avenue and Delta Drive
Clinton WI 53525

Contact and Telephone Number: Robert Ploog, Vice President and General
Manager
(608) 676-2288

Brief Description of Forge Shop

Clinton is one of three open-die shops owned by Scot. Attractive building and grounds. Interior is clean, orderly, well-lighted, and spacious. Staff includes knowledgeable professionals.

Product is commercial quality carbon steel forgings. Selling price probably averages about \$0.70/lb. Shop ships about 18 million pounds per year, which means that they probably heat about 22 million pounds to forging temperature (2300 F). Charges to furnaces are billets, blanks for rings, and long bars (that can be longer than the furnaces).

Baseline Furnaces

Clinton has three box furnaces, generally similar in size.

Furnace 5F3 is equipped with a Hague retrofit package.

Furnace 5F7 is a replacement for "old reliable" 5F1, a Scot-built furnace that in spite of its considerable age was relatively efficient thermally when compared with averages in other forge shops. 5F7 incorporates Scot's considerable in-house experience with furnace design and operation. It has a steel shell, lightweight fiber ceramics, six North American high-velocity burners (nonrecuperative), double doors (side-by-side), and state-of-the art air/fuel controls. Cost was about \$100,000. It was placed into operation about February, 1982.

Furnace 5F2 is another Scot "old reliable", currently being rebuilt along the lines of 5F7.

Except for 5F3 (Hague), none of the Clinton box furnaces has recuperative features.

In addition to the three box furnaces, Clinton has a relatively new car-bottom furnace (5F6) with 8 recuperative Hotwork burners totaling a capacity of about 12 million Btu/hr.

Typical operation in forging furnaces is about as follows:

- 6 a.m. Start forging. Furnace charge (average 45,000 lb) at temperature.
- Noon Furnace load has been forged. Shut down fuel.
- 4 p.m. Recharge furnace with steel.
- 9 p.m. Re-light furnace. Full fire 2300 F (requires about 5 hrs).
- Soak to 6 a.m.

Hague Equipment

In December 1977, Scot ordered two identical retrofit packages from Hague at a total cost of \$110,300 (one for Clinton and one for Spring Grove). It was, in the opinion of management, a "ground floor" price that would be substantially higher today. Including freight and installation, management estimated installed cost for the Clinton package as about \$65,000 (1977 cost). Installation date was about June 1978.

The furnace shell was built by Scot with a design similar to the "old reliables" (steel shell, fiber lining, conventional burners). It was operated for a short time as a conventional box furnace prior to retrofit in June 1978. The retrofit included two recuperators, each connected to two burners, ducting, Oxsen, and automatic air/fuel control. Rating is 8 million Btu/hr. Fuel is natural gas. This Hague-equipped box furnace is designated 5F3.

The Hague-equipped box furnace (5F3) was relocated about August-September 1981 as part of a plant-expansion program. At that time, it was given a major rebuild and modernization. Rebuilding included (1) installation of four new Hague "Mark 4" burners with total capacity of 10 million Btu/hr, (3) hearth rebuild, (4) new recuperator tubes, (5) updating of air/fuel ratio electronics, and (6) installation of a new Dresser gas meter. Prior to this time, metering of fuel to this furnace was not dependable, so that resulting data were viewed as questionable both by plant management and by the Battelle investigators.

Fuel

Heating value of the natural gas is 1025 Btu/cu. ft. Prices were \$2.31/million Btu in 1978, \$3.08 average in 1980, \$3.60 in mid-1981, and \$4.00 in May 1982.

Metering of Fuel

All Clinton forge furnaces were equipped from "Day 1" with Rockwell diaphragm meters of dubious accuracy. Therefore, all fuel-consumption data prior to installation of new meters must be viewed with caution.

New Dresser (Roots) meters were ordered by Scot in April 1980, and were delivered March 1981. Eight new meters were purchased by Scot to equip each of the forge furnaces at Scot-Clinton and at Scot-Spring Grove. Installation of the new meters was delayed because of an impending plant expansion and relocation of some furnaces. Meters cost about \$2,600 each, with temperature compensation, no pressure compensation. Installation of the new meters occurred in the period August-September 1981.

Maintenance Experience and Costs

Management provided a log of Hague replacement parts acquired August-November 1978 at no charge through the original warranty (including one set of recuperator tubes). In June 1979, the two recuperators were re-tubed at no charge for parts. In 1979 through 1980, about \$14,000 was paid by Scot for replacement parts, including a number of recuperator tubes provided at no charge in October 1980. These records do not include labor costs. The records are only indicative of the general level of maintenance expense. Management considers incremental maintenance cost as "high but tolerable".

In the period since the Hague-equipped furnace (5F3) was rebuilt in October 1981 through the latest reporting date (May 1982), required maintenance and parts replacement on the rebuilt furnace has been reported to be "virtually zero".

Management at Scot-Clinton volunteered that Clinton's relatively favorable experience with maintenance costs on their Hague equipment is "100% out of phase" with the experience with its "twin" at Scot-Spring Grove, that the reason for this difference is not known, and that the difference is "surprising" because Spring Grove has on its staff a higher level of furnace expertise.

Performance Data

Up through the time of the Interim Report (June 1981), raw data on daily fuel consumption and steel throughput for each forging furnace were being logged routinely by Scot to "maintain discipline". However, because of the questionable gas meters, the fuel-consumption data were considered to be not of sufficient quality to justify detailed analysis.

Prior to the Hague retrofit, however, Scot did sufficient data analysis to convince them that the original furnace had a fuel consumption of about 3.4 cubic feet per pound of steel on 1-shift operation, and similarly determined that after retrofit the fuel consumption under the same conditions was about 2.0 cubic feet per pound. On this basis, management estimated that the retrofit accounted for a saving of about 40 percent. It should be recognized that this saving was obtained over a baseline condition that represented an excellent, fiber-lined, furnace with air/fuel control, but lacking recuperation. Therefore, the saving can be attributed mainly to the recuperation feature of the retrofit.

During the period while the above data were being collected, Clinton was operating 1 shift per day, with average loads of 45,000 pounds in the Hague furnace, about 15 loads per month.

In January 1982, Scot-Clinton provided Battelle with raw data on daily fuel consumption and steel throughput for the period since new meters were installed (September-October 1981) into January 1982 for the rebuilt and modernized Hague unit (5F3). During this period, the furnace was handling charges consisting mainly of bars and billets in the range of 60,000 to 80,000 pounds of steel average per day.

The results of Battelle's analysis of these data are as follows:

	Hague box; 5F3
<u>Weight of steel</u>	
Total, lb. (days)	2,426,259(41)
Avg; lb/day	59,200
<u>Energy rating; mill. Btu/hr</u>	10
<u>Start-up to forging temp.</u>	
Total Btu, million (days)	2,093(41)
Avg. Btu/day, mill.	51.05
Avg. Btu/lb	862

(Continued)

Hague box;
5F3

Start-up to shutdown

Total Btu, million (days)	2,447 (41)
Avg. Btu/day, mill.	59.68
Avg. Btu/lb	1009

Pattern of Daily Use, Avg.

12.5 hr at avg 4.1
mill. Btu/hr =
avg 5.12 mill.
Btu/day

4.8 hr at avg 1.8
mill. Btu/hr =
avg 8.6 mill.
Btu/day

17.3 hr at avg of
59.8 mill. Btu/day

A major conclusion from this analysis is that the Hague-equipped furnace was being operated at exceptionally high thermal efficiency. Part of this is due to inherent characteristics of the furnace, and part is due to the know-how and close supervision being given by Scot management to conservation of energy used by these furnaces.

In May 1982, management of Scot-Clinton provided additional data comparing the operation of the Hague-equipped box furnace (5F3) with the new Scot-built nonrecuperative box furnace (5F7). Data are for the month of April 1982. When comparing these data with the prior performance of 5F3, note must be made of the fact that the charge mix changed between the two sets of data. The earlier data for September-October 1981 into January 1982 for 5F3 (Hague) involved loads of steel bars and billets averaging 60,000 to 80,000 pounds per day. The following data for April 1982 comparing 5F3 (Hague) with 5F7 (Scot nonrecuperative) involve average loads of about 45,000 pounds per day of stock for forging of rings.

	5F3 Hague, Rebuilt Sept. 1981	5F7 Scot, Nonrecuperative Built Feb. 1982
Average load of ring stock, lb/day	40,000-45,000	40,000-45,000
Burner rating, million Btu/hr	10	10
Average specific fuel use in April 1982, Btu/lb	1200	1420

The conclusion from these data is that under these conditions the rebuilt and modernized Hague-equipped furnace had a specific fuel consumption about 15 percent lower than the new Scot-built nonrecuperative furnace. Scot management estimated that current costs to reproduce and install each of these furnaces at 1982 prices would be \$200,000 to \$250,000 for the Hague furnace and \$100,000 to \$150,000 for the Scot furnace.

Indicated Payback Period

The situation at Scot-Clinton is such that a meaningful quantitative estimate of payback period of the Hague components in comparison with a "conventional" furnace is difficult. The Hague equipment was purchased and installed at 1977-1978 prices and costs. Some parts were replaced under warranty. Records on maintenance costs are incomplete. Then in early 1982 the furnace was rebuilt and Hague components were replaced and updated. Fuel consumption data prior to September-October 1981 are suspect. Fuel cost has escalated from \$2.31 (1978) to \$4.00 per million Btu (1982).

Based on early data (1977-1978) shortly before and shortly after the original Hague retrofit (showing a "before" consumption of 3.4 cu.ft./lb and an "after" consumption of 2.0 cu.ft./lb), 180 loads of 45,000 pounds per year, and an average fuel cost of \$3.10 per million Btu, estimated fuel saving was about \$36,000 per year. Discounting this for an apparent \$7,000 per year in incremental maintenance costs, annual net saving attributable to the \$65,000 investment was about \$29,000.

Based on the most recent data (1982) comparing the rebuilt and modernized Hague-equipped furnace (5F3) with the new Scot-built nonrecuperative furnace (5F7) for 45,000 lb/load, 180 loads/year, \$4.00/million Btu, and a fuel saving of 220 Btu/lb, estimated fuel saving was about \$7,000 per year. This saving is attributable to the Hague equipment, which is estimated by Scot management to involve about \$100,000 in additional capital investment (at 1982 prices).

The two comparisons given above indicate that during the period 1977 to 1982, Scot personnel learned to design and build their own nonrecuperative furnaces having exceptionally high thermal efficiency (requiring, say 3400 Btu/lb of steel in 1977 and 1400 Btu/lb in 1982). Thus, Scot-Clinton's "baseline" nonrecuperative furnace has been steadily improving. This performance has reached the point where it is only about 15 percent lower than that for a Scot Hague-equipped furnace that involves about \$100,000 in added investment cost. Under these conditions, the payback period on the additional investment is long, and the economic justification for the Hague equipment is at best marginal.

May 11, 1982

Forge Furnace Host Site Description

Company Name and Address: Scot Forge Company
8001 Wynn Road
Spring Grove IL 60081

Contact and Telephone Number: Wayne Meierdirk, Plant Engineer
Fred Gruber, Staff Accountant
(815) 675-2332

Brief Description of Forge Shop

Spring Grove is one of three forge shops owned by Scot. The Spring Grove building and grounds are attractive. Interior is clean, well-lighted, and spacious. Staff includes knowledgeable professionals.

Forgings are open die and are large--up to 25,000 pounds each and up to 37 feet in length. Most forgings are generally cylindrical. Quality is commercial. Production is in the range of 18 to 25 million pounds per year.

Stock is partially "billets" up to 28 x 28-inch cross section; partially cylindrical ingots from about 20 to 30 inches in diameter. Ingots are cheaper than billets, have lower yield (say 92 percent) because of hot tops, and require slower heating than billets so as to avoid cracking during heating.

Furnace operation at Spring Grove is different from Scot-Clinton. At Clinton, it has been customary for furnaces to be turned off at the end of a day's work. At Spring Grove, furnaces are generally kept hot and in use for about 6 days each week.

The box furnaces at Spring Grove are used in two different ways--as heating furnaces to bring cold stock to forging temperature and as "turnaround" furnaces used to bring forgings in process back up to forging temperature.

Baseline Furnaces

Of the five non-Hague forge furnaces at Spring Grove, two are turnaround box furnaces. Therefore, their mode of operation is not comparable to the Hague furnace, which is used for heating cold stock. The turnaround furnaces are 6F2 (14 million Btu/hr) which is "Scot conventional" (meaning good tight construction and a fiber lining), and 6F8 (4 million Btu/hr), which is also "Scot conventional".

Spring Grove has four furnaces used to heat cold stock, and sometimes to do "turnaround" reheating. They are:

		<u>Nominal million Btu/hr</u>
Box Furnace 6F1	- Hague retrofit (Sept. 1978)	8
Box Furnace 6F3	- Scot-built with Hotwork burners	4
Box Furnace 6F9	- Scot-built with Hotwork burners (about Sept. 1981)	6
Car-Bottom Furnace 6F10	- Contracted furnace with Hotwork burners (about February 1982)	10-12

In the Interim Report (June 1981), the Hotwork box furnace 6F3 was considered to be the best "baseline" available for comparison with the 6F1 Hague-equipped box furnace. Spring Grove does not have any nonrecuperative stock-heating furnaces. Prior to the publication of the Interim Report in June, 1981, both furnaces were being used for essentially the same service. Since the Interim Report, the Hague-equipped furnace has been used mostly for heating billets and the Hotwork-equipped furnace for heating ingots. Thus, the service load on these two furnaces differs.

Hague Equipment

Furnace 6F1 was a "Scot conventional" box furnace. It was retrofitted in September 1979, with a Hague package identical to the retrofit package installed at Scot-Clinton. It consists of two recuperators (each of which supply two Hague burners), and Oxsen fuel/air controls. Normal loads of cold stock are 80,000-100,000 pounds. As at Scot-Clinton, the retrofitted furnace is rated at 8 million Btu/hr.

Fuel

Fuel is natural gas. Price in early 1982 was about \$3.50 per million Btu.

Metering of Fuel

As at Scot-Clinton, forge furnaces were originally equipped with old Rockwell (diaphragm) meters in which management had little confidence. New Dresser meters purchased by Scot were delivered March 1981, but were not installed immediately because of the high priority being given to a shop-expansion program. Fuel-consumption data obtained prior to the date of the Interim Report (June 1981) were indicative of general levels of performance, but were sufficiently uncertain as to be suspect for specific analysis. Fuel-consumption data reported since June 1981 are judged to be reliable.

Maintenance Experience and Costs

Data available from shop records are fragmentary, and not suitable for detailed analysis. The shop office estimated that for the 15-month period from September 1979 through December 1980, costs for replacement parts for 6F1 (Hague) totaled about \$30,000. Plant engineers estimated that incremental maintenance labor costs during the period averaged 50 hours per month.

In April 1982, Scot-Spring Grove management provided data on maintenance labor required for the period January-November 1981. Total maintenance time required for the 11-month period was 785 hours for 6F1 (Hague).

In April 1982, Spring Grove provided Battelle with daily fuel-consumption and steel throughput data for Furnace 6F1 for the month of February 1982. Analyses of these data give the following results:

	6F1 Hague-equipped <u>box furnace</u>
Daily steel throughput, lb	
Range	40,000-180,000
Average	76,843
Average fuel consumption, Btu/lb	1095

These data showed the usual characteristic that smaller loads required higher fuel use per pound of steel. For example, with smaller loads such as 40,000 pounds, specific fuel use was in the general range of about 2000 Btu/lb. With larger loads such as 160,000 pounds, specific fuel use averaged about 700 Btu/lb.

Indicated Payback Period

Because Spring Grove has no "conventional" nonrecuperative stock-heating furnaces, data are not available to compare the Hague-equipped furnace with a conventional furnace. Accordingly, no computation of payback period could be made.

Comment

Management at Scot-Spring Grove is just beginning a head-to-head comparison of the relative performances of all four of its stock-heating furnaces (three box and one car-bottom). Results are expected to be available about the end of 1982.

May 11, 1982

Forge Furnace Host Site Description

Company Name and Address: Canada Forgings
P. O. Box 308
Welland ONT L3B 5P8

Contact and Telephone Number: Gary J. Moskalyk, Plant Manager
(416) 735-1220

Brief Description of Forge Shop

This is a closed-die plant nestled in behind Atlas Steel. CanForge also has an open-die shop in Welland. External appearance is excellent. Internally, facilities are crowded and typical of a job shop.

Plant size is "medium". Shipments in 1980 were about 6.8 million pounds of steel forgings, mostly carbon steel. Plant includes 8 "old" slot furnaces and one Hague slot furnace. Plant has about 95 union workers, about 95 at the other plant, and a total salary force of about 50 persons. It is a short-run job shop with frequent die changes. Plant has operated mostly on one shift, but in 1980 was mostly 2-shift. Quality and nature of forgings probably average. Record-keeping appears to be well above average. This is a good "typical" job forge shop. Management is knowledgeable.

Baseline Furnaces

The eight "conventional" slot furnaces were "home built". Loads from about 800 to 6000 pounds of steel per hour. Newest is about 6 years old. Some of these are metered. Estimated cost of building a new 3500-pound-per-hour conventional furnace is \$30,000 if built by own staff; \$45,000 if contracted (1981 prices).

Two furnaces are of special interest because both have been metered (gas and steel) since August 1979. Furnace 19 is a 2-burner conventional slot furnace that is smaller than the Hague furnace and is used on lighter stock. Furnace 20 is larger than the Hague furnace (top fired with 8 burners in 4 zones) and is used to heat stock heavier than in the Hague furnace. Furnaces 19 and 20 are the closest in operating conditions to the Hague furnace.

Hague Furnace

A Hague Model 4 (4 million Btu/hr; 3500 lb steel/hr) slot furnace was installed August, 1979. It is fired with natural gas and has dual-fuel capability, but has never been used on oil.

At the time of purchase, list price with options was \$81,600 (US), but CanForge paid \$68,000 (US) on a discount basis because the furnace had been built for another customer that did not complete the deal. Transportation and installation costs estimated by management were about \$15,000.

Fuel use and steel weights were monitored daily from August 27, 1979, through January 14, 1980. This was discontinued when the meter failed.

Fuel

Natural gas is taken to have a fuel value of 1025 Btu per cubic foot. In early 1980, gas cost was reported to be about \$2.00 (US) per thousand cubic feet, and in early 1981, about \$2.25 (US).

Metering of Fuel

For 2 years, CanForge monitored fuel consumption daily on Furnaces 17 (Hague), 19, and 20 using Dresser meters with readings corrected for line pressure. Following the failure of the meter on the Hague furnace in January 1980, a replacement meter was requested from Hague. The replacement was received on a loan basis from Hague in March, 1981, was immediately installed on the Hague furnace, and daily monitoring was resumed.

Maintenance Experience and Costs

In early 1980, management reported that Hague estimated that annual costs for replacement parts would be about \$6900 (US) for the Hague furnace. Actual costs were running higher. With gas at \$2.00 (US) and 1-shift operations, management projected annual fuel savings at \$7192. This is low because the furnace is operated at less than half of its rated throughput in pounds per hour, gas price was relatively low, utilization of all furnaces is low because of frequent downtime for changes of dies and steels, and about 5 to 10 percent of downtime is scheduled for furnace maintenance. In one quarterly period, labor cost for maintenance on the Hague furnace was \$4920. On balance, management considered incremental maintenance costs to be higher than annual fuel savings.

In early 1981, management estimated that annual incremental costs for replacement parts and labor were about \$10,000 - \$12,000. Based on experience to date, management had the following expectations for parts needs:

Hot tubes (12 in first two rows): Two sets per year at \$200 per tube = \$2400 per set; \$4800 per year.

Rear tubes (12 in second two rows): One set per year, say \$2400.

Burner tips: Replace 2 tips 4 times per year, say \$1000.

Slot-closure doors: Life has been 3 months. Four sets per year will cost \$4800.

In September 1981, CanForge supplied Battelle with a log of major maintenance and parts replacement for the Hague furnace in the period November 1979 through July 1981. Unfortunately, there is no log of associated expenses, but the costs probably exceed the projected estimate of about \$7,000 per year. A considerable amount of work went into door replacement (at least 5 times) before CanForge designed and installed doors (stainless steel) of their own design. The ethylene glycol door-cooling system caused recurrent problems and shutdowns, and at least two fires, until CanForge replaced it with an air-cooled system of their own design. Recuperator tubes were replaced at least twice. Burner tiles and tips were replaced a number of times.

Preliminary Performance Data

Furnace 17 (Hague) replaced two smaller older furnaces that were in poor condition. Over a test period of 1 week prior to removal, the old furnaces consumed about 7450 Btu per pound of steel. The Hague furnace on the same job consumed about 4200 Btu/lb. This was a decrease of 44 percent, but the basis was two small old furnaces ready for scrapping.

For the period August 27, 1979, through January 14, 1980, CanForge monitored steel throughput and fuel consumption daily on Furnace 17 (Hague), Furnace 19 (smaller than Hague and used on lighter stock), and Furnace 20 (larger than Hague and used on heavier stock). The raw data were provided by CanForge to Battelle for analysis. Results are presented graphically in Figures B-1 and B-2.

FIGURE B-1. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT: CANADA FORGINGS (1980 DATA)

FIGURE B-2. TOTAL ENERGY CONSUMPTION VS. THROUGHPUT: CANADA FORGINGS (1980 DATA)

Late in 1981, CanForge supplied Battelle with data on daily steel throughput and fuel consumption for each of these three furnaces for the period May into November 1981. From analysis of the 1981 data and comparison with the 1980 data it is apparent that:

- Average daily throughput of steel increased from 1980 to 1981 by about 62 percent for each of the three furnaces.
- For each of the two nonrecuperative furnaces, specific fuel consumption per pound of steel heated was reduced by about 26 to 29 percent from 1980 to 1981. This was about the amount of decrease expected to result from the higher throughput, as given in Figure B-1 (which is taken from the 1981 Interim Report). That is, each of the two nonrecuperative furnaces performed in 1981 as it did in 1980, and as predicted in the Interim Report.
- For the Hague furnace, specific fuel consumption per pound of steel heated decreased by only about 8 percent from 1980 to 1981. This decrease was lower than was expected to result from the higher throughput, as given in Figure B-1. That is the Hague furnace did not perform with as high an efficiency in 1981 as in 1980. CanForge management confirmed this from their own observations, but did not offer any opinion to explain the result, other than to observe that the Hague installation was undergoing gradual deterioration.

Data pertinent to the above observations are as follows:

	<u>1980 Data</u>	<u>1981 Data</u>	<u>Change, 1980-1981</u>
Steel throughput, avg. lb/day			
Fce 19 (nonrecup.)	4,000	6,500	+62%
Fce 17 (Hague)	8,000	13,000	+62%
Fce 20 (nonrecup.)	20,000	32,000	+60%
Specific Fuel Consumption, avg. Btu/lb			
Fce 19	10,000	7,400	-26%
Fce 17 (Hague)	3,700	3,400	- 8%
Fce 19	7,000	5,000	-29%

Because one of the nonrecuperative furnaces (No. 19) at CanForge is smaller than the Hague furnace and is used on smaller loads and lighter stock than the Hague furnace, and the other nonrecuperative furnace (No. 20)

is larger and is used for heavier loads and heavier stock, it is not possible to determine the relative performance of the Hague furnace by direct comparison. Therefore, resort has been made to the idea of a hypothetical "Furnace 19.5" which is nonrecuperative, larger than Furnace 19, and smaller than Furnace 20. The probable performance of this hypothetical furnace was established by interpolation of data on the performances of nonrecuperative baseline furnace of the same size and throughput of the Hague furnace, using CanForge conditions of operation.

Furthermore, performance curves for each of the three real furnaces and the hypothetical furnace were used to estimate specific fuel consumptions in 1980 and 1981 for each of the furnaces at an average throughput rate of 10,000 lb/day. Results were as follows:

	<u>Estimated Average Specific Fuel Consumption at Average Steel Throughput of 10,000 lb/day</u>		
	<u>1980 Data</u>	<u>1981 Data</u>	<u>Change, 1980-1981</u>
Fce 19 (nonrecup.)	4,700	5,000	+6%
Fce 17 (Hague)	3,000	4,500	+50%
"Fce 19.5" (hypothetical nonrecup.)	8,100	8,200	+1%
Fce 20 (nonrecup.)	11,000	11,000	0%

This analysis confirmed the prior observation that the Hague furnace yielded a substantial fuel saving of about 63 percent when compared with the hypothetical baseline furnace ("Furnace 19.5") using 1980 data (as given in the Interim Report). However, when 1981 data are used, the saving attributable to the Hague furnace declined to about 45 percent. This 45 percent is consistent with the first tests by CanForge when they reported (as mentioned above and in the Interim Report) that a 1-week test on the old furnace that was replaced by the Hague furnace averaged 7450 Btu/lb on the same work that the new Hague furnace averaged about 4200 Btu/lb--a fuel saving of 44 percent attributable to the Hague furnace.

Indicated Payback Period

Indicated payback period was calculated for 1980 data for the situation where the Hague furnace (No. 17) is operated at an average rate of 10,000 pounds of steel per day, 250 days per year (2.5 million pounds per

year), and is compared with a similar rate of production in "Furnace 19.5". The installed cost of the Hague furnace is based on the list price, not the discounted price. The cost of energy is taken at the Canadian level (\$2.00 U.S. in 1980) escalated at 20 percent annually. The tax and tax credits are taken to be the same as in the U.S., and are the same as used in other payback analyses in this study. All funds are converted to U.S. dollars.

Under these conditions (using 1980 data), the indicated payback period is 4.2 years, as shown in the accompanying tabulation. If 1981 performance data were used for both the nonrecuperative and the Hague furnaces, payback period would be almost doubled.

HAGUE SLOT FURNACE AT CANADA FORGINGS

Selected Performance Data (1980)

- A. Steel throughput, lb/day
 B. Fuel use, MM Btu/day
 C. Fuel use, Btu/lb Steel

Furnace 17 (Hague)	"Furnace 19.5"(a) ("Conventional")
10,000	10,000
30	81
3000	8,100

Financial
Analysis^(b)

① Total installed furnace cost, \$	91,000 ^(c)
② Estimated useful life, years	14.5 ^(d)
③ Estimated salvage value, \$	(e)
④ Investment tax credit, \$	9100 ^(d)
⑤ Energy saving tax credit, \$	9100 ^(d)
⑥ Assumed tax rate, %	46 ^(d)
⑦ Assumed general inflation rate, %/yr.	10.5 ^(d)
⑧ Estimated energy cost in Year 1, \$/MM Btu	2.00
⑨ Assumed energy cost inflation rate, %/yr.	20 ^(d)
⑩ Annual energy saving, MM Btu/yr	12,750 ^(f)
⑪ First year maintenance cost increment, \$	10,000 ^(g)
X Payback period, yrs.	4.2

- a. See text for description of "Furnace 19.5".
 b. Converted to U.S. \$.
 c. At list price, not discounted price.
 d. Taken to be same as U.S.
 e. Not required for accelerated depreciation.
 f. (81-30) MM Btu/day x 250 days.
 g. Hague estimate + 50% for labor.

May 17, 1982

Forge Furnace Host Site Description

Company Name and Address: Earle M. Jorgensen Company
8531 East Marginal Way South
Seattle WA 98124

Contact and Telephone Number: John LaVillette, Energy Manager
(206) 762-1100

Brief Description of Forge Shop

This is an open-die shop (mostly presses) devoted to forging, machining, and heat treating of ingots that are produced mainly in Jorgensen's neighboring electric-arc steelmaking shop. Ingot sizes are from about 4000 to 128,000 pounds each. Total throughput is about 86 million pounds of ingots per year. Typical operation is 2 shifts per day, 6 days per week.

Usual method of operation involves charging a load of ingots into a hot furnace, bringing the ingots up to temperature, soaking, and then removing ingots as needed in the forging operations. The furnaces may be used for both heating of ingots, for reheating in process (turnaround), or both at the same time.

The forge furnaces of interest operate on long and different cycles, so that gas-meter readings are taken once per week.

Data collection involves a problem of measuring steel throughput. There are several different steel weights involved, (1) ingot weight, (2) cropped weight, (3) weight of forging, and (4) shipping weight (a high percentage of the forgings is machined prior to shipment). Lacking information on the ratios between these weights, and specific weights charged to particular furnaces both for original heating and for turnaround, recourse must be made to estimates provided by plant personnel.

Baseline Furnaces

The shop contains 13 forge furnaces of various sizes and types, plus some "low-temperature" (1300 to 1700 F) furnaces.

Four car-bottom furnaces are of particular interest in the present study. They were originally identical (15 x 30 x 10 feet), built about 1964 by J. T. Thorpe. They are rated at 25 million Btu/hr, and designed for loads

of about 100 tons, but typical loads average about 80 tons. They are brick-lined and equipped with North American burners. The heating rate is about 100-120 F per hour (with cold loads charged to a hot furnace). One of these furnaces has been retrofitted with a Hague package. The other three are available as baseline furnaces. Some data provided by Jorgensen was derived from Furnace F-21, which is one of the three car-bottom baseline candidates. The physical condition and tightness of the baseline furnaces is not good.

Hague Equipment

One of the originally similar car-bottom furnaces (F-25) was retrofitted about December 1979, with a Hague package by Hague on a turnkey contract. The retrofit included two top-mounted Model 12 recuperators (each with 60 tubes), five burners (Model 275-7200), Oxsen system, and individual burner-management controls on each burner.

Although the original furnace (before retrofit) was rated at 25 million Btu/hr, the retrofitted furnace was downrated to 15 million Btu/hr. Early in its operation it was found to fire at a maximum rate of 13 million Btu/hr. This gave too slow a heating rate--about 40 F per hour instead of the desired 100-120 F per hour. Although Hague made adjustments to improve the heating rate, this furnace has a lower heating rate than its companions. Also, it is generally maintained in better condition than its companions. It is inspected periodically and adjusted by Hague.

During the summer of 1981, a ceramic-fiber lining was installed in Furnace F-25.

Fuel

The baseline and Hague furnaces are fired with natural gas. The Hague furnace (F-25) has dual-fuel capability, and was operated on oil for a period of 2 weeks to test this capability. Gas price as of February 1981, was said to be about \$4.20 per million Btu, and \$5.50 as of May 1982.

Metering of Fuel

Each of the four car-bottom furnaces of interest (and others) is equipped with an American rotary gas meter. These meters (about 26 total) were purchased by Jorgensen from the local gas utility. They were judged by the utility to be no longer satisfactory for utility use, were reconditioned, and were sold to Jorgensen. Battelle has not been able to establish the degree of accuracy and reliability of the meters being used to provide performance data.

Maintenance Experience and Costs

No detail has been provided by the host site. Personnel there have estimated on two different occasions that annual total maintenance cost for the recuperators, burners, and control system is \$10,000-\$25,000. This level of cost is contested by Hague personnel who contend that replacement parts included in the Jorgensen estimate are still in inventory at Jorgensen.

As of June 1981, Jorgensen continued to report problems with short life of burner tips (about 6 months per set).

In addition to the costs mentioned above, Jorgensen personnel said that there is an additional large cost because of lost production time. Once per quarter, seven days have been lost during inspection periods--5 days to cool the furnace and 1 or 2 to reheat it. In addition, there have been unscheduled shutdowns, mainly because of burner problems.

Jorgensen reported that the performance of the F-25 furnace deteriorates between quarterly inspections. Immediately after inspection and adjustment, average fuel consumption over 168 hours (1 week) was about 5.2 million Btu/hr (including periods of high fire and low fire). Three months later, fuel consumption for essentially similar service increased to about 6.7 million Btu/hr. Hague personnel contend that under the Jorgensen conditions the air/fuel ratio system requires adjustment monthly to maintain efficiency.

As of May 1982, Jorgensen management reported that maintenance costs for the Hague equipment continue to be high, but provided no specifics other than to state that delays and downtime have been incurred because of long lead times to obtain replacement recuperator tubes from the manufacturer.

Performance Data

During February 1981, Jorgensen provided the following data for the Hague-equipped furnace and a baseline furnace:

	<u>Btu per pound of steel</u>	
	<u>Fce F-25</u>	<u>Fce F-21</u>
	<u>(Hague)</u>	<u>(Baseline)</u>
November, 1980	2400	7700
December, 1980	1700	4800
January, 1981	<u>2600</u>	<u>3100</u>
Average	2230	5200

In the opinion of management, because of the method of operation of these furnaces, the most valid comparison is based on averages over the 3-month period. On this basis, the Hague furnace consumed 57 percent less gas per pound of steel than the baseline furnace.

However, the results above are influenced by the unusually high specific fuel consumption of 7700 Btu/lb for baseline Furnace F-21 in November 1980. In September 1981, Jorgensen reported that F-21 over the 4-month period December 1980-March 1981 had an average specific fuel consumption of about 3900 Btu/lb. ("High Temperature Waste Heat Recovery Systems"; S. Young, S. Hawkes, and J. LaVillette; Proceedings of the 1981 International Gas Research Conference, September 28-October 1, 1981; Los Angeles, California.) On this basis, the Hague-retrofitted furnace consumed about 43 percent less gas per pound of steel than the baseline furnace.

Management also made the point that part of the difference is accounted for by the fact that F-25 is maintained structurally better and with less leakage than F-21. The package of Hague equipment does not account for the full amount of the 57 percent saving. In the opinion of management, the Hague equipment per se was responsible for a fuel saving of "about 30 percent" based on F-21 and the other baseline furnaces.

On the other hand, Hague personnel point out that although F-25 leaks less than F-21 on the average, leakage from F-25 is so high that only a portion of the combustion gases pass through the recuperator. This penalizes the heat-recovery system for reasons that have nothing to do with the heat-recovery system.

As of the date of the Interim Report (June 1981), Battelle expected that additional performance and economic data would be provided by Jorgensen. Repeated contacts were made to expedite this, but no useful additional quantitative data were obtained.

Indicated Payback Period

Insufficient information. Jorgensen considers purchase price and other financial information to be proprietary.

In September 1981, Jorgensen and Hague reported that Jorgenson "is satisfied that the Hague International recuperative system payback (before taxes) is approximately 1.5 years". (Ibid; Young, Hawkes, and LaVillette.) No data were provided as the basis for this statement.

May 17, 1982

Forge Furnace Host Site Description

Company Name and Address: W. Pat Crow Forgings, Inc.
P. O. Box 1720
200 Luxton Street
Fort Worth TX 76101

Contact and Telephone Number: John Westmoreland, Chief Engineer
(817) 536-2861

Brief Description of Forge Shop:

This company is mainly a supplier to the aircraft industry. They still produce some run-of-the-mill steel forgings, but these are not being encouraged because they are low-profit items. Metals forged include carbon, alloy, and stainless steels; titanium alloys; and aluminum alloys. Their average selling price for steel is about \$2.00-\$2.50 per pound, as compared with less than \$1.00 for conventional steel forgings. The facility includes an "old" forging shop and a "new" shop.

The old shop is typical of many older installations. It has a dirt floor and a low roof, and is equipped with steam forge hammers and conventional heating furnaces.

The new shop, built at a cost of about \$1.6 million, is large, high-ceilinged, well-lighted, and insulated. It contains two new Hague slot furnaces located near two large air-driven forge hammers. The compressors are located at the other end of the building, and furnish hot (380 F) air to the hammers through insulated lines.

Baseline Furnaces

The old shop includes about six conventional slot furnaces used to heat steel (plus a number of other furnaces). At least one of the old steel slot furnaces has recently been rebuilt with ceramic fiber insulation, and others will be rebuilt.

Hague Equipment

The new shop includes two Hague slot forge furnaces.

The Hague Model 4 furnace (4 million Btu/hr) became operational about August 1980. It is usually run on two 8-hour shifts per day. Reported performance has been good, but, because of lack of a gas meter, performance data were not obtained until late in the program.

The Hague Model 5 furnace (4.5 million Btu/hr) was delivered before the Model 4 furnace, but was not placed into operation until about January 1981, because the furnace was delivered with too small a recuperator and a brick hearth rather than the specified steel hearth. A replacement recuperator was fabricated and supplied by Hague, and the hearth was replaced. Although this furnace was provided with a Dresser (Roots) meter, no significant data were provided, because of the lack of a meter for a baseline furnace.

Fuel

Fuel for all forge furnaces is natural gas. Price in November 1980 was \$2.50 per 1000 cubic feet, and in September 1981 was \$2.75.

Metering of Fuel

The availability of gas meters hampered data collection at this site. None of the potential baseline furnaces was metered. The one Dresser meter installed on the Model 5 Hague furnace was unused for a long period because the furnace was not operating. The Model 4 Hague furnace that was operating was not equipped with a meter. Attempts by site management to obtain meters from the local gas utility or from Hague were unsuccessful.

In July 1981, Battelle purchased two new Dresser (Roots) gas meters for loan to Crow. This was done because (1) the Crow site offered good potential for obtaining performance data, but data were not being obtained because of a lack of meters; and (2) the Crow site was selected for a special more-detailed furnace-comparison analysis, as described in Appendix C of this report.

Maintenance Experience and Costs

No data.

Performance Data

The Crow management was cooperative, but for most of the period of this study comparative data could not be provided because of the lack of meters. Even after two meters were purchased and loaned to Crow (July 1981), shop-type production data were not obtained. There were two reasons for this--(1) About the time that the meters became available, the work load dropped off so that furnace use became erratic and sporadic, not suitable for the generation of good data, and (2) the two new meters were used as the basis for the more-detailed test described in Appendix C.

From the special test conducted at Crow and described in Appendix C, it is possible, however, to compare the performance of Crow's Hague slot furnace Model 4 with the performance of a nonrecuperative furnace built by Crow. Two runs were made in each furnace; one run at roughly 50 percent of the rated throughput of the furnace and the other at about 100 percent of the rated throughput.

Under both conditions, specific fuel consumption (Btu/lb of steel) was lower for the Hague furnace. But the degree of difference between the two furnaces was influenced significantly by (1) the throughput rate and (2) the basis on which the specific fuel consumption was calculated. Results are summarized as follows:

	<u>"Net" Basis^(a)</u>	
	<u>Hague, recuperative</u>	<u>Crow, nonrecuperative</u>
<u>At "50% of Capacity"</u>		
Net steel heated, lb/hr	1733	895
Net specific fuel consumption, Btu/lb	3694	4223
<u>At "100%" of Capacity"</u>		
Net steel heated, lb/hr	2133	1735
Net specific fuel consumption, Btu/lb	1608	2280

(a) "Net" includes startup fuel for cold furnace and adjusts for delays in the test program.

With the lower rate of throughput ("50% of capacity") and on a "net basis", the Hague furnace used 12 percent less fuel per pound of steel than the Crow furnace. At the higher rate of throughput, the Hague furnace consumed 29 percent less fuel per pound of steel than the Crow furnace.

	Basis of "Net Minus Startup" ^(b)	
	<u>Hague, recuperative</u>	<u>Crow, nonrecuperative</u>
<u>At "50% of Capacity"</u>		
Specific fuel consumption, Btu/lb	1972	2715
<u>At "100% of Capacity"</u>		
Specific fuel consumption, Btu/lb	1058	1790

-
- (b) The basis "Net Minus Startup" approximates the performance expected if each furnace were to be operated continuously, so that the influence of startup fuel is minimized.

With the lower rate of throughput and neglecting startup fuel, the Hague furnace consumed about 27 percent less fuel per pound of steel than the Crow furnace. At the higher rate of throughput and neglecting startup fuel, specific fuel consumption in the Hague furnace was about 41 percent lower than for the Crow furnace. This latter saving attributable to the Hague furnace (40.9 percent) indicates what is possible if full advantage could be taken of the energy-conserving features inherent in the Hague furnace. However, production conditions at Crow are such that this has not been possible.

Details of these special tests at Crow are given in Appendix C of this report.

Indicated Payback Period

When the Hague furnace and the Crow nonrecuperative furnace are compared on the basis of heating 4000 pounds of steel per day (roughly "50% of capacity"), specific fuel consumptions were about 2600 and 3800 Btu/lb,

respectively, a saving of 1200 Btu/lb for the Hague furnace (from Figure C-15 in Appendix C). For 250 days per year and fuel at \$3.00 per million Btu, this represents a fuel saving of about \$3600 per year for the Hague furnace.

When the two furnaces are compared on the basis of 7500 pounds of steel per day (roughly "100% of capacity"), specific fuel consumptions were about 1500 and 2200 Btu/lb, respectively, a saving of 700 Btu/lb for the Hague furnace (from Figure C-15). For 250 days and \$3.00 fuel, this represents a fuel saving of about \$3900 per year for the Hague furnace.

Crow management estimated in May 1982 that the installed costs of the two furnaces under discussion were about \$135,000 for the Hague furnace and about \$45,000 for the Crow nonrecuperative furnace. On this basis, the incremental cost for the Hague equipment is about \$90,000. Considering the manner in which Crow uses their furnaces, and the high degree to which they have developed their own ability to build efficient nonrecuperative furnaces, the payback period for the incremental cost of Hague recuperative equipment clearly is very long--well in excess of 15 years.

Forge Furnace Host Site Description

Company Name and Address: Reed Rock Bit Company
6501 Navigation Blvd.
P. O. Box 2119
Houston TX 77001

Contact and Telephone Number: Kevin T. Daly, Engineering Dept.
(713) 924-5517

Brief Description of Forge Shop

This is a relatively modern shop with knowledgeable operators and management. Normal output is about 11,000 tons of product per year. By far, most of the product is steel forgings for rock bits. Three rotary forge furnaces, one of which has been modified and retrofitted with a Hague package, are used in conjunction with three closed-die presses. Billets are generally 3 to 5 inches square, and weigh about 10 to 45 pounds. Production is generally on a 2-shift basis. Forging temperatures are 2200 to 2350 F.

For a typical 30-day period in April-May, 1980, analysis by plant personnel shows that the mode of operation of the furnace that was subsequently modified and retrofitted was about as follows:

	<u>Percentage of total time</u>
Total run time	26.0
Set up/reset	9.5
Idle (furnace on)	1.5
Idle (furnace on-third shift)	22.2
Idle (furnace off-weekend- holiday)	<u>40.8</u>
	100.0

A description of the Hague retrofit package on one of Reed's rotary-hearth forge furnaces was presented to the Third Annual Industrial Energy Conservation Technology Conference, Houston, April, 1981. It was titled, "A Ceramic Waste Heat Recovery System on a Rotary Forge Furnace: An Installation and Operating History", by T. M. Worstell (Reed), T. E. Campbell (Hague), and S. B. Young (Hague).

Baseline Furnaces

The three rotary-hearth furnaces at Reed are as follows:

- Hagen furnace (old). Shop identification number FR-907. 11 ft 6 in. ID. Fiber lining installed September 17, 1979. Interior wall removed and retrofitted with Hague equipment November, 1980. Rated at 8 million Btu/hr before and after retrofit.
- Salem-Brosius furnace (old). 17 ft 3 in. ID. 16 million Btu/hr.
- Kozma furnace (old). 21 ft ID. 16 million Btu/hr.

Hague Equipment

Following refractory repairs, installation of ceramic fiber lining, and installation of a gas meter in September 1979, Reed monitored fuel consumption and steel throughput of Furnace FR-907. At the time of retrofit with the Hague package in November 1980, structural modifications were made to remove an interior furnace wall to increase steel capacity. Subsequent changes in fuel efficiency are attributable to some combination of the two changes made at the same time; (1) change in the furnace structure, and (2) installation of the Hague waste-heat recovery system.

The Hague recuperator on Furnace FR-907 is a single-pass recuperator containing 60 tubes. The face is 12 tubes wide, and there are 5 rows; the first row of smooth tubes and four rows of finned tubes. The five Hague burners are rated two at 1 million Btu/hr and three at 2 million Btu/hr. The retrofit package includes a zirconium oxide air/fuel ratio control that is being used as a sensor; control is manual.

Since the retrofit, Reed has monitored fuel consumption and steel throughput on Furnace FR-907, and has provided the raw data to Battelle for analysis.

Fuel

The fuel is natural gas provided by Lone Star Gas in 1981 at about \$2.91 per million Btu. Heating value is 1020 to 1060 Btu per cubic foot.

Metering of Fuel

Furnace FR-907 was equipped with an American 3.5 CVM gas meter in mid-1979. It is the only one of the three furnaces that is metered. The meter is calibrated quarterly by an outside contractor of good reputation. The meter was provided by Reed.

Maintenance Experience and Costs

No major problems with recuperator. Continuing problems with deterioration of burner parts, requiring periodic shutdowns for maintenance and repair.

Performance Data

At the time of installation of the Hague heat-recovery package on Furnace FR-907, the furnace was also modified by removing a center wall. This permitted an additional row of billets to be charged. The combination of the retrofit and the modification resulted in two effects:

- More steel could be and was loaded and heated per day
- Energy consumption per pound of steel and per day were lowered.

In the previously referenced paper by Worstell, et al., it was reported that average monthly gas consumption for October and November 1979, and for April and May 1980, all before retrofit and modification was about 2.87 million cubic feet. After retrofit and modification, for December 1980, January and February 1981, monthly average gas consumption rationalized to about the same throughput of steel was about 1.62 million cubic feet. These data were for overall operation of the furnace, including overnight idling and idling during shift changes. It should be recognized that another change that occurred from before to after the retrofit was increased production rate, which is not reflected in these average results on fuel consumption. For this set of conditions, average fuel saving per day was about 43 percent.

In the same paper, results were given in terms of first-shift actual running times and throughputs. The respective results before and after retrofit and modification were 3921 and 1798 Btu per pound of steel, showing an energy saving of 54 percent when most of the influence of idling time was neglected.

Reed personnel provided their raw data covering daily steel throughput and daily gas consumption on Furnace FR-907 to Battelle for independent analysis. Data covered two periods:

- April 23 through May 22, 1980; "before retrofit and modification"
- December 1980 and January 1981; "after retrofit and modification".

Most of the "before" data were for 2-shift operation, and most of the "after" data were for 3-shift operation, to take advantage of the higher hearth capacity and faster heating of the modified and retrofitted furnace. Fuel heating value was taken as 1050 Btu per cubic foot. Daily results for steel throughput and gas consumption (including idling periods) were plotted individually and regression parameters were determined. The number of good-quality data points was 22 for the "before" situation and 8 for "after".

The results of the Battelle performance analysis to date (shown on the attached graphs, Figures B-3 and B-4) show that:

- The average daily throughput of steel increased from 25,060 pounds "before" to 50,600 pounds "after".
- The average energy consumption decreased from 6749 Btu per pound of steel "before" to 1707 Btu/lb "after". This large decrease includes the effects of both higher thermal efficiency of the furnace and a doubling of average daily steel throughput.

The performance results to this point were presented in the Interim Report (June 1981). For the "before" condition, the specific fuel consumption as determined here from Reed data (6749 Btu/lb) was considerably higher than that reported by Worstell et al in 1981 (3921 Btu/lb). However, for the "after" condition, agreement is good (1707 Btu/lb compared with 1798 as reported by Worstell et al).

In January 1982, Reed provided Battelle with additional fuel-consumption data on the modified Hague-retrofitted furnace covering the period October 22 to December 4, 1981. During this period, Reed shop and engineering personnel estimated that average steel throughput during steady peak operation was about 2250 lb/hr. Estimation of throughput was necessary because Reed was not able to provide actual daily throughputs of steel through each furnace. However, for the earlier period April 1980 through January 1981 (as reported above) they were able to extract this information from daily payroll records.

Analysis of the latest data (October to December 1981) shows that for 7-hour runs (15,750 lb/day) average specific heat consumption was about 4100 Btu/lb. For 17-hour runs (38,250 lb/day), average specific heat consumption was about 5100 Btu/lb. Each of these conditions involved considerably lower daily throughputs and considerably higher specific fuel consumptions than for the test period given in the Interim Report (Figure B-3). However, extrapolation of the Hague-retrofitted data in Figure B-3 down to a daily throughput of 15,750 lb/day would predict an average specific fuel consumption of about 4400 Btu/lb. This is consistent with the latest data for 7-hour runs (about 4100 Btu/lb).

FIGURE B-3. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT: REED ROCK BIT COMPANY (LATE-1980 AND EARLY-1981 DATA)

FIGURE B-4. TOTAL ENERGY CONSUMPTION VS. THROUGHPUT: REED ROCK BIT COMPANY (LATE-1980 AND EARLY-1981 DATA)

The most recent data on 17-hour runs (about 5100 Btu/lb at 38,250 lb/day) reveal fuel consumptions much in excess of predictions based on earlier data. For 17-hour runs, the most recent data show specific fuel consumptions about the same as the average for 38,250-pound days before the furnace was modified and retrofitted (Figure B-3). This unexpected result may be caused by (1) a major change in the mode of operation of the furnace and/or (2) a major inaccuracy in the Reed estimation of actual steel throughput in 17-hour runs.

Combining all of the available performance data, it is clear that the modification and retrofitting of this furnace demonstrated a capability to obtain specific heat consumptions at a level of about 1700 Btu/lb, but that the mode of operation in late 1981 and early 1982 has been such that actual heat consumptions averaged as high as about 5100 Btu/lb, about the same as was obtained before modification and retrofit. The Reed case history is an excellent example to show that the mode of operation of a furnace can influence average thermal efficiency more than the particular design of the furnace (recuperative or nonrecuperative).

Indicated Payback Period

For the purpose of financial analysis, average performance of Furnace FR-907 before modification and retrofit was taken to be 25,000 pounds of steel per day, 167 million Btu/day, and 6700 Btu per pound of steel. After modification and retrofit, averages of capability were taken to be 50,000 pounds of steel per day, 85 million Btu/day, and 1700 Btu/lb of steel.

Because of the wide disparity in production rates, the financial analysis was based on a common throughput rate of 40,000 pounds per day. This is within the range of performance for the furnace both "before" and "after", as shown by the performance charts. From the performance charts, for a daily throughput of 40,000 pounds of steel, other parameters were determined to be fuel use of 200 million Btu/day "before" and 84 million Btu/day "after", and 5000 Btu/lb of steel "before" and 2100 Btu/lb "after" (an average fuel saving of 58 percent).

Financial analyses were made for two options that differed in the treatment of the original investment. The options and the results, both for a daily throughput of 40,000 pounds of steel, were as follows:

- Option 1. The investment cost was taken to be \$93,000, which includes costs for modifying the furnace wall to permit charging of more steel, purchase of the Hague equipment, and installation. (Reed personnel stated that although \$93,000 was budgeted for this work, actual costs were probably about \$105,000.) With this treatment, which is our preferred treatment because it includes the cost of wall removal that contributed to the fuel saving that has been reported, calculated payback period is 1.5 years.
- Option 2. The investment cost is taken to be the \$68,000 price of the Hague package, plus 15 percent for installation. This option ignores the cost of removing the furnace wall. Under this condition, calculated payback period is 1.3 years.

A summary of the conditions used in the payback analyses is given in the attached table. Note should be taken of the fact that this analysis is based on conditions and data as of late 1980 and early 1981 when the modified furnace was being used at high steel throughput and close to its apparent capability. For the actual conditions of operation of the furnace in late-1981 and early-1982, payback period is longer.

June 1, 1981

HAGUE RETROFIT ON ROTARY FORGE FURNACE AT REED ROCK BIT COMPANY

Average Performance Data (1980-1981)

	Before Retrofit		After Retrofit	
	Case 1	Case 3	Case 2	Case 4
	(a)	(b)	(a)	(b)
A. Steel throughput, lb/day	25,000	40,000	50,000	40,000
B. Fuel use, MM Btu/day	167	200	85	84
C. Fuel use, Btu/lb steel	6700	5000	1700	2100

Financial Analysis, Case 3 vs. Case 4

	Option 1	Option 2
① Total installed furnace cost, \$	93,000 ^(d)	78,000 ^(e)
② Estimated useful life, yrs.	14.5	14.5
③ Estimated salvage value, \$	(c)	(c)
④ Investment tax credit, \$	7800	7800
⑤ Energy saving tax credit, \$	7800	7800
⑥ Assumed tax rate, %	46	46
⑦ Assumed general inflation rate, %/yr.	10.5	10.5
⑧ Estimated energy cost in Year 1, \$/MM Btu	2.91	2.91
⑨ Assumed energy cost inflation rate, %/yr.	20	20
⑩ Annual energy saving, MM Btu/yr.	29,000 ^(f)	29,000 ^(f)
⑪ First year maintenance cost increment, \$	4600	4600
X Payback period, yrs.	1.5	1.3

- a. Average based on analysis of reported data.
- b. Average based on extrapolation of reported data.
- c. Not required for accelerated depreciation.
- d. Reported total cost including modification of furnace.
- e. Hague equipment cost of \$68,000 plus 15% freight and installation.
- f. (200-84) MM Btu x 250 days = 29,000 MM Btu.
- g. Assumed 5% of \$93,000.

May 19, 1982

Forge Furnace Host Site Description

Company Name and Address: K. O. Forge, Inc.
3315 Carr Street
Houston TX 77026

Contact and Telephone Number: Bob Morris, Engineer
Larry Rodgers, Secretary-Treasurer
(713) 224-0927

Brief Description of Forge Shop

K. O. Forge is a moderate size open-die shop. It is on the same site as Olds Press, which is a closed-die shop under the same management. Forging size at K. O. ranges up to about 5000 pounds. The largest stock routinely heated measures about 14 x 14 x 40 inches (about 2200 pounds). Over 90 percent of production is carbon steel. Information on amount of annual tonnage output was not provided by management.

Baseline Furnaces

K. O. had four old box furnaces. Observation showed that they leak substantial flame around the doors, and are obviously thermally inefficient.

The normal procedure has been as follows. Forge furnaces are loaded at night, and ignited about 2 a.m. Heated stock is removed starting in the morning for forging, and is continued until the day's work is done. Usually this is completed on one shift, sometimes more. The usual furnace load was said to be about 5000 pounds, but, as discussed later, during a 26-day test period in late 1980 on one of these box furnaces (since dismantled), the mean furnace load was about 7800 pounds.

Hague Equipment

A new Hague box furnace was delivered to K. O. Forge during February 1981. After delivery, a fiber lining was installed inside the roof and an insulating veneer placed around the door. Startup, under supervision of a Hague engineer, was during March 1981.

The new Hague furnace is rated at 5 million Btu/hour. It has two Model 275-7200 Hague burners, recuperator, and Oxsen air/fuel control system.

Price of the new furnace was stated to be about \$125,000, plus about \$5,000 freight, plus installation, for a total cost of about \$140,000.

Fuel

The fuel for the shop is natural gas from Lone Star at \$2.70 per million Btu in February 1981 and \$3.60 in December 1981.

Metering of Fuel

Hague provided a meter to collect data on the performance of a baseline furnace. The data were collected for a 26-day period from October 17 through November 4, 1980 (reported later). The same meter was subsequently transferred to the new Hague furnace in the same configuration.

The meter is an American (Singer) CVM positive-displacement, Model 2M, with digital readout, uncompensated for pressure or temperature.

For their internal analyses, K.O. management used the meter readings directly with no correction for pressure. K.O. Engineering was of the opinion that at the time that the raw data were obtained on the baseline furnace (since dismantled), the line pressure was about 25 psig. On that basis and other factors, Battelle initially applied a meter correction factor of 3.03 to the raw data as analyzed for the Interim Report (June 1981). This yielded fuel consumptions that were so high that they remained under question. Subsequent to the Interim Report, Battelle did additional in-plant work and investigation, including measurement of line pressure at the meter as installed on the new Hague furnace. Meter pressure was determined to be 18.5 inches of water, about 11 osig or 0.7 psig. Therefore, for this final analysis Battelle has applied a pressure-correction factor of 1.05 to the raw data for both the old baseline furnace and the new Hague furnace.

Maintenance Experience and Costs

No substantial problems with the heat-recovery system have been experienced during the first 8 months of operation of the Hague furnace. No replacement parts were ordered with the furnace. Costs for maintenance and repair are not available.

Several types of mechanical problems were encountered. A ring-gear on the door-raising mechanism failed, and was replaced. Ceramic outer rings of the burner nozzles had short lives because of cracking. Improved rings

were provided by Hague. The most serious problems involved cracking of the castable lining of the furnace. Under the direction of Hague, and outside contractor was employed to reline the entire furnace. Results were not completely satisfactory, because cracking has continued to be a problem.

The Oxsen control system initially did not function well because the door was opened frequently. This allowed excess air into the furnace. This problem was corrected by installing a microswitch and time-delay unit on the door so as to inactivate the Oxsen when the door was opened and to delay its reactivation until 30 seconds after the door was closed. This gives sufficient time for the air entering the open door to be purged before the Oxsen reactivates. K. O. claims that the result is good control of combustion ratio.

Performance Data

K. O. provided Battelle with raw data on steel throughput and meter readings for one old nonrecuperative box furnace on a daily basis from October 3 to November 4, 1980 (26 working days). Steel throughput was calculated by counting the sizes of billets placed in each furnace load (one load per day). Over the period, billet sizes were from 4-inch square to 16-inch square with weights from 23 to 1360 pounds per piece.

Over the period of the test on the old nonrecuperative box furnace, daily loadings of steel varied from about 3000 to 14,000 pounds. Daily fuel consumption varied from about 2800 Btu/lb (for daily loadings of about 14,000 pounds) to about 11,000 Btu/lb (for daily loadings of about 3000 pounds). Regression analysis of the daily data showed a mean throughput of about 7800 pounds per day and a mean fuel consumption of about 4800 Btu/lb. These results (and those for the new Hague furnace) are shown on the accompanying graphs (Figures B-5 and B-6).

It was the intention of K. O. management to shut down one of the old box furnaces when the new furnace became operational. This was done, and the new furnace was started on a basis of one load per day, averaging about 7000 to 8000 pounds per load, as for the old furnaces. However, early experience showed that the new furnace heated steel much more rapidly than the old furnaces. Therefore by early June 1981, the new furnace was being charged late in the day with a load about 20,000 pounds, soaked during the night on low fire, brought up to forging temperature (2300 F) early in the morning, following which the steel was used for forging. When the furnace was emptied, it was sometimes recharged with a second, usually smaller, load that was heated and used, still on the same shift. With this mode of operation, management was able to shut down two of the old box furnaces.

FIGURE B-5. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT; K. O. FORGE

FIGURE B-6. TOTAL ENERGY CONSUMPTION VS. THROUGHPUT; K. O. FORGE

Although the new Hague furnace is metered, K. O. did not begin monitoring daily steel throughput and fuel consumption of the new furnace prior to early June 1981.

During the first few days of operation of the Hague furnace, shop personnel made informal estimates of its performance, without the benefit of actual daily logs. Their preliminary opinion was that the new furnace saved at least half the fuel required by the old furnaces. Engineering personnel at K. O. also concluded that the new furnace is so "tight" and efficient in comparison to the old furnaces that it is more economical to idle the new furnace overnight on low fire with a load in place rather than to turn the fuel off overnight.

Raw data were provided to Battelle for the operation of the new Hague furnace over the period October 13 to December 16, 1981 (29 working days). Daily fuel consumption varied from about 1500 Btu/lb (for daily loadings of about 23,000 pounds) to about 3300 Btu/lb (for daily loadings of about 6000 pounds). The mean throughput was about 13,000 pounds per day at a mean fuel consumption of about 2100 Btu/lb (as shown in Figure B-5).

Comparing the overall operation of the new furnace with the old furnace, mean daily throughput was increased from 7800 to 13,000 pounds per day (an increase of 67 percent) and mean specific fuel consumption decreased from 4800 to 2100 Btu/lb (a decrease of 56 percent).

If the two furnaces are compared on the basis of equal throughput at the mean throughput of the Hague furnace (13,000 pounds per day), which is within the range for reported throughput of the old furnace, fuel consumption in the old furnace was about 3000 Btu/lb (as shown in Figure B-5). Thus, the overall fuel saving experienced with the new furnace can be divided into two components. Reduction in specific fuel use in the old furnace from 4800 Btu/lb to 3000 Btu/lb (67 percent of the overall drop) is attributable to the increased throughput, and the further reduction from 3000 Btu/lb to 2100 Btu/lb (33 percent of the overall drop) is attributable to inherent differences in construction and characteristics of the two furnaces.

Indicated Payback Period

For financial analysis, the overall drop in fuel consumption is credited to the new furnace. The position is taken that if it had not been for the new furnace, the mean daily throughput would not have increased (even though such an increase was within the capability of the old furnace). This position tends to maximize annual fuel savings relative to other positions that might have been taken.

If the Hague furnace is operated at the daily mean demonstrated during the test period (13,000 lb/day) for 250 days/yr, its annual throughput will total 3.25 million pounds. At a mean fuel consumption of 2100 Btu/lb

and gas priced at an average of \$3.15 per million Btu in 1981, the first-year fuel cost would be \$21,499. If the same throughput (3.25 million pounds annually) had been heated in the old furnace at its demonstrated mean fuel consumption of 4800 Btu/lb, its annual fuel cost at the same price for fuel would have been \$49,140. The difference in fuel costs between the two alternatives, \$27,641 in the first year, represents annual fuel savings attributable to the new furnace. This is a saving of 56 percent of the projected fuel cost if the new furnace had not been implemented.

The simple payback period based solely on first-year fuel saving (ignoring effects of tax credits, income taxes, general escalation, escalation of fuel price, and maintenance expenses) is $\$140,000/\$27,641 = 5.1$ years.

The payback period based on the cumulative discounted annual after-tax cash flow (as described in Appendix A) is 4.7 years. The basis and results of this calculation are given in the following tabulation.

May 19, 1982

HAGUE BOX FURNACE AT K.O. FORGE

Relative Performance Data

Old Furnace	Hague Furnace
7800	13,000
37.4	27.30
4800	2100

- A. Steel throughput, lb/day
 B. Fuel use, MM Btu/day
 C. Fuel use, Btu/lb steel

Financial Analysis

① Total installed furnace cost, \$	\$140,000
② Estimated useful life, yrs.	14.5
③ Estimated salvage value, \$	(a)
④ Investment tax credit, \$	14,000
⑤ Energy saving tax credit, \$	8,000(b)
⑥ Assumed tax rate, %	46
⑦ Assumed general inflation rate, %/yr.	10.5
⑧ Estimated energy cost in Year 1, \$/MM Btu	3.15(c)
⑨ Assumed energy cost inflation rate, %/yr.	20
⑩ Annual energy saving, MM Btu/yr.	8,775(d)
⑪ First year maintenance cost increment, \$	7,000(e)
X Payback period, years	4.7

- a. Not required for accelerated depreciation.
 b. 10% of \$80,000. Allows \$60,000 for basic furnace.
 c. 1981 = Year 1.
 d. For throughput of 13,000 lb/day, 250 days/yr = 3.25 million lb/yr.
 e. Assumed 5% of \$140,000.

May 20, 1982

Forge Furnace Host Description

Company Name and Address: National Flame & Forge, Inc.
330 West 25th Street
P. O. Box 7385
Houston TX 77008

Contact and Telephone Number: Jim McCroskey, Superintendent
Dickie Wilson
(713) 869-5724

Brief Description of Forge Shop

This is a large, relatively sophisticated plant operating under a knowledgeable management. Normal output is over 1 million pounds of steel forgings per month, for both jobbing and captive end uses. Much of the steel is AISI 1055 and is converted into mud-pump liners. Billets weigh about 180 to 6000 pounds (up to 20 inches square), and average about 300 pounds. They are heated, forged, pierced, and back-extruded into hollow cylindrical liners for mud pumps, followed at least in some cases by heat treatment and machining.

Baseline Furnaces

In addition to a large new Hague pusher furnace, National has 9 old box furnaces. None was suitable as a baseline for the Hague furnace because they are of a different type (box versus pusher) and the mode of operation is different (batch versus continuous). Heat ratings for the box furnaces range from about 1.5 to 16 million Btu/hr. None of the box forge furnaces was metered prior to 1982. Management estimated in mid-1981 that their overall fuel consumption is about 5000 to 7000 or more Btu per pound of steel heated. In May 1982, management revised this estimate to about 4500 Btu/lb.

Hague Equipment

The new Hague furnace is a pusher type designed by National and Hague and built by Hague. It was delivered in October 1980, and began operation in March 1981.

The inside of the furnace chamber is about 10 ft wide, 24 ft long, and 3.5 ft high. It started as a 10-burner furnace with two heating zones. From the feed end, the burner order was 1.0 million Btu/hr (Model 2600), 1.8 (Model 4600), 1.8, 1.0, and 1.0; a total of 13.2 million Btu/hr for both sides.

The furnace as supplied was rated by Hague to have a conservative capacity of 10,000 pounds per hour, possibly as high as 15,000 lb/hr. Expected energy consumption (Hague) is about 900 Btu per pound of steel heated when the furnace is operating close to rated capacity.

Purchase price, transportation, and installation costs are estimated by management at about \$350,000. Hague has indicated that purchase price was \$280,000. Purchase price in 1982 appears to be about \$450,000.

The new Hague pusher furnace operated with its original burner capacity from March into October 1981. By October it had been determined that the forging operations fed from this furnace could not handle the full output of the furnace. Therefore, the furnace was being operated at much reduced throughput. Under these conditions, specific fuel consumption according to National Flame records was averaging about 2120 Btu/lb--considerably higher than expected.

During October 1981, the burner capacity was lowered. The two Model 2600 burners at the feed end were shut down. Four of the larger Model 4800 burners were converted to smaller Model 2600 burners. The result of these changes was to lower the rated total burner capacity from 13.2 million Btu/hr to about 11.2 million.

During the first week of December 1981, hydraulic lines on the pusher mechanism ruptured, causing extensive fire damage to the control system, wiring, gas regulator, meter, and spare-parts inventory. The furnace was placed back into operation on December 11, but without a gas meter. Therefore, this furnace has not been monitored for performance since the end of November 1981.

Fuel

Fuel is natural gas supplied by InTex. Price in February 1981 was about \$3.80 per million Btu.

Metering of Fuel

None of the box forge furnaces was metered until late in this program. A Dresser (Roots) meter formerly installed on a heat treating furnace was relocated to the new Hague furnace. Line pressure at the meter is about 25 psig. Daily pressure-correction factors were supplied as part of raw data.

Maintenance Experience and Costs

Partially because of changes made in the Hague equipment and the fire, meaningful data on maintenance costs are not available.

In the period July-November 1981, six new sets of doors were installed.

Performance Data

From startup (March 1981) to December 11, 1981, the Hague furnace was monitored daily for fuel consumption and steel throughput. Because of the considerable amount of mechanical equipment on a pusher furnace, there has been some need for mechanical debugging.

Management reported in June 1981 that monthly throughput of steel through the new furnace had been averaging about 1 million pounds and that fuel consumption had probably been averaging about 1900 Btu/lb of steel. These were estimates prior to analysis of daily logs. Based on management's estimate of 6000 Btu/lb required overall for the old box furnaces, the new furnace appeared to be saving about 68 percent of the fuel.

Subsequent to the Interim Report (June 1981), National Flame furnished Battelle with daily raw data covering the entire period of operation of the Hague pusher furnace. These data were submitted to regression analysis covering several periods of time. Raw data were edited to remove entries that covered more than 1 day of operation. For example, raw data sometimes combined work on Saturday and Monday into a single set of data for Monday.

The major results of the regression analyses are given in Figure B-7, and are compared below with cumulative specific fuel consumptions as calculated by National Flame.

	National Flame Hague Pusher Furnace		
	March 23- Aug. 19, 1981	Oct. 23- Nov. 20, 1981	March 23- Nov. 20, 1981
Range of single-day throughput, lb	14,000-83,000	23,000-57,000	--
Mean of daily throughput, lb	39,500	32,400	--
Mean fuel consumption, Btu/lb	2,080	1,989	--
National Flame cumulative fuel consumption as of last day in period, Btu/lb	2,157	--	2,133

FIGURE B-7. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT; NATIONAL FLAME & FORGE

During the first 5-month period of its operation, the Hague furnace was used much below its rated capacity, because forging facilities were unable to handle more steel. During the first month after the furnace was down-scaled in burner capacity, mean daily throughput decreased further, mainly because of general business conditions. In spite of this, specific fuel consumption (Btu/lb) decreased after the downscaling. This was reflected also in the decrease of the cumulative average fuel consumption as calculated by National Flame.

October 21, 1981 provided one point of particularly interesting data. Throughput on this day was 158,000 pounds, about four times the average daily output and about twice as high as previous high days. Specific fuel consumption was 1147 Btu/lb, the lowest for any day recorded. This suggests that the expectation by Hague that the furnace is capable of reaching 900 Btu/lb when operated close to capacity is reasonable.

At its rating of 10,000 pounds per hour on a continuous basis, this furnace should be capable of heating 240,000 pounds of steel per day. Average use is about one-sixth of the rating, and only rarely has the furnace been used as high as one-third of its rating. This relatively low throughput has caused mean specific fuel consumption to be about twice what the furnace is capable of accomplishing.

Indicated Payback Period

Using the method of financial analysis selected for this study (Appendix A), the payback period for the \$350,000 original investment, even at the relatively low (for this furnace) output of 1 million pounds per month, is about 2.2 years. During the second year, the saving in fuel cost amounts to about \$220,000 annually. Annual fuel saving will be increased and payback period shortened if and when the furnace is operated closer to its rated capacity.

A summary of the conditions used for the payback analysis is given in the attached table.

June 4, 1981

HAGUE PUSHER FURNACE AT NATIONAL FLAME & FORGE

Average Performance Data

Old Box Furnaces	New Pusher Furnaces
1,000,000	1,000,000
6000	1900
6000	1900

- A. Steel throughput, lb/mo.
 B. Fuel use, MM Btu/mo.
 C. Fuel use, Btu/lb steel

Financial Analysis

① Total installed furnace cost, \$	350,000
② Estimated useful life, years	14.5
③ Estimated salvage value, \$	(a)
④ Investment tax credit, \$	35,000
⑤ Energy saving tax credit, \$	35,000
⑥ Assumed tax rate, %	46
⑦ Assumed general inflation rate, %/yr.	10.5
⑧ Estimated energy cost in Year 1, \$/MM Btu	3.80
⑨ Assumed energy saving, MM Btu/yr.	20
⑩ Annual energy saving, MM Btu/yr.	49,200
⑪ First year maintenance cost increment, \$	17,000 ^(b)
X Payback period, years	2.2

a. Not required for accelerated depreciation.

b. Assumed 5% of \$350,000.

May 24, 1982

Forge Furnace Host Site Description

Company Name and Address: Western Forge and Flange Company
780 Reed Street
P. O. Box 327
Santa Clara CA 95052

Contact and Telephone Number: Peter Zaklan, President
(408) 727-7000

Brief Description of Forge Shop

Western Forge is a medium-size jobbing company with plants at Santa Clara CA and Albany CA. Production by weight is about equally divided between the two plants; about 200,000 pounds per month from each plant. Total employment is about 56 persons. The number of persons at Albany is lower than at Santa Clara, but billet weights are higher.

Forgings are produced in open dies and closed dies using steam hammers. Materials include carbon steel, stainless steel, superalloys, aluminum, and other nonferrous metals. Most production is in short runs, with weights of individual forgings ranging from about 0.5 to 2500 pounds. About 7 percent of production by weight is for the nuclear industry.

Steel billets are heated in gas-fired box furnaces. Operation is one shift. Typically, billets are loaded and furnaces fired early in the morning. With this type of batch operation, furnaces typically are operated at a relatively low fraction of their full capacity.

Baseline Furnaces

The Santa Clara plant has about 5 old box furnaces and the Albany plant about 3. The old "conventional" furnaces are typically brick-lined, equipped with simple temperature controls, and simple air-fuel ratio controls (no sensing of oxygen level). About 1976, in preparation for possible gas curtailments, several of the old furnaces were converted to dual-fuel systems, but the furnaces have never been switched in production from gas to oil.

The Santa Clara plant includes two recuperated furnaces. One is a small 3-burner Selas box furnace (3 million Btu/hr) equipped with a metallic recuperator rated at 650 F for air preheat. Data provided for

8 days of operation of this furnace indicated a fuel saving of about 47 percent compared with similar operations with the "conventional furnaces". Specific fuel consumption of the Selas furnace over the monitoring period was about 3750 Btu/lb of steel. A description of this unit in Industrial Heating, January 1981, indicated a capability of 1500 Btu/lb at rated capacity.

The other recuperated furnace in the Santa Clara plant is a larger (7 or 8 feet) fiber-lined box furnace equipped with two 1.5 million Btu/hr Hotwork self-recuperative burners. This is just being placed into operation. Fuel savings (compared with "conventional") are expected to be about 50 percent.

Hague Equipment

The Albany plant (540A Cleveland Avenue, Albany CA 94706) has a new Hague Model 4 two-burner box furnace (4 million Btu/hr), beside which a rebuilt 12,000-pound hammer will be placed. The Hague furnace began operation in March, 1981, but operated only a few days until it was shut down to repair cracks (presumably developed during shipment) in the hearth, walls, and roof. During the repair period, the walls and roof were lined with fiber insulation.

Fuel

All steel-heating furnaces at both plants are fired with natural gas, although some of the old furnaces have dual-fuel capability. Gas price from Pacific Gas and Electric in June 1981 was \$4.50 per 1000 cubic feet. Heating value is taken at 1000 Btu/cubic foot.

Metering of Fuel

Gas consumption of the Hague furnace was monitored by a Dresser (Roots) meter furnished by Hague. The same meter was used earlier to monitor performance of a conventional furnace for comparison. Fuel consumption of the Hotwork furnace at Santa Clara was monitored by a Dresser meter loaned to Western Forge by the gas company.

Raw data on gas consumption as reported to Battelle were uncorrected for pressure at the meter. The line pressure at the meter at Santa Clara was reported to be 5 psig, which requires a meter pressure factor of approximately 1.33. Fuel-consumption data reported here for Albany include that factor.

Maintenance Experience and Costs

Insufficient information. The substantial cracking of refractories following the start-up of the new Hague furnace presumably resulted from shipping damage.

Performance Data

Western Forge provided Battelle with raw data on daily gas-meter readings and daily steel throughput for the following conditions:

- "Conventional" old box furnace at Santa Clara. Nine days of operation in November 1980.
- "Conventional" old box furnace at Albany. Five days of operation. These data contained inconsistencies such that only the averages are being used in the present study.
- New Hague box furnace at Albany. Seven days of operation in March 1981.
- New SelaS box furnace at Santa Clara. Eight days of operation in October and November 1980.

Results of analyses for the Hague furnace and the two conventional box furnaces are plotted on the attached figures (Figures B-8 and B-9). The average performance for the conventional furnace at Albany is in line with the fuel performance of the conventional furnace at Santa Clara, although the conventional furnace at Albany was operated at about twice the daily throughput of steel as the Santa Clara furnace.

The old conventional furnace at Albany and the new Hague furnace at Albany were operated during the monitoring periods at closely similar average daily throughputs of steel (6700 to 6900 pounds per day), but throughputs on individual days varied from about 3,000 to 10,000 pounds. This is a low rate of utilization for the Hague furnace.

Using the limited amount of data available from Western Forge, our analysis shows that at a steel throughput rate of 7000 pounds per day for each furnace, the conventional old box furnace consumed about 5300 Btu/lb of steel and the new Hague box furnace consumed about 2400 Btu--representing a fuel saving of about 55 percent by the Hague furnace.

FIGURE B-8. SPECIFIC ENERGY CONSUMPTION VS. THROUGHPUT, WESTERN FORGE AND FLANGE COMPANY

FIGURE B-9. TOTAL ENERGY CONSUMPTION VS. THROUGHPUT, WESTERN FORGE AND FLANGE COMPANY

Indicated Payback Period

Two financial analyses were made as follows:

- Option 1 involves 1-shift operation heating 7000 pounds per day in either furnace for 250 days per year. The payback period for the Hague furnace is 5.5 years, even though by the time that is reached (Year 1986) the gas price is taken to have escalated to about \$11 per million Btu. The long payback period is caused mainly by the installed cost of the Hague furnace (\$146,000) and the low rate of its utilization (equivalent to about 2 hours per day at rated capacity).
- Option 2 is an extrapolation to 2-shift operation, 250 days per year, heating 7000 pounds on each shift. It is assumed that maintenance and repair costs per year do not increase as a result of 2-shift operation, and that average gas consumption per pound of steel decreases by about 8 percent because of 2-shift operation. With such conditions, the payback period could be 3.2 years.

The financial analysis did not take into consideration state-tax energy credits that may be available in California.

A summary of the financial analysis is given in the attached table.

May 15, 1981

HAGUE BOX FURNACE AT WESTERN FORGE AND FLANGE, ALBANY CA

Average Performance Data

- A. Steel throughput, lb/day
 B. Fuel use, MM Btu/day
 C. Fuel use, Btu/lb steel

Old Conventional Box Furnace, 1 shift/day	New Hague Box Furnace, 1 shift/day
7000	7000
37.1	16.8
5300	2400

Financial Analysis

	Option 1	Option 2
① Total installed furnace cost, \$	146,000	→
② Estimated useful life, yrs.	14.5	→
③ Estimated salvage value, \$	(a)	→
④ Investment tax credit, \$	14,600	→
⑤ Energy saving tax credit, \$	14,600 ^(b)	→
⑥ Assumed tax rate, %	46	→
⑦ Assumed general inflation rate, %/yr.	10.5	→
⑧ Estimated energy cost in Year 1, \$/MM Btu	4.50	→
⑨ Assumed energy cost inflation rate, %/yr.	20	→
⑩ Annual energy saving, MM Btu/yr.	5075 ^(c)	11,000 ^(d)
⑪ First year maintenance cost increment, \$ ^(e)	7300	→
X Payback period, years	5.5 ^(c)	3.2 ^(d)

- a. Not required with accelerated depreciation.
 b. Additional state energy credit may be available in California.
 c. 1 shift, 250 days/yr.
 d. 2 shifts, 250 days/yr.
 e. Assumed 5% of ①.

May 20, 1982

Forge Furnace Host Site Description

Company Name and Address: Taylor-Wharton
Division of Harsco Corporation
2900 William Penn Highway
P.O. Box 1742
Easton PA 18042

Contact and Telephone Number: A. James Schall, Plant Engineer
(215) 258-7271

Brief Description of Forge Shop

The Taylor-Wharton forge shop is engaged mainly in the production of gas cylinders of the type commonly seen in laboratories and industrial plants. Customers include such well-known names as Air Products and Linde.

The cylinders are a premium product subject to 100% X-ray and pressure tests. The most common size is 9 inches in diameter, holding 250 cubic feet of gas at 2500 psi. Such cylinders are tested at about 4000 psi. Other sizes and designs are tested at up to 10,000 psi.

In 1980, production was about 31 million pounds of cylinders. The plant also produced about 3.5 million pounds of wear-resistant forgings from Mn steel, mainly for railway applications, but these are of no special pertinence to the present project.

The cylinders are forged from billets of 4130 Cr-Mo-Ni steel, at a furnace temperature of about 2400 F. (Note higher than average temperature.)

The procedure is as follows. Billets are heated in a pusher-type furnace and are moved by roll conveyor to a vertical extrusion press where they are formed into a stocky cup. The cup is moved immediately to a horizontal press where the cup is drawn into a full-length cylinder of final wall thickness. Next, the cylinder is sawed to length to remove ears resulting from extrusion. Cylinders are allowed to cool and then are inspected. Up to this point, project-related furnaces are not involved.

Inspected cylinders of full diameter along their length are then hot spun at the open end to reduce the diameter and to provide the upper dome outlet that eventually is drilled and tapped to accept the valve and meters. The open end of a cold cylinder is placed through one of the four holes in the working side of a "spinner" furnace that is maintained at temperature--about 2400 F. These holes are the equivalent of the slot in a slot furnace. The depth of insertion into the furnace is about 12 to 18 inches. After about 2 minutes, the cylinder is removed, placed in the spinner, and spun to the required form and dimensions. There is no reheating

(turnaround) at this stage. The spinner (forge) furnaces operate about 16 hours per day, 5 days per week.

Baseline Furnaces

At the spinning station, the furnace equipment formerly consisted of two old (1917) slot-type furnaces, each with three heating holes (instead of a slot). Furnaces were home built, and controls were rudimentary.

Following delivery of a new Hague "slot" furnace in early 1981, one of the old furnaces was dismantled to provide space for the new Hague unit. Some performance data were collected on the old furnace just prior to its dismantling. The other old furnace remains.

Hague Equipment

The new Hague furnace was delivered in early 1981, and was first operated (for a short period) on March 23, 1981. It is a Model 4 "slot" furnace modified to have four round heating holes in the active wall instead of the conventional slot. It has two burners, and is fiber-lined. Rating is 4 million Btu/hr; 3500 pounds of steel/hr.

The Hague furnace was not operating when the site was visited by Battelle staff on April 8, 1981. The furnace was not operating because of two factors. The furnace was delivered with solenoid valves too light to operate with the specified fuel oil. The solenoids burned out. Replacements were on order. Because the new furnace is considerably taller than its predecessor, the overhead crane could no longer move cylinders in and out of the working area by lifting them over the furnace. Rerouting of the crane path caused cylinders to be carried over the heads of working personnel. A safety "roof" was designed and constructed to protect workers.

The Hague furnace is physically much larger than its predecessor and the remaining old furnace, although all three are rated at the same output, 100 cylinders per hour (which is set by the spinning machines). The prior and the remaining baseline furnace are about 3.5 feet deep (outside). This gives sufficient inside space to insert the ends of cylinders about 1.5 feet into the furnace. The Hague furnace is about 7 feet deep (outside), but the required insertion depth is the same. The Hague furnace, therefore, has a substantial amount of unrequired internal volume.

Fuel

The new Hague furnace has dual-fuel capability. Prior to January 1982, it was operated on No. 4 fuel oil. This required heaters to lower its viscosity prior to feeding it to the burners. Price of the oil in May 1981 was \$0.94 per gallon (\$6.38 per million Btu). All data furnished to date have been with oil as the fuel. Since January 1982, the Hague furnace has been operating on natural gas, but operation has been so intermittent that no useful data have been provided since the furnace was converted to gas. The remaining nonrecuperative baseline furnace continues to be fueled with oil.

Metering of Fuel

Each furnace is appropriately metered. Meters are calibrated about quarterly.

Maintenance Experience and Costs

No quantitative data. Major problem has been with modules of roof lining falling off. During plant shutdown in mid-1982, it is expected that some recuperator tubes will be replaced.

Performance Data

Data were provided by Taylor-Wharton for the operation of the superseded (now discarded) original baseline furnace during the month of February 1981. Daily oil consumption varied over a wide range (from less than 250 to more than 650 gallons per day). From analysis of the raw data, 470 gallons per day appears to be the best average. During this time, the furnace was used to heat the ends of 9-inch cylinders. Calculation by T-W personnel indicates that the weight of steel heated per 9-inch cylinder is 10.8 pounds.

Other raw data were provided by Taylor-Wharton for daily oil consumption of the baseline furnace for all of 1980. Analyses of these again shows a wide range of reported daily consumption (from less than 200 to more than 800 gallons per day). However, the 1980 data are not restricted to 9-inch cylinders. Other cylinders are larger, and involve the heating of moderately more steel per cylinder.

Data on the amount of steel heated per day are incomplete. Daily counts of the number and sizes of cylinders processed through each furnace each day would be desirable for correlation with daily readings of fuel

consumption. However, the best information available to date is that throughput averages about 1200 cylinders per furnace per day. For 9-inch cylinders, this is about 13,000 pounds of steel treated per day.

Taylor-Wharton personnel consider that the average oil consumption for the old furnace was about 500 gallons per day. This is accepted for the present analysis, because it is consistent with the raw data presently available, but may be in error by about 10 percent either way.

For the new Hague furnace, T-W reported an average fuel rate of 12.5 gallons per hour, which is taken to be 200 gallons per 16-hour day. Based on an average of 500 gpd for the old furnaces and 200 gpd for the Hague furnace, the indicated fuel saving for the new furnace is 60 percent. On the basis of 13,000 pounds of steel heated per day, oil consumption apparently averaged about 5760 Btu/lb of steel heated in the baseline furnace and 2300 Btu/lb in the Hague furnace (a saving of 60 percent for the new furnace).

Indicated Payback Period

Financial analysis was conducted for three options as follows:

Option 1 compares the old and new furnaces under the condition where each is used 250 days/yr, 16 hr/day, on 1200 9-inch cylinders per day. Both are fueled with oil costing an average of \$0.94 per gallon (\$6.28 per MMBtu) in 1981 and escalating to an average of \$1.35 per gallon in 1983. Average fuel consumption is taken as 500 gallons per day in the old furnace, and 200 gallons per day in the new furnace (a saving of 60 percent in the new furnace). The payback period is 2.9 years.

Option 2 is the same as Option 1, except that the fuel consumption in the new furnace is taken to average 250 gallons per day (50 percent saving). The payback period is 3.4 years.

Option 3 is the same as Option 2, except that both furnaces are taken to be fired with natural gas costing an average of \$3.64 per million Btu in 1981 and escalating to \$7.55 in 1985. This option is included because Taylor-Wharton recently converted the Hague furnace to gas. The payback period, because of the lower dollar value of the fuel saved, is 4.9 years.

The data used in the financial analysis are summarized in the attached table.

May 15, 1981

NEW HAGUE SLOT FURNACE AT TAYLOR-WHARTON

Average Performance Data

Baseline; Old Conventional furnace	New Hague furnace
13,000	13,000
74.9	29.9
5760	2300

- A. Steel heated; lb/day^(a)
 B. Fuel use; MM Btu/day^(a)
 C. Fuel use, Btu/lb steel^(a)

Financial Analysis

	Option 1	Option 2	Option 3
① Total installed furnace cost, \$	185,000		→
② Estimated useful life, yrs.	14.5		→
③ Estimated salvage value, \$	(b)	(b)	(b)
④ Investment tax credit, \$	18,500		→
⑤ Energy saving tax credit, \$	18,500		→
⑥ Assumed tax rate, %	46		→
⑦ Assumed general inflation rate, %	10.5		→
⑧ Estimated energy cost in Year 1, \$/MM Btu	6.28	→	3.64
⑨ Assumed energy cost inflation rate, %/yr.	20		→
⑩ Annual energy saving, MM Btu/yr. ^(c)	11,250	9350	→
⑪ First year maintenance cost increment, \$ ^(d)	9200		→
X Payback period, yrs.	2.9 ^(e)	3.4 ^(f)	4.9 ^(g)

- a. Option 1. 149,700 Btu/gallon.
 b. Not required for accelerated depreciation.
 c. For 250 days/year, 16 hr/day.
 d. Assumed 5% of ①.
 e. With 60% saving of fuel oil.
 f. With 50% saving of fuel oil.
 g. With 50% saving of natural gas.

APPENDIX C

TASK 4. DETAILED EVALUATION OF HAGUE RECUPERATIVE FURNACE COMPARED WITH NONRECUPERATIVE FURNACE

REPORT

on

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

TASK 4. DETAILED EVALUATION OF HAGUE
RECUPERATIVE FURNACE COMPARED
WITH NONRECUPERATIVE FURNACE

to

OFFICE OF INDUSTRIAL PROGRAMS
DEPARTMENT OF ENERGY

December 10, 1981
(Revised February 2, 1982)

by

P. A. de Poutiloff and F. C. Holden

BATTELLE
Columbus Laboratories
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Columbus, Ohio 43201

C-i

EXECUTIVE SUMMARY

To supplement the performance comparisons of the Hague furnace with conventional furnaces, currently being done under production conditions, a more detailed comparison has been made under controlled conditions. Trials were made at W. Pat Crow Forgings, Inc. on a Model 4 Hague slot-forging furnace and on a nonrecuperative unit designed and built at W. Pat Crow (WPC). Two runs were made on each furnace, with loading rates estimated at 50 and 100 percent of rated capacity (from about 900 to 2100 pounds of steel per hour). Steel billets were weighed and heated to forging temperature to provide a measure of useful output, and measurements of gas consumed were used to compute the energy input. Corrections were made to compensate for time lost in handling billets and other unavoidable delays.

Operating data are presented graphically and in tabular form to provide a reasonably complete record of the operating characteristics of both furnaces.

The Hague recuperative furnace was more efficient thermally than the WPC nonrecuperative furnace under each condition tested. However, the difference in efficiency varied considerably depending upon the basis used to compare the data and on the level of throughput in the test.

On a "net" fuel basis that includes adjustments for experimental deviations and which includes fuel to heat the furnace from a cold start (the usual basis for batch processing and by far the most common method of processing used in the industry), the fuel saving (per pound of steel) attributable to use of the Hague furnace was about 12 percent when the furnaces were operated at about 50 percent of throughput capacity, and about 29 percent when the furnaces were operated close to full throughput capacity.

On a basis of "net-minus-startup", which subtracts startup fuel, the Hague furnace consumed about 27 percent less fuel per pound of steel when the furnaces were operated at about 50 percent of capacity, and about

41 percent less when the furnaces were operated close to full capacity. This basis becomes most meaningful when furnaces are operated for long periods without intervening cooling. In most forge shops, however, individual runs are short rather than long.

Averaging the specific fuel consumption (Btu per pound of steel) for each furnace at both conditions of throughput, the Hague furnace consumed 18 percent less fuel than the Crow furnace.

ACKNOWLEDGMENTS

The furnace trials described in this report were conducted by P. A. de Poutiloff, J. D. Foti, and F. C. Holden of Battelle's Columbus Laboratories at the W. Pat Crow Forgings, Inc. plant in Ft. Worth, Texas. Mr. Harry Brown of EG&G-Idaho was present for most of the trials as an observer representing the Department of Energy.

The authors express their appreciation to the management and staff of W. Pat Crow Forgings, Inc. for their cooperation, advice, and assistance during these trials. Particular thanks are due to Mr. John Westmoreland, Chief Engineer, whose interest and participation contributed much to the study, and to Mr. Albert Sherman and Mr. Billie Jenkins who so ably performed the hard work of handling the billets.

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TASK 4. DETAILED EVALUATION OF HAGUE
RECUPERATIVE FURNACE COMPARED
WITH NONRECUPERATIVE FURNACE

by

P. A. de Poutiloff and F. C. Holden

BACKGROUND AND OBJECTIVES

As part of its mission to encourage energy conservation in industry, the Department of Energy's Office of Industrial Programs (OIP) has supported a number of programs aimed at the development and commercialization of energy-conserving devices. Among the systems selected was an advanced version of forge furnace designed and marketed by Hague International, Inc., of South Portland, Maine. Twelve of these furnaces at eleven sites were evaluated in a demonstration program supported by OIP. Included were slot, box and pusher forge furnace units manufactured by Hague, as well as retrofits of recuperators and other devices on existing furnaces of several types--rotary, box, and car-bottom. An interim report presenting the preliminary results of this program was issued on June 30, 1981,* and the final results are contained in the body of this report.

In the demonstration program (reported separately), the performance of the Hague furnace is compared with those of conventional furnaces in the same forging plant under the same or closely equivalent production conditions. In most plants, operating conditions are such that neither the Hague furnace nor the comparison furnace is operated near its capacity except for brief periods. The amount of steel heated to forging temperature per day in a particular shop typically varies over a range of as much as 10:1. In addition, operating practices from one shop to another vary substantially for a number of both technical and nontechnical reasons.

*Interim Report on "An Energy Audit of Three Energy-Conserving Devices in a Steel-Industry Demonstration Program; Task I: Hague Forge Furnaces".

A valid comparison can be made between units in a given plant under production conditions because the principal variable of throughput can be normalized, and because the operating practice factors are generally similar. It is difficult, however, to compare furnace performance from one plant to another. Further, production data show the performance of a furnace under conditions less favorable (and sometimes far less favorable) than those of which the unit is capable.

A decision was made by OIP to conduct trials on a single installation that would provide information on furnace performance more closely matched to the capabilities of the units. These trials, although conducted on furnaces in an industrial environment, permit closer control of operating variables and a larger number of measurements than are possible under production conditions.

Negotiations were completed with W. Pat Crow Forgings, Inc., of Ft. Worth, Texas to conduct the furnace trials during the week of October 12, 1981. This site was selected for several reasons:

- Management was cooperative and receptive to the idea of conducting the trials in their plant
- They had available two Hague furnaces and several comparison furnaces, as well as gas meters
- The selected comparison furnace was newly built and represented "current good practice" for an un-recuperated unit
- It was possible to schedule the furnace trials during a period that would not interfere with production.

TECHNICAL APPROACH

The overall approach for these furnace trials was similar to that used for the demonstration programs in which two furnaces were compared under similar operating conditions. The basic measurement of performance in each

case is the useful energy output as a percentage of total energy consumed. The useful energy output is determined by the weight of steel and the temperature to which it is heated. The energy consumed is a direct function of the amount of fuel (natural gas) used. In the W. Pat Crow trials, the throughput weights of steel heated in each furnace were adjusted to rates estimated to be about 50 percent of rated furnace capacity in the first run and about 100 percent in a second run (total of four runs).

Description of Site and Equipment

The furnace trials described here were conducted at the forging plant of W. Pat Crow Forgings, Inc., Ft. Worth, Texas. W. Pat Crow (WPC) is a medium-size plant specializing in aircraft-quality forgings, as well as production of steel forgings for the oil industry. The forgings are produced in two buildings; one old and one new. The two Hague furnaces are located in the new building, whereas the comparison furnace is in the old building. All furnaces are fired with natural gas and the Hague furnaces and the comparison furnace were equipped with 5M125 Dresser Roots meters.

The Hague Model 4 furnace is a slot type with four closures, two side-mounted burners, and a top-mounted recuperator that exhausts directly into the building space above. The furnace walls are cast refractory within a steel shell, supported by a welded steel structure. The interior volume is about 180 cubic feet. The furnace is equipped with a Hague Oxsen Control Unit that here is used normally only to indicate the oxygen content of the flue gas (e.g., the air/fuel ratio trim control is not operating). The furnace exhaust is ducted through its roof into the recuperator. A top-mounted blower supplies air to the recuperator and, in turn, the two burners. The furnace is mounted on pneumatic pads to isolate it from the vibration of the nearby hammers. It has been in operation since the summer of 1980. A general view of the Hague Model 4 furnace is shown in Figure C-1. It is essentially the same as the unit illustrated more clearly in Figure 1 of this report (page 10).

The furnace temperature is controlled and recorded from a Pt-PtRh thermocouple extending into the central cavity about 2 feet above the floor.

FIGURE C-1. GENERAL VIEW OF HAGUE MODEL 4 SLOT FORGE FURNACE

The burners are rated at a total of 4 million Btu/hour (cold), and the unit is rated at 3500 pounds of steel per hour.

The comparison furnace was designed and built by W. Pat Crow Forgings (WPC) and is representative of current state of the art. It is a box furnace, ceramic-fiber lined with a volume of about 185 cubic feet. It is fired with four North American burners, two on each side, with a total rating of 5 million Btu/hour. The door is designed so that the unit can function as a slot furnace with an adjustable slot opening. The door can be opened to different levels to permit its use for larger pieces. Furnace temperature is controlled and recorded from a Pt-PtRh thermocouple. It is rated nominally at about 2500 pounds of steel per hour. The exhaust gases exit through the front opening directly up into the building. Two views of the WPC furnace are shown in Figures C-2a and C-2b.

Instrumentation

The furnace trials provided an opportunity to obtain data, in addition to those normally taken, that would aid in the description of operating characteristics as well as to serve as a check on performance data. The Hague furnace was fitted with Chromel-Alumel stainless-steel-sheathed thermocouples at several points in the recuperator and in the combustion-air system, with readouts to an Esterline Angus 24-point recorder. Thermocouples were also inserted into the furnace cavity as a check of temperature uniformity. These were found only to confirm the control-temperature measurements, and they were removed after the initial run because they interfered with handling of the billets. The following temperatures were recorded.

- Air to recuperator (ambient)
- Air at recuperator exit
- Air at left burner
- Air at right burner
- Flue gas entering recuperator
- Flue gas at recuperator exit.

FIGURE C-2a. UNLOADING BILLET FROM WPC FURNACE

FIGURE C-2b. GENERAL VIEW OF WPC FURNACE

Thermocouples were used also to monitor surface temperatures on the roof of the furnace and on the front face of the recuperator. Other surface-temperature measurements were taken manually at 15-minute intervals with an Omega Temperature Probe, Type K, at several points on the back and sides of the furnace shell.

Fewer temperature measurements were needed on the WPC comparison furnace, because it was not equipped with a recuperator. Thermocouples placed on the furnace roof were used to record surface temperatures. The surface temperatures at the back and side walls were measured with the Omega surface probe at 15-minute intervals throughout the test runs.

An optical pyrometer was the principal device used to establish that the billets were heated to forging temperature (nominally 2200 F). Readings were confirmed in several instances by the judgment of the operators that the billets were at a temperature (color) suitable for forging. Additional temperature checks were made during each run with a thermocouple probe that was inserted into a hole drilled to the center line of three selected billets. The average steel temperature for each run was calculated from these thermocouple measurements and from the optical-pyrometer readings.

Periodic measurements of ambient temperature (wet and dry bulb) were taken with a sling psychrometer. Ambient temperature was used to correct the gas-meter readings.

Pressure measurements were taken periodically with manometers at the gas meter, and at several points in the combustion-air system. The combustion-air lines were not fitted with orifice plates, so that no air flow measurements could be made. The pressure drop across the recuperator was measured during the runs on the Hague furnace.

Tubes were inserted into both furnaces to obtain flue-gas samples. Tubes were designed with a coil to cool the gas before the sample reached the Orsat equipment. Although a defective sampling system precluded Orsat measurements during both runs on the Hague furnace, readings of oxygen level were taken from the Oxsen meter. A subsequent check on that unit was made by comparing the Orsat results against the Oxsen readout. This check confirmed the readings that were taken of oxygen content from the Oxsen

instrument (about 4%) during the two runs. The flue-gas sampling tube for the WPC furnace was inserted through the open slot to a point within the furnace and above the slot. This method was used because the design of that furnace did not provide a separate path for the exhaust gases. The resulting Orsat readings for oxygen content were high (5-12%), and probably reflect mixing of outside air through the open slot with the flue-gas samples, rather than actual combustion conditions.

Billets

The billets for these trials were prepared from 1040 steel bar 3.5 inches in diameter and sheared into 10-inch lengths. Although the sheared ends were rough and frequently cracked, the billet weights were remarkably consistent. A total of about 220 billets was available, averaging slightly less than 27 pounds each. The plan called for recycling the billets as the runs progressed. Thus, it was necessary to account for scaling losses occurring during each heating cycle. Given the logistics of weighing, loading and unloading, heating and cooling the billets, it was not feasible to track each billet individually. For each cycle, a sample group of billets (typically 25 to 30) was weighed. The mean weight of the sample was taken as representative for that cycle of heating and cooling. Three billets in which holes were drilled for temperature measurement were cycled more often. These three were weighed individually and were used as control samples. The results of these weight measurements are illustrated in Figure C-3, which shows the scaling factor used for various numbers of heating cycles.

Fuel-Consumption Data

Each furnace was provided with a Dresser 5M125 Roots meter, uncompensated for gas pressure or temperature. Accordingly, it was necessary to measure gas pressure and temperature at the meter to correct the digital meter readings from actual cubic feet (acf) to standard cubic feet (scf). A water-leg manometer attached at the meter was used to obtain pressure data at 15-minute intervals. These did not vary widely during the

FIGURE C-3. SCALING FACTOR FOR 1040 STEEL BILLETS HEATED TO ABOUT 2150 F

runs. Average pressures were 6.0 and 7.5 inches of water for the WPC and Hague furnaces, respectively. The data points are shown in Figure C-4. The gas-supply lines for both furnaces ran for considerable distances within the building, so that ambient temperature values were taken as equal to gas temperatures. These ranged from 77 to 91 degrees Fahrenheit for the four runs.

The pressure correction factor (F_p) is expressed as:

$$F_p = \frac{P_s + P_g}{14.73}, \text{ where } P_g \text{ is the gas pressure, psig,}$$

and P_s is the atmospheric pressure at the site, psig, obtained from barometric pressure readings.

The temperature correction factor (F_T) is:

$$F_T = \frac{520}{460 + T_g}, \text{ where } T_g \text{ is the gas temperature in degrees Fahrenheit.}$$

The application of these two factors converts the differences in meter readings (acf) to standard cubic feet (scf).

The gross heating values for the natural gas were obtained from the local gas company for the last 18 months. The average of the last 12 months (1021.4 Btu/scf) was used to convert standard cubic feet to Btu's. Little error (less than 2%) would have been introduced in this particular case by using meter readings (acf) and assuming 1000 Btu's/acf.

GENERAL DESCRIPTION OF TEST RUNS

For each test run, the furnace was lighted off by a member of the maintenance staff between 6 and 7 a.m. During the 1 to 1-1/2 hour time required for the furnace to reach operating temperature, the recording instruments were started and checked out. Routine measurements were made and recorded at 15-minute intervals. Billet loading began after the furnace control temperature reached the set point. The billets were loaded onto the hearth in two or three rows from left to right until the desired number had been

FIGURE C-4. SUMMARY OF GAS-PRESSURE READINGS AT METER

loaded. In most loads, at least one billet with a hole drilled for temperature-probe measurements was included in the front row. The times at which billet loading began and finished were recorded for each load.

When the billets reached forging temperature, as measured by the optical pyrometer and the operator's estimate of "color", the billets were unloaded from left to right in pairs (or threes for three-row loads) and replaced by cold billets until the entire load had been removed and replaced with another. The hot billets were thrown into a metal tote box that subsequently was taken outside the building and cooled to ambient temperature by running a stream of water over the billets. As each of the drilled billets was removed, a thermocouple probe was quickly inserted for a temperature check. The three check billets were kept separated from the others for reuse.

This process of loading and unloading billets was repeated for the duration of each test run. Data were recorded either manually at 15-minute intervals or continuously by strip-chart recorder.

During the first two runs (on the Hague furnace), two delays resulted in billet soaking times greater than planned. On the first run, a 15-minute delay was caused by need to reshape the tongs being used to remove billets from the furnace. On the second run, a 20-minute delay resulted from severe storm-water flooding that later isolated the plant for several hours. These delays were recorded and are accounted for in the analyses that follow.

ANALYSIS OF DATA

The basic data are presented graphically in Figures C-5 through C-12. For each furnace run, the first plot shows gas consumption and weight of steel heated as functions of time. The second illustrates the temperature measurements at various points as functions of time.

The plots of weight of steel heated show the times during which the billets were being handled (unloaded and loaded) as slanted lines, and the times during which the billets were being heated as horizontal lines. The

FIGURE C-5. GAS CONSUMPTION AND STEEL THROUGHPUT; HAGUE MODEL 4 SLOT FURNACE; RUN NO. 1

FIGURE C-6. TEMPERATURE MEASUREMENTS; HAGUE MODEL 4 SLOT FURNACE; RUN NO. 1

FIGURE C-7. GAS CONSUMPTION AND STEEL THROUGHPUT; HAGUE MODEL 4 SLOT FURNACE; RUN NO. 2

FIGURE C-8. TEMPERATURE MEASUREMENTS: HAGUE MODEL 4 SLOT FURNACE; RUN NO. 2

FIGURE C-9. GAS CONSUMPTION AND STEEL THROUGHPUT; W. PAT CROW FURNACE;
RUN NO. 1

FIGURE C-10. TEMPERATURE MEASUREMENTS; WPC RUN NO. 1

FIGURE C-11. GAS CONSUMPTION AND STEEL THROUGHPUT; W. PAT CROW FURNACE; RUN NO. 2

FIGURE C-12. TEMPERATURE MEASUREMENTS; WPC FURNACE; RUN NO. 2

point captioned "Billet Heating Time-Net" represents the total heating time minus the time required for handling. It represents the point that would have been reached if the billets could have been loaded and unloaded instantly. Projecting a line vertically from this point to an intersection with the gas-consumption curve shows the amount of gas that would have been used under these idealized conditions. For the first two runs, the excess soak times described earlier are subtracted to give the net billet heating time. The results that are calculated and presented in the following sections are described as "gross" values corresponding with the total actual time, and as "net" values for the times corrected as described. Table C-1 summarizes the significant numerical data and results for all four furnace trials. The calculations and sources for each item are indicated in the final column of the table.

DISCUSSION OF RESULTS

Several comments should be noted before embarking upon a discussion of the numerical results. It should be noted that neither furnace was specially adjusted nor tuned before these trials. From the flue-gas analyses that were obtained during the runs, it appears that both furnaces were operating with 20 percent or more excess air. Operation in this mode is normal at W. Pat Crow.

Recuperator Effectiveness

A significant difference between the two furnaces evaluated in these trials is the recuperator that supplies preheated combustion air to the burners of the Hague furnace. The recuperator extracts heat that otherwise would be wasted from the combustion gases and recirculates that energy back into the furnace. The resulting improvement in overall thermal efficiency, as reflected by improved fuel economy, increases with the temperature of the preheated air. For the conditions of operation in these trials, the percent fuel saved by recuperation is roughly 3 percent for each 100 F increase in combustion air temperature.

TABLE C-1. SUMMARY OF DATA

Item	Hague Run #1 10/12/81	Hague Run #2 10/13/81	WPC Run #1 10/15/81	WPC Run #2 10/16/81	Source
(1) Furnace on (CDST)	6:47 a.m.	6:18 a.m.	6:26 a.m.	6:20 a.m.	Data Sheet
(2) Furnace Off (CDST)	10:45 a.m.	12:15 p.m.	12:52 p.m.	1:05 p.m.	Data Sheet
(3) Tot. Operating Time (Hr)	3.97	5.95	6.43	6.75	(2) - (1)
(4) Gas Meter Rdg., Start	442700	456700	525800	542100	Data Sheet
(5) Gas Meter Rdg., Finish	455800	475100	542100	563200	Data Sheet
(6) Total Gas Used (ACF)	13,100	18,400	16,300	21,100	(5) - (4)
(7) Fuel Rate, ACF/Hr	3300	3092	2535	3126	(6) ÷ (3)
(8) Billet Loading, Start	8:15 a.m.	7:30 a.m.	8:14 a.m.	7:30 a.m.	Data Sheet
(9) Billet Unloading, Finish	10:45 a.m.	12:15 p.m.	12:52 p.m.	1:05 p.m.	Data Sheet
(10) Gross Heating Time (Hr)	2.50	4.75	4.63	5.58	(9) - (8)
(11) Handling Time (Hr)	0.63	1.07	0.58	1.28	Data Sheet
(12) Other Excess Time (Hr)	0.25	0.33	-	-	Data Sheet
(13) Net Heating Time (Hr)	1.62	3.35	4.05	4.30	(10) - [(11) + (12)]
(14) Avg. Billet Temp (F)	2167	2157	2050	2162	Data Sheet
(15) Heat Content (BTU/lb)	352	351	335	351	(14) and Fig. 12
(16) No. of Billets Heated	103	264	135	281	Data Sheet
(17) Scaling Factor (%)	100	99.3	98.5	97.4	Figure 3
(18) Total Weight Heated (lb)	2808	7146	3625	7461	27.261bs x (16) x (17)
(19) Useful Heat Output (BTU)	988,416	2,508,246	1,214,375	2,618,811	(15) x (18)
(20) Gas Used for Net Heat (ACF)	10,300	11,700	15,400	17,200	Figs. 5, 7, 9, 11
(21) Avg. Gas Pressure (PSIG)	0.27	0.27	0.22	0.22	Data Sheet
(22) Avg. Gas Temp. (F)	77	91	84	87	Data Sheet
(23) Avg. Atm. Pressure (PSIA)	14.725	14.696	14.774	14.779	Data Sheet
(24) Pressure Corr. Factor	1.018	1.016	1.018	1.018	[(21) + (23)] ÷ 14.73
(25) Temp. Corr. Factor	0.968	0.944	0.956	0.951	520 ÷ [460 + (22)]
(26) Avg. Gas GHV (BTU/SCF)	1021.4	1021.4	1021.4	1021.4	Gas Co.; 12 Mo. Avg.
(27) Corrected GHV (BTU/ACF)	1007	982	994	989	(24) x (25) x (26)
(28) BTU's Consumed, Gross	13,191,700	18,068,800	16,202,200	20,867,900	(27) x (6)
(29) Gross Efficiency (%)	7.49	13.88	7.50	12.55	[(19) x 100] ÷ (28)
(30) Gross BTU/lb	4698	2529	4470	2797	(28) ÷ (18)
(31) Gross lb/hr Heated	1123	1504	783	1337	(18) ÷ (10)
(32) BTU's Consumed, Net	10,372,100	11,489,400	15,307,600	17,010,800	(27) x (20)
(33) Net Efficiency (%)	9.53	21.83	7.93	15.39	[(19) x 100] ÷ (32)
(34) Net BTU/lb	3694	1608	4223	2280	(32) ÷ (18)
(35) Net lb/hr Heated	1733	2133	895	1735	(18) ÷ (13)
(36) Gas Used, Startup (ACF)	4800	4000	5500	3700	Data Sheet
(37) Gas Used, Net-Minus-Startup (ACF)	5500	7700	9900	13,500	(20) - (36)
(38) BTU's Consumed, Net-Minus-Startup	5,538,500	7,561,400	9,840,600	13,351,500	(37) x (27)
(39) Net-Minus-Startup Efficiency (%)	17.85	33.17	12.34	19.61	[(19) x 100] ÷ (38)
(40) Net-Minus-Startup BTU/lb	1972	1058	2715	1790	(38) ÷ (18)
(41) Max. Top Shell Temp (F)	170	170	180	180	Data Sheet
(42) Max. Side Wall Temp (F)	230	275	280	288	Data Sheet

The effectiveness of a recuperator in recovering heat is usually expressed in terms of the air preheat and the furnace-gas exit temperatures as follows:

$$E = \frac{T_2 - T_1}{T_g - T_1} \times 100$$

where

T_2 = Air outlet temperature, F

T_1 = Air inlet temperature, F

and T_g = Exhaust gas temperature, F.

Typical values for the two runs made on the Hague furnace were: $T_2 = 800$ F; $T_1 = 80$ F; $T_g = 2350$ F. The effectiveness calculated from these data is about 32 percent, whereas this type of equipment is expected to have an effectiveness of about 50 percent. At this higher effectiveness, the air preheat temperature would have been 1100 to 1200 F, and the corresponding fuel savings about 10 percent above those actually achieved.

The reason for the low effectiveness is not known, although it was confirmed by the operating staff that the temperatures achieved are characteristic of this unit. Earlier test results presented by Hague⁽¹⁾ showed that about 5 hours were required to reach a steady-state temperature for air preheat; this is consistent with the results from these tests.

Performance Measures

Two performance measures have been chosen to describe the behavior of the two furnaces in this test. The first is thermal efficiency, defined as

$$E = \frac{\text{Useful Heat Output (Btu)}}{\text{Energy Input (Btu)}} \times 100$$

(1) Final Report on Demonstration and Testing of High Performance Slot Furnace, April, 1978, Contract No. EC-77-C-02-4236, Hague International, South Portland, Maine to U. S. Department of Energy.

and the second is Specific Energy Consumption, defined as

$$\text{SEC} = \frac{\text{Energy Input (Btu)}}{\text{Weight of Steel Heated (lbs)}}$$

These two quantities are inversely related, and are equivalent for situations where the steel is heated to the same temperature.

The energy input is taken as the energy supplied by the fuel consumed (natural gas) over a suitable time interval. This is obtained as the product of the difference in meter readings, the meter pressure- and temperature-correction factors, and the gross heating value of the fuel. Different time intervals may be considered suitable in various operations, and the operating performance numbers that result will differ accordingly. In these trials, we have reported the performance results on three bases, as described below:

(1) Gas Consumed--Gross. This includes the total gas consumed during the run from furnace startup until all the billets were removed. This value, therefore, includes the energy required to bring the furnace up to operating temperature as well as that used during various delays caused by handling and other circumstances.

The furnace performance calculated using this energy value should be typical of production conditions. When averaged out over many cycles or days of operation, a reasonable comparison can be made between two units in the same plant.

(2) Gas Consumed--Net. This value is calculated by subtracting from the total the amount of fuel used during unscheduled delays and in billet handling. It includes the fuel consumed in bringing the furnace up to forging temperature. For the trials reported here, it provides a fairer comparison between the two units because for various reasons (not related to the furnaces) more delays were encountered during the runs on the Hague furnace.

(3) Gas Consumed--Net Minus Startup. This energy is the same as (2) - Gas Consumed--Net, but with the deletion of the energy required to bring the furnaces up to operating temperature. This value will give the highest performance numbers, and is typical of the performance that might be expected in a 3-shift or continuous operation. Performance calculated on this basis, expressed either as a thermal efficiency or as Btu/lb of steel heated, should be close to the highest of which the furnace is capable.

Useful Energy Output is defined as the amount of heat added to the product. It is calculated as the product of the weight of steel heated, its specific heat, and the temperature difference between start and finish. It is convenient to combine the last two terms into the Heat Content (Btu/lb) for steel. Values for Heat Content are plotted as functions of temperature in Figure C-13. The weight of steel heated is the product of the number of billets heated, the average billet starting weight, and a scaling factor corresponding with the number of times the billet had been heated previously. For the first run on the Hague furnace, none of the billets had been previously heated. For the second run, half the billets had been heated once. For the WPC furnace runs, the billets had been heated previously once for Run No. 1 and twice for Run No. 2.

Furnace performance was calculated as described above, and the numerical results are listed in Table C-1. The results are presented graphically in Figures C-14 through C-19 on both linear and logarithmic scales.

Regardless of the basis chosen for computing the performance values, the Hague furnace was the more efficient of the two. The advantage was greatest when the comparison is made on the basis of Net-Minus-Startup fuel used, and least when based on the Gross fuel used. For Net-Minus-Startup fuel, the specific energy consumption for heating 7500 lbs of steel was about 1000 Btu/lb for the Hague furnace and about 1800 Btu/lb for the WPC furnace.

Although this represents a potential fuel savings of about 41 percent for the Hague furnace, it should be noted that the performance of the WPC furnace is excellent for an unrecuperated unit, and is well above the

FIGURE C-13. HEAT CONTENT OF IRON AND STEEL AS A FUNCTION OF TEMPERATURE (COMPOSITE OF DATA FROM SEVERAL SOURCES)

FIGURE C-14. SPECIFIC ENERGY CONSUMPTION COMPARED ON BASIS OF GROSS GAS USED

FIGURE C-15. SPECIFIC ENERGY CONSUMPTION COMPARED ON BASIS OF NET GAS USED

FIGURE C-16. SPECIFIC ENERGY CONSUMPTION COMPARED ON BASIS OF NET-MINUS-STARTUP GAS USED

FIGURE C-17. FURNACE EFFICIENCY COMPARED ON BASIS OF GROSS GAS USED

FIGURE C-18. FURNACE EFFICIENCY COMPARED ON BASIS OF NET GAS USED

FIGURE C-19. FURNACE EFFICIENCY COMPARED ON BASIS OF NET-MINUS-STARTUP GAS USED

performance of the average slot forge furnace. It likewise should be noted that the air preheat developed by the Hague recuperator was several hundred degrees lower than would be expected. At 1100 to 1200 degrees F preheat, the Hague furnace should be capable of performing at a specific heat consumption well below 1000 Btu/lb.

Based upon observations during these furnace trials, the second runs on each furnace were judged to be near their heating capacities under the conditions of operation (e.g., batch heating). Under typical production conditions, they would be operated at lower heating rates and at correspondingly lower efficiencies. Because this plant currently is operating on a single shift, the performance data for production runs would be expected to be close to the Net basis of comparison (Figures C-15, C-18) rather than the Net-Minus-Startup basis (Figures C-16, C-19).

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