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FOUNDRY ENERGY CONSERVATION WORKBOOK

Fall 1990

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INTRODUCTION

There is no longer any need to stress the importance of saving energy. Price increases and the realization that reserves of fossil fuels are finite and limited is an internationally recognized fact of modern life.

As a result, many governments, while searching for alternative energy sources and supporting new energy development programs, are taking direct action to conserve those resources that still remain. This workbook and the seminars that will be represented using this workbook are examples of this type of effort.

The foundry industry is a significant user of energy and therefore, a natural candidate for efforts to save energy and improve efficiency by both governmental agencies and technical/trade associations. These efforts are designed to both improve the national energy position and improve the industry's efficiency and profitability.

Increased energy cost and the reduced availability of fossil fuels at certain times have provided the incentive to curb waste and to utilize purchased energy wisely. Energy costs now approach and sometimes exceed 10% of the sales dollar of many foundries. Although energy use by foundries has gradually decreased on a per/ton basis in recent years, the foundry industry must continue to find ways to utilize energy more efficiently.

A. ENERGY UTILIZATION

The average foundry consumes approximately 70 to 80 percent of its total energy input in three principal areas of operation:

- Melting operations
- Heat treating operations
- Ladle heating operations

Areas of secondary importance for energy reduction measures are:

- Cleaning and finishing operations
- Mold and core making
- Pouring and shake-out

- Sand reclaim system
- Dust and fume collection
- Compressed air systems
- Heating, ventilation and air conditioning systems
- Process cooling water systems
- Domestic hot water heating systems

Additional areas where energy conservation measures may be utilized:

- Building lighting systems
- Building weatherproofing
- System shut down during nonproduction periods
- Improvement in preventive maintenance programs

Long term process changes for significant energy reduction measures are:

- Scrap preheating
- Increasing yield
- Reduction in casting weight
- Reduction in holding furnace operations
- Preheating of castings
- Cogeneration systems

As stated above, approximately 70 to 80% of a foundry's energy input is consumed by melting, heat treat and ladle heating operations. Investment casting facilities and foundries in colder climates, however, would reduce this percentage due to the relatively large amounts of energy consumed for large process air conditioning systems and make-up air ventilation systems.

The following is a typical example of the energy mix and annual consumption rates in a steel foundry:

Item	Btu's per yr ($\times 10^6$)	% overall energy
<u>Natural Gas</u>		
Heat treat	30,180	42
Ladle heating	16,490	23
Core drying and misc. gas	681	1
Subtotal	47,351	
<u>Electricity</u>		
Arc furnace (5 tons)	13,000	18
Induction furnace (250 kW)	1,000	1.5
Lighting	750	1.0
Major motors	7,000	10
Misc. Electrical	3,000	3.5
Subtotal	24,750	100
Foundry total	72,101	

NOTE: Above figures not applicable to nonferrous operations.

The above figures are purely hypothetical from the standpoint of yearly energy consumed by various processes; the overall energy utilization percentages are fairly representative of a steel foundry operation. The energy mix is approximately 56% gas and 34% electricity.

Based on the above observations this energy conservation workbook will address the three primary energy consuming processes, as previously mentioned, namely metal melting, heat treating and ladle preheating. An in-depth energy management analysis will be performed, by utilizing hypothetical mathematical models, to illustrate the potential energy savings and energy cost reduction measures possible by modification of existing equipment and/or changing basic process operations.

The principal areas for the "in depth" analysis will be as follows:

A. Gas Consuming Equipment

1. Heat treat furnaces:

- (a) Installation of recuperators to preheat combustion air.
- (b) Changing of burner system from atmospheric type to sealed - pressure regulated burners.
- (c) Upgrading of heat treat furnaces to eliminate cracks and openings.

- (d) Change conventional fire brick to ceramic fiber liners.
- 2. Crucible or reverberatory furnaces:
 - (a) Installation of recuperators to preheat combustion air.
 - (b) Change burner system.
 - (c) Replace castable refractory with vacuum - formed ceramic fiber.
 - (d) Provide charge access covers while furnace is in a holding mode.
 - (e) Install electric melt furnaces.
- 3. Ladle heating:
 - (a) Change burner from atmospheric to gas and compressed air with regulators.
 - (b) Install insulated covers
 - (c) Add insulation
 - (d) Change to electric ladle heating
- B. Coke Consuming Equipment (Cupola)
 - 1. Twin blast lined cupola
 - 2. Hot blast lined cupola with recuperation
 - 3. Hot blast water cooled cupola with recuperation and gas afterburners
 - 4. Oxygen enriched cupolas
- C. Electrical Consuming Equipment
 - 1. Electric Arc Melting Furnace
 - (a) Off-peak melting
 - (b) Controlling demand
 - (c) Maximizing heat transfer
 - (d) Load management and optimization
 - (e) Installing water cooled blocks

2. Induction Furnace Melting (Coreless)
 - (a) Off-peak melting
 - (b) Improve operational methods
 - (c) Improved furnace design
 - (d) Oxygen-fuel assisted melting
 - (e) Water cooling heat recovery
 - (f) Maximization of melting capacity
3. Induction Furnace Melting (Channel)
 - (a) Off-peak melting
 - (b) Improve furnace design
 - (c) Water cooling heat recovery

Energy conservation associated with other foundry processes (i.e., those that collectively represent approximately 20% of total energy input) will be discussed briefly, however, no attempt will be made to quantify possible energy savings.

PERFORMING AN "IN-HOUSE" ENERGY AUDIT

An efficient energy management program can only be implemented successfully if energy consumption habits of various foundry equipment is identified and recorded in a logical and workable format.

The result of active energy management is improved energy utilization; this invariably pays off in dollars, as well as making a major contribution to the national drive towards energy conservation.

To effect this result management should implement the following procedures:

1. Understand the plant's energy services and organize for day-to-day control.
2. Cost the energy services to determine incentives for potential profit.
3. Apply the same basic business principles to energy services that are used for other materials and supplies.
4. Encourage a long range energy plan that fits future plans of the foundry.
5. Initiate regular performance reports on energy usage.

Before the above work assignments can be put into effect, a comprehensive plant energy audit must be conducted. The following is a step by step procedure for an "in-house" audit.

1. Analyze gas, electricity and miscellaneous fuel bills for the past 12 months and convert all energy information into Btu's; use the following conversion figures to accomplish this:

- 1 kWh = 3,412 Btu's
- 1 MCF natural gas = 1,000,000 Btu's
- 1 pound coke - 12,500 Btu's
- 1 gallon of propane = 91,600 Btu's

While tabulating annual consumption of energy sources into Btu's and dollars, an attempt should be made to determine which departments use how many Btu's of which fuel type (installation of in-house metering is essential for accurate data).

2. Analyze and record production schedules for the same time frame used for energy consumption. Total number of units in pounds produced by each department and the entire foundry should be recorded, also on a month to month basis. Make sure all information is recorded in units or weight and not a combination of both.
3. Physically inspect all equipment and identify systems or processes which are wasting energy and offer the best cost effective energy program. To determine equipment efficiencies, the following data should be recorded:
 - (a) Total running time of equipment per day
 - (b) Hourly energy consumption converted to Btu's
 - (c) Operating temperatures
 - (d) Flue and stack temperatures
 - (e) Flue and stack airflow rates
 - (f) Combustion data: i.e., CO₂ content of flue gas
 - (g) Type and model number of gas burners
 - (h) Ancillary motor horsepower
 - (i) Material through-put in pounds
 - (j) Electrical demand profile and power factors

4. Utilization of data gathered under items 1, 2, and 3 will be sufficient to calculate:

- Available heat to do useful work
- Efficiency of equipment
- Available heat for reclamation
- Electric power utilization and efficiency
- Percent energy savings

Section 3 will show examples of how to construct an energy flow diagram by utilization of mathematical models. Also, Section 3 will illustrate the necessary procedures required to calculate potential energy savings.

Construction of energy flow diagrams for various equipment processes will identify which areas offer the greatest energy saving potential. The final step is to make an economic evaluation in order to calculate the return on investment for capital improvements. Return on investment (ROI) will require the following input information.

- First Cost (Capital Expenditure)
- Annual Operating Costs
- Annual Fuel Savings
- Projected Fuel Price
- Estimated Life

A simple method for economic analysis is to calculate the payback period; this method utilizes the above basic data and will be used in this study.

SECTION 2 ENERGY USE IN FOUNDRIES

A. ELECTRICAL POWER

USE IN FOUNDRIES

As stated previously the typical usage of electrical energy in a steel foundry amounts to approximately 34% of the total energy used. The percentage could be much higher in foundries engaged in around the clock electric melting and minimal heat treat operations. Nonferrous foundries, on the other hand, will generally utilize less than 34% of electrical energy due to heavy gas melting.

Electrical energy is used in the following foundry operations:

- Melting metal
- Refining metal
- Holding melted metal
- Transporting melted metal
- Mixing and transporting sand
- Transporting cores and molds
- Cleaning and finishing (air compressors)
- Environmental control
- Miscellaneous equipment
- Lighting
- Heat treating

ELECTRICAL TERMINOLOGY

In this section reference will be made to various electrical units; to enable an understanding of each unit, the following identification is provided:

Pressure (Volt);	The volt, the pressure or potential difference required to produce one ampere in a resistance of one ohm. 1 kilo-volt (kv) = 1,000 volts.
Quantity (Coulomb);	The quantity of electricity conveyed by one ampere flowing for one second. Ampere hour, one ampere for one hour.

The watt is the power generated by a steady current of one ampere at a pressure of one volt. The kilowatt (kw) = 1,000 watts. One horsepower = 746 watts.

The joule is the energy conveyed by one watt during one second, the kilowatt hour (kwh) is one kilowatt flowing for one hour.

The farad is the electrostatic capacitance which will hold a charge at a pressure of one volt.

The ampere, the rate of flow of a unvarying electric current.

The product of the rated load amperes and the rated range of regulation in kilovolts (kva).

The cost of purchasing electrical power from the utility companies is derived from four major factors; they are, energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Other incidental items which affect the power charges are, character of service, service voltage, and equipment charges - these are fixed charges.

Example of a Typical Bill

KILOWATT-HOUR METER NO.				KILOWATT-HOUR METER NO.									
SERVICE FROM TO		READINGS FROM TO		KWH	SERVICE FROM TO		READINGS FROM TO		KWH				
05	24	06	25	1352	1415	756,000	05	24	06	25	0941	0981	480,000
(7)						(2)	(7)				(3)		
TOTAL KWH						756,000	YEAR 1979		TOTAL KVARH		480,000		

BILLING DEMAND: 3840 (5)

BILLING CONSTANTS: 12000 KWH (2) 12000 KVARH (3) A

MAXIMUM DEMAND: 3840 (4)

REACTIVE DEMAND: 2438 (5)

RATE SCHEDULE

(9) INCL. STATE TAX @ 1 CENT/100 KWH A-7 (1)

DEMAND CUSTOMER OR SERVICE CHARGE:	3,615.70	(8)	<div style="border: 1px solid black; height: 150px; margin-bottom: 10px;"></div> <p style="text-align: center;">SERVICE ADDRESS</p>
ENERGY CHARGE:	29,010.33	(9)	
(10) GROSS BILL:	32,626.03		
VOLTAGE DISCOUNT:			
POWER FACTOR ADJUSTMENT:	706.77 CR.	(11)	<p>PREVIOUS BALANCE</p> <p>DEPOSIT REFUND</p> <p>AMOUNT DUE: 31,652.88</p>
(13) NET BILL:	266.38 CR.	(12)	
31,652.88			

(14)

EXPLANATION OF EXAMPLE ELECTRIC BILL

1. The utility rate schedule A-7 is the key to analyzing the electric bill. It is normally included as part of the contract.
2. The energy used expressed in kilowatt-hours (KWH) is determined by the difference of two monthly meter readings times the billing constant 2A .

The billing constants 2A and 3A are also described as "Meter Multipliers". They are determined by the product of the current and potential transformer ratios installed at the particular location.

3. The reactive power used, sometimes called "wattless power", expressed reactive kilowatt ampere hours (KVARH) is determined from a separate reactive meter similar to the KWH meter 2 above.

This power is required to magnetize the steel cores of motors and transformers. It is not registered on the KWH meter.

4. The maximum demand in kilowatts for the current month is read from a separate register on the KWH meter. The value is the largest quantity of kilowatts consumed during a time interval prescribed in the contract. Example - 30 minutes.
5. The reactive demand in KVAR is calculated from the formula $KVAR = KW (KVARH/KWH)$.
6. The billing demand is the average of the maximum demand for the past 11 months and the current month's demand. The minimum is half of the past 11-month value.
7. Date and time span of the current billing.

8. The service charge, as specified in the rate schedule, is based on the billing demand item 6 and the service charge, is also used as the minimum billing if the energy usage falls to a low value.
9. The electrical energy charge is based on the kilowatt hours used as shown in item 2 . Certain adjustments are made to the energy charge determined from the meter readings as follows:
 - a) Energy cost adjustment known as "ECAC" varies with the change in fuel cost to the utility.
 - b) Fuel balance factor usually is a credit.
 - c) Load management factor.
 - d) State tax as indicated on the monthly bill.
10. The gross bill is the summation of items 8 and 9 .
11. The voltage discount is available for services that are metered on the high voltage or primary side of the power company transformer. This discount is made to compensate for the utility transformer losses which are now included in item 2 .
12. The power factor adjustment may be a penalty or a discount depending on the amount of reactive power, item 3 , required by a plant. Power factor is defined as the ratio of the kW to KVA, sometimes stated as the ratio of "real power to the apparent power", this value is not read directly from the utility meters but must be calculated. A simpler method, using a hand calculator, is to solve as a right angle triangle where power factor (PF) = KW/KVA = KWH/RKVAH

$$RKVAH = (KWH)^2 + (RKVAH)^2$$

$$\text{This month's PF} = 756,000 / \sqrt{(756,000)^2 + (480,000)^2} = 0.849$$

$$\%PF = 100(0.849) = 85.9\% \text{ Power Factor}$$

On this rate schedule a power factor over 70.7% provides a credit; below a penalty, however, other utilities may use a different break even point - 85% is used by many.

13. City tax where applicable.

14. Net bill is the summation of all of the above charges, adjustments, and credits.

THE ENERGY CHARGE

Energy charge is based on the number of kilowatt hours (kWh) used during the billing cycle. The total kilowatt hours are multiplied by the energy charge for total energy billing. The energy charges can vary with the type of service, voltage, and energy consumption. Example - energy rate schedules are as follows:

Example 1. General service schedule which is applied to electrical load demand of up to 8,000 (kWh) kilowatt hours per month. Thus a non-demand charge schedule, the cost of energy and demand are one charge.

Example 2. Rate schedule A-12 is applied to electrical load demand of 30 to 1,000 kilowatt (kW) of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Example 3. Rate schedule A-22 is applied to electrical load demands of 1,000 to 4,000 kilowatt (kW) of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty. This rate schedule has a "time of day" billing rate for energy and demand for both summer and winter. The summertime hour periods are from 1 May to 30 September; the energy and demand charges change between the following hours:

- Peak hours - 12:30 pm to 6:30 pm = 6 hours
- Partial peak hours - 8:30 am to 12:30 pm = 4 hours
- Partial peak hours - 6:30 pm to 10:30 pm = 4 hours
- Off peak hours - 10:30 pm to 8:30 am = 10 hours

The wintertime hour periods are from 1 October to 30 April; the energy and demand charges change between the following hours:

- On peak hours - 4:30 pm to 8:30 pm = 4 hours
- Partial peak hours - 8:30 am to 4:30 pm = 8 hours
- Partial peak hours - 8:30 pm to 10:30 pm = 2 hours

Off peak hours - 10:30 pm to 8:30 am = 10 hours

Example 4. Rate schedule A-23 is applied to electrical load demands of 4,000 and above kilowatts (kW) of demand per month. All other charges and "time of day" billing hours and periods are the same as rate schedule A-22. Additional rates are available for the purchase of supply voltage of 4,500 or 12,000 volts, this schedule provides for a high voltage discount of the total energy and demand charges.

THE FUEL-ADJUSTMENT CHARGE

This charge is tied directly to the energy charge and can only be reduced by a reduction in overall energy usage. The fuel-adjustment charge permits the utility companies to adjust the total cost for producing energy due to increased fuel costs, without making a request for a rate increase.

THE DEMAND CHARGE

This charge compensates the utility company for the capital investment required to serve peak loads, even if that peak load is only used for a few hours per week or month. The demand is measured in kilowatts (kW) or kilovolt amperes (kVA); these units are directly related to the amount of energy consumed in a given time interval of the billing period. The demand periods vary with the type of energy demand; the high fluctuating demand has a short demand period which can be as short as five minutes, but generally demand periods are of 15 or 30 minutes. The period with the highest demand is the one used for billing demand charges. For instance, on a 15-minute demand period with a 70 kilowatt demand, and then adding a further 70 kilowatt demand for 15 minutes and then dropping back to 70 kilowatts for the rest of the billing period, the billing demand then is 140 kilowatts for that month. This represents the interval of maximum energy demand from the utility system for that month. Demand charges can be a significant portion of the total electrical bill; in some cases, demand charges can amount to as much as 80 percent of the bill. The demand charge can be reduced by smoothing out the peaks in energy demand by rescheduling of work or through a demand control program to shed loads when a demand limit is approached. This concept is particularly important for foundries using electric melting processes.

POWER FACTOR

Power factor, in simple terms, is the ratio of actual power used in a circuit, expressed in watts or kilowatts, to the power which is apparently being drawn from the line, expressed in volt-amperes or kilovolt amperes. Mathematically, power factor is expressed as

$$PF = \frac{KW}{KVA} \text{ or } KVA \times PF = KW$$

Power factor can also be defined as the mathematical factor by which the apparent power is multiplied in order to obtain active power. For example: Assume a load on a 480 volt 3-phase system: The ammeter indicates 200 amps and the watt-meter reads 120 KW - What is the power factor of the load?

The apparent power for a 3 phase circuit is given by the expression;

$$\begin{aligned} \text{KVA} &= \frac{E \times I \times \sqrt{3}}{1000} \\ &= \frac{480 \text{ volts} \times 200 \text{ amps} \times 1.73}{1000} = 290.6 \text{ KVA} \end{aligned}$$

$$\text{Therefore: } \text{PF} = \frac{\text{KW}}{\text{KVA}} \text{ or } \frac{120}{290.6} = \underline{41.2\%}$$

From the above example it is apparent that by decreasing the power drawn from the line (kVA) the power factor can be increased.

POWER FACTOR IMPROVEMENT

Preventive measures involve selecting high-power-factor equipment. Only high-power-factor ballasts should be used for fluorescent and high-intensity-discharge (HID) lighting. Power factor of so-called normal-power factor ballasts is notoriously low, on the order of 40 to 55 percent.

When induction motors are being selected, the manufacturer's motor data should be investigated to determine the motor power factor at full load. In the past few years, some motor manufacturers have introduced premium lines of high-efficiency, high-power-factor motors. In some cases, the savings on power factor alone can justify the premium prices charged for such motors. Motors should also be sized to operate as closely as possible to full load, because power factor of an induction motor suffer severely at light loads. Power factor decreases because the inductive component of current that provides the magnetizing force, necessary for motor operation, remain virtually constant from no load to full load, but the in-phase current component that actually delivers work varies almost directly with motor loading.

Corrective measures for poor power factor involve cancelling the lagging current component with current that leads the applied voltage. This cancellation can be done with power-factor-improvement capacitors, or by using synchronous motors. Capacitors have the effect of absorbing reactive current on a one-to-one basis, because almost all of the current flowing through a capacitor leads the applied voltage by 90 deg. A capacitor rated at 100 kilovolt-amperes capacitive (kvac) will, therefore cancel 100 kilovolt-amperes reactive (kvar).

Synchronous motors provide an effective method of improving power factor because they can be operated at leading power factor. Moreover, power factor of a synchronous motor can be varied by varying the D.C. excitation applied to the motor. To be effective in improving power factor, remember, a synchronous motor cannot be applied to intermittent loads, because overall plant power factor will decrease when the motor is not in service.

A synchronous motor can be used in lieu of an induction motor, with a resulting improvement in power factor. In this example, using a synchronous motor to serve a load with actual power requirements of 1,000 kW, improves power factor on the load center from 80 percent to 89 percent. This improvement at the load center contributes to an improvement in overall plant power factor, thereby reducing the power factor penalty on the plant electric bill. The burden on the load center, plant distribution system, and entire electric-utility system is 400 kVA less than if an induction motor with a power factor of 85 percent were used. Power factor can be improved still more by operating the synchronous motor at leading power factor.

POWER DEMAND CONTROLS

The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded. The role of such a power demand controller has been widely recognized, the "time of day" billing rates will make it far more necessary in the future. The type of controller best suited for a foundry operation is that which will predetermine the demand limit and the demand interval.

The overall usage of power is constantly monitored from the power company meter, the power usage of all the controlled loads is also monitored. By having this information the controller can calculate when an overrun of the desired demand limit will occur. The controller will delay any shed action to allow time for loads to shed normally. When it is determined that it will be necessary to shed one or more loads, to keep from exceeding the demand, the controller at the last possible moment will shed the necessary loads. This means that shedding will occur only once during a demand interval and maximum use of available power will be realized.

DEMAND SHIFTING

Due to the lack of availability and the increased cost of natural gas and petroleum products, industry has come to rely on electrical power as a major source of energy. The use of electrical energy has increased at a greater rate than was anticipated and therefore a critical shortage has also been created in some areas. This is particularly true during the normal working day hours. Over the past few years this condition has caused situations known as "brown-outs", which is controlled curtailment of power.

Even with power companies doing their best to cope with the problem by building new generating stations, installing additional equipment in existing facilities, and operating all equipment at maximum capacity, they still have not been able, in some cases, to keep up with the rapid growth in the demand for electrical energy.

The demand for electrical energy is not constant, but occurs in peaks and valleys. Power companies are obligated to have enough equipment available to meet a customer's peak demand, even though this equipment is only used during the peak periods and is not in use during most of the working day. In order to finance the equipment necessary to provide this peak demand service for industrial users, the power demand charge was created. In some localities this high demand rate is the rate which is paid for the next year, even if it is never reached again, and the price paid for power demand can be very high.

With peaks and valleys in electrical demand, caused by electrical melting during the normal work day, maximum demand peaks should be controlled by sequencing the furnace's operation and maximum power input to each furnace. By applying this procedure, the revised operation would level out the peak demands and produce a flat demand profile during normal day time melting. With this melting operation the "Load Factor" would be improved, thus preventing high maximum demand peaks, which are developed through all furnace's operating on full power at the same time. (See Figures 2-1 and 2-2 for comparison.)

OFF-PEAK MELTING

With the revised billing methods of "time of day" rates being adopted by the electrical utility companies, any energy user of 1,000 kilowatts (kW) or over of demand, each month, will be billed on the "time of day" billing rate schedule. It will be noted from the schedule that demand and energy charges are high during normal working hours, with no demand charge during the night hours and very low energy charges. If the metal melting operation was moved to a night operation, maximum savings could be made on energy costs with no demand cost charge. The amount of night melting will depend on the total melting and holding capacity available.

If the melting and holding capacity is limited, it may require molding and pouring to be carried out at night together with melting to take full advantage of the "off-peak" electrical rates.

For graphic illustration of off-peak melting operations see Figure 2-3. For load profile for off-peak melting see Figure 2-4.

CAUTIONARY NOTE - It may be difficult to obtain adequate supervisory personnel for night shift operations resulting in quality and productivity problems.

FIGURE 2-1.

SUMMER "TIME OF DAY" BILLING
KILOWATT DEMAND PROFILE
(UNCONTROLLED)

FIGURE 2-2.

SUMMER "TIME OF DAY" BILLING
KILOWATT DEMAND PROFILE
(CONTROLLED)

KILOWATT
DEMAND
(x 10)

KILOWATT DEMAND BY "TIME OF DAY" BILLING

KILOWATT
HOURS
(x 100)

KILOWATT ENERGY USAGE BY "TIME OF DAY" BILLING

FIGURE 2-3 GRAPHIC ILLUSTRATION OF "OFF-PEAK" MELTING

FIGURE 2-4 LOAD PROFILE - "OFF-PEAK" MELTING

MAXIMIZATION OF MELTING CAPACITY

In this and other sections of this study references and recommendations have been or will be presented for electrical energy conservation in the melting of metal. As previously stated, approximately 34% of the total energy used in a typical steel foundry is electrical. Of the 34% approximately 20% is used for melting or holding melted metal. The total kilowatts used for melting a ton of metal can only be reduced with improved furnace efficiency and operation, which will reduce the melt rate (tons/hour) and reduce energy consumption (kilowatt hours/ton). Areas where maximizing the melting capacity can save substantial energy are:

- Load factor should operate at high percent power utilization. The measure of the efficiency of utilization of electrical energy, taken on a monthly basis, is determined as the ratio of the average consumption in the month to the peak demand in that month.

- Electrical power costs per ton of metal melted will increase when "holding" metal for any length of time due to decreased power utilization. This condition is due to the thermal losses becoming proportionally larger when the furnace is in the idling mode, thus a melting operation should utilize full furnace power whenever possible and restrict holding time, thereby maximizing energy-saving potential.

- During slagging and charging of induction furnaces, it is necessary to open the furnace cover or lid to accomplish the intended actions. When the lid is open, thermal losses occur due to radiation from both the lid refractory and from the molten iron. The longer the "lid-open" time, the greater the loss of energy from the furnace. It follows that the energy consumption charge will increase with increased "lid-open" time, thus "lid-open" time should be no longer than absolutely necessary. The same principles apply to opening the roof on an arc furnace.

- The use of on-load solid-state stepless power controls has the following advantages:

1. Furnace power can be maintained at a maximum level throughout the lining campaign.
2. Furnace power can be phased back exactly as required by the plant demand control system.
3. Furnace power can be phased back easily while tapping and charging which increases productivity.

A good furnace operator can save energy in many ways. Fast charging and slagging of the furnace, with minimum cover "open time", will save the most heat energy. Bringing metal to temperature shortly before it is dispatched to the molding line and not keeping the metal in the furnace at its highest temperature for a prolonged period of time will result in less heat losses via refractory and spout; an added advantage is prolonged lining life. With an automatic molding line operation, it would be practical to deliver metal to the pourer in constant intervals, and deliver only the amount of metal he can pour in the molds rather than

supply him with a constant amount of metal he cannot pour off before it cools down to the point where pigging is required.

Some foundaries melt off-peak and hold so that pouring can be completed during the day-shift, thereby reducing demand charge.

MELT FURNACE IMPROVEMENT

Electric Arc Furnaces

The arc furnace is a refractory-lined vessel. At the beginning of the melting cycle it is filled by swinging aside the movable refractory lined roof and dumping in a charge of metallic scrap. The electrical energy needed to convert this charge to liquid metal is transmitted through several electrical distribution components, ending with the electrodes in the arc furnace (See Figure 2-5).

The furnace transformer takes the high transmission voltage and converts it into a lower operating voltage. The operator can choose from several operating voltage levels called "tap voltage".

Energy consumption, measured in kwh per ton, is fairly constant in most arc furnace operations, ranging from 450 to 550 kwh/ton of charge, depending on the scrap type and length of heat. There are few opportunities to decrease power consumption in electric arc furnace melting because the roof is off only for charging. However, heat can be recovered from the cooling water or furnace stack. Scrap preheating is an effective energy and electrode saver, as is the use of oxy-fuel burners.

Energy cost savings however can be substantial by applying the following procedures:

- Off Peak Melting
- Demand Limiting
- Demand Shifting

Energy conservation in arc melting is closely tied to power distribution, power demand regulation, furnace regulation and, most important, operating practices.

In a given furnace, the fastest heat usually not only produces the most tonnage but also converts energy most efficiently. The heat transfer at the arc should be optimized under various operating conditions. "Bore down" and "melt down" are normally best performed using maximum power for long arcs whose increased mobility speeds up the conversion of scrap to hot metal with minimum electrical losses. During meltdown, where the arc is surrounded by scrap, approximately 75 percent of all energy is used and thermal losses are at a minimum. During the refining period, when sidewalls are bare and only energy at a low power level is needed, to raise the bath temperature a few degrees, thermal losses are correspondingly higher.

Energy conservation in arc melting can be affected by many different variables. The most important ones are:

- arc furnace regulation — This system automatically lowers and raises the electrodes during the automatic mode of operation, always responding to the change in secondary current and voltage, and maintaining a pre-set distance between the electrode tip and the furnace charge. A regulating system which is not optimized can result in long and inefficient heats, requiring additional energy.
- power system characteristics — Primary power distribution switching by the supply and power company can change the existing short-circuit capacity and perhaps the primary voltage which in turn affects the arc length, resulting in excessive electrode consumption or excessive refractory erosion. This type of variable will also affect furnace productivity resulting in a higher consumption of energy.
- operating delays — Interruption in melting, scheduled or unscheduled, by unnecessarily lengthening the heat time, reduces furnace output and adds to the thermal losses in melting and can greatly increase the consumption of energy.
- human element — People are responsible for most major problems or improvements in energy conservation. Unnecessarily long, inefficient heats caused by many different interruptions always require additional energy. Energy can also be wasted by not using optimum voltage selection or by inappropriate changing power input, power factor and current due to misuse of electrical control devices. More and more arc furnace melt shops are placing increased emphasis on operator training in order to achieve better production and improved energy conservation.

A power profile or power program, which takes into consideration the full equipment capability, can be used with or without automated operation to greatly improve overall melting performance and energy management. This program defines precisely when to change the power input characteristic or when to recharge by noting the consumption of energy (kw/hr) in relation to weight and makeup of charge material.

FIGURE 2-5. SCHEMATIC ARRANGEMENT OF THE ELECTRODES, THEIR SUPPORTING MASTS, AND THE ELECTRICAL LEADS FOR AN ELECTRIC-ARC STEELMAKING FURNACE

Induction Furnaces

Iron foundries that utilize electricity for melting use mostly coreless and channel type induction furnaces. All induction furnaces operate on the principle that when alternating current is passed through a coil, a magnetic field is created which induces eddy currents in a metal charge placed within that field. The degree of heating achieved is dependent on the rate of variation of the magnetic field (frequency) and on its intensity (power).

Channel furnaces are used for melting and duplexing, the requirements to always keep a heel in the furnace and the limitations of inductor power level limits their application as a primary melter. Electrical efficiency of an inductor is 94-95 percent, this is extremely high compared to coreless furnaces with a 76-81 percent efficiency.

Coreless furnaces lose approximately one fifth of the total energy consumed to the cooling water system, therefore considerable work has been done to improve furnace design.

The use of profile "D" (see Figure 2-6), for the power coil, reduces the penetration of magnetic flux lines through the outside corners which minimizes eddy current losses. Also, "D" profile allows the coil to be wound tighter with sufficient creepage distance which improves efficiency.

The cooling coils (Figure 2-7), on top and bottom, extract energy which should have gone into the melt. The use of newer castable backup refractory helps eliminate the need for cooling coils.

Electrical efficiency of the induction furnace can be increased by as much as 10% with these improvements. A foundry shipping 20 tons a day (at 50% yield) can save approximately \$20,000 annually with 10% improvement in efficiency (cost of electricity 4 cents kwh including demand charge).

FIGURE 2-6

FIGURE 2-7

Electric Resistance Heated Reverberatory Melting Furnace (for Aluminum Melting)

Much like the fuel-fired furnace, the Electric Reverberatory Melting Furnace (ERMF) is constructed with an aluminum-resistant refractory lining and a structural steel shell. The total height of the furnace is much lower because the bath depth is more shallow, and less space is required above the bath. The furnace is heated by silicon carbide or other resistance elements mounted horizontally above the bath. Heat is transferred through direct radiation from the elements and radiation from the refractory roof and sides.

The second type ERMF metal melting system employs electric immersion type elements. The elements are inserted into silicon carbide tubes which are immersed into the molten aluminum. Through radiation, the element passes its heat to the silicon carbide tube and through conduction, the tube releases its heat into the bath. With the heating length of the element six inches from the bottom of the bath, temperature uniformity is good. With this immersion type, heat does not have to be transferred down through the bath from the surface.

Because the electric furnace does not need a flue, the heating chamber can be made almost airtight with the only heat loss being through the shell and from exposed radiant metal surfaces. A well is provided for charging of scrap and solids so there is no need to open the access door to the main chamber.

Metal Melting Loss

The metal loss from dross, due to oxidation, is approximately one percent for 11,000 lbs. of aluminum metal. At the present metal cost of \$1.00 per pound this represents a very significant loss, and potential for savings.

Metal Quality

With the melting of aluminum metal, low gas levels and minimum oxide inclusions are a must. The only source of hydrogen gas in an ERMF is from the materials being charged into the furnace. Treatment of scrap and clean ingots keeps hydrogen gas at low levels.

Working Conditions

Working conditions around an ERMF are vastly superior to gas-fired reverberatory furnaces, the two major differences being noise and heat. ERMF are practically noiseless, while a bank of gas-fired reverberatory furnaces creates noise levels close to OSHA limits of 90 decibels. The heat loss from a bank of gas-fired reverberatory furnaces is extremely high and could amount to approximately 15 times more than the ERMF.

Furnace Covers

Uncovered charging and dip-out wells and bath radiate 20,000 Btu/ft²/hr vs only 500 Btu/ft²/hr for a covered well, a factor of 40 times. The importance of well covers in a holding situation cannot be over-emphasized.

Graphite Rod Holding Furnace

As the graphite rod holding furnace is not a primary melting furnace, this furnace will not be addressed with regards to cost savings. The efficiency and utilization of energy input to metal holding is high. The power factor is maintained at near unity. With this type of unit not much design improvement is possible.

Ladle Metallurgy

In recent years, a great deal of emphasis has been placed on the concept of "Clean Steel Technology" in the steel foundry industry. Considerable research funding has been applied to the definition and production of clean steel. From a foundryman's standpoint, "Clean Steel" generally means low levels of sulfur and phosphorus, low gas content, and a minimum of inclusions, both macro and micro. These requirements are, of course, driven by the marketplace and these trends will continue.

These challenges have been met in the basic steel industry through the use of various ladle refining technologies. These processes, however, have been difficult to transfer directly to the foundry industry because of the small size ladles used in the typical foundry. These ladles are generally 5-ton capacity and smaller. Heat losses in small ladles are proportionally greater than for large ladles which severely restricts the time available for ladle treatments. In addition, a reagent to be used for desulfurization or inclusion control should have maximum time available for complete dissolution which implies introduction to the ladle at the very bottom and a sufficient depth of metal to allow dissolution during the time available for flotation to the upper surface. Small foundry ladles often do not have sufficient depth to allow this to occur.

A further consideration is the nature of the slag cover on the ladle. Slags that are effective in lowering the sulfur and oxygen content often have relatively high melting points and tend to crust and be non-reactive under the conditions described above. In order to overcome these problems, a good deal of work is in progress to develop viable foundry size ladle furnaces that would compensate for the heat losses and allow sufficient time for effective refining.

It is apparent from the above discussion that these ladle refining processes all result in increased processing time in the ladle and temperature losses that at times may be quite severe. One method commonly used to compensate for these heat losses is to tap the heat at a considerably higher temperature than otherwise required. However, to carry out extensive ladle refining operations without some sort of reheating would likely result in temperature losses that would be too

great to be compensated simply by using a higher tap temperature. In addition, the use of a higher tap temperature results in excessive energy consumption, excessive refractory wear and unnecessary reoxidation.

The above considerations, then, have led to the interest in developing a foundry sized ladle furnace capable of compensating for heat losses during refining, melting substantial alloy additions, and controlling (increasing if necessary) the pouring temperature.

Another feature of a foundry ladle furnace is that it is capable of increasing productivity by performing a major part of the total heat cycle in a separate vessel. This allows the primary melting unit to perform the function that it was designed for, that is, melting. Most melting furnaces, particularly arc furnaces, are very inefficient refining vessels due to shape, power input levels, and lack of stirring capability. It is for this reason, that refining is more efficiently conducted in a separate unit that is specifically designed and equipped to perform these functions. The use of this concept can increase productivity in the melting operation by approximately 20-30 per cent.

Plasma Fired Cupola

A cupola is a vertical cylindrical shaft furnace which is conventionally used in the foundry industry for the production of cast iron. One of the main features of such a furnace is counter-flow preheating of the charge material by upward-flowing hot gases. Because the conventional cupola relies on the combustion of metallurgical coke for its source of energy, the velocities of the gases are high. To avoid entrainment of scrap particles in the flowing gas stream, bridging and oxidation of small size scrap must be avoided, limiting the flexibility of choice of melt materials. Finer materials such as turnings and borings, which are much cheaper than conventional scrap, cannot be fed directly into the cupola unless they are first briquetted, a costly and inconvenient process.

In order to circumvent these problems, a plasma fired cupola has been jointly developed by Westinghouse, Modern Equipment, General Motors, and EPRI. This cupola, a more-or-less conventional cupola shaft furnace fitted with plasma torches, has the distinct advantage of providing the energy for iron melting independent of coke combustion. Since the volume of plasma gas needed to introduce this energy is much smaller than the volume of coke combustion products, the velocities of the gases rising in the plasma-fired cupola are relatively low. Therefore, low-cost charge materials like borings and turnings can be fed directly into the cupola.

Beyond allowing the use of low cost charge materials, the plasma-fired cupola has other key benefits. The oxidation of alloy elements (silicon, chromium, manganese, etc.) and their corresponding loss to the slag is a costly characteristic of conventional cupolas. By using a plasma super-heated blast at the tuyere level of the cupola, a faster reaction rate between the carbon of the coke and the oxygen of the blast air is realized, and high CO/CO₂ ratios result. This produces a highly reducing atmosphere which reduces the oxidation losses. Therefore, the

recovery of the alloy elements is increased. Moreover, the temperature in the bottom section of the cupola can be significantly increased. With this, reducing conditions can be established to a level sufficient that silicon can be produced through the reduction of silica. Procedures such as this are not practical in conventional cupolas. They apply the combustion of coke, oil or gas and attain operating temperatures of the order of 3000° F maximum. With plasma technology, temperatures in the reaction zone can reach 10,000° F.

Another economic benefit of the plasma-fired cupola is the increase in productivity due to the significantly higher operating temperatures. The melting capacity of a conventional cupola can be increased by as much as fifty percent by using plasma as an energy source. Further, the start-up of the plasma-fired cupola has been found to be much faster than the conventional cupola, thereby reducing labor cost.

The environmental benefits of the plasma-fired cupola are also noteworthy. Because of the availability of electrical energy for the melting of the iron, coke consumption and thus the generation of combustion products, can be minimized. As a result, levels of environmental emissions are reduced proportionately. Coke is required in the plasma-fired cupola to provide a source of carbon for the iron and to provide for the proper porosity of the charge material as it moves downward through the cupola shaft. It also contributes to the preheating of the upward flowing gases. Coke combustion also provides a portion of the energy required for the iron melting. Using plasma, the proportions of electrical energy and coke consumption energy can be optimized to achieve the lowest cost production on hot metal.

The initial experimental work involved a pilot-scale test cupola using a single 1500 kW Westinghouse plasma torch at the Westinghouse Plasma Center located at the Waltz Mill site in Madison, Pennsylvania. Based on the results of this work a commercial installation was constructed at the General Motors Central Foundry Division plant in Defiance, Ohio.

This cupola, called the Plasma Melter, began life as a conventional 13-ft.-diameter cupola and was retrofitted with six 1.5 megawatt direct current Westinghouse plasma torches in the tuyere section of the cupola. Blast air volume was reduced from 25,000 cfm for conventional operation to 10,000 cfm in the Plasma Melter.

The Plasma Melter produced iron for its first castings in March 1989, and is now operating on a two-shift basis with electrodes inspected and maintained over the weekends. The rated capacity of the Plasma Melter is 45 tons/hour.

This installation has been economically justified on the basis of being able to use in-house turnings and borings as melt stock without costly briquetting. These economics may not apply to all foundries, however, this technology should find wide application and contribute to the profitability of many organizations.

Plasma Assisted Cupola

A somewhat different approach to the use of plasma heating with cupola melting is the "Plasma Assisted" system developed by Aerospatiale in France. In this approach, a conventional hot-blast cupola was retrofitted with a plasma torch located in the wind box to serve as a supplemental heating device.

A demonstration study was conducted at the Sept-Fons (France) foundry of Automobiles Peugeot by fitting a portable, 2 MW plasma torch to an existing 20 ton/hour hot-blast cupola. The current installation produces gray cast iron for mass-produced parts such as cylinder blocks, hub-drums, disc brakes and exhaust manifolds. Hot blast temperature (without plasma assist) ranges from 660-930° F depending on the blast rate.

The test campaign was run using hot-blast temperatures ranging from 1650-2370° F, again depending on the blast rate. The principal advantage realized by this approach was the ability to use a higher percentage of low-cost steel scrap in the charge. In addition, Peugeot reported savings in coke consumption. Further, the use of oxygen enrichment was not required resulting in further savings. Based in Peugeot's figures, a payback period of 2.2 years was realized. The generally favorable results of this demonstration effort resulted in the commissioning of a 4 MW production unit in 1988. Operating results of this installation have not yet been reported in the literature.

Additional study of this approach is required, and it appears that the use of a lower preheat temperature may allow a lower cost installation as far as refractories, insulation, etc. are concerned. This, in turn, would shorten the payback period - perhaps significantly. This approach has considerable merit and should be studied further with the goal of optimizing the relationship between preheat temperature and installation/operating costs.

B. NATURAL GAS AND EQUIVALENT FOSSIL FUELS

USAGE IN FOUNDRIES

As stated previously in this study, a typical steel foundry uses up to 66% of its fuel energy input for gas fired equipment. In most foundries overall efficiency of melt furnaces, heat treat furnaces and ladle heating is about 20% or even lower which, in relative terms, means that for every 100 units of gas energy input only 20 units are utilized to heat the product, the remaining 80 units are expended in furnace losses and exhaust losses, Figure 2-8.

FIGURE 2-8 PROCESS ENERGY FLOW DIAGRAM

By drawing a process energy flow diagram, as illustrated above, one can actually see the major areas of concern. Once the above information has been developed, an energy flow diagram of the same process under ideal conditions can be developed. By comparing the actual diagram to the ideal, one can further improve chances of maximizing energy savings while minimizing capital investment.

While energy recovery is usually the first area addressed for energy conservation, a closer look at the problem will usually prove that improvements in the combustion air to gas ratio, furnace pressure controls, insulation, and refractory produce the bulk of the available energy savings at the least capital cost.

TERMINOLOGY AND THE BILL

Unlike electricity, gas utility bills are very simple to read, the following is a typical example of a monthly gas utility bill:

1	SERVICE PERIOD		SERVICE ADDRESS: _____		
	06-18-79	07-18-79			

2	RATES	THERMS	\$ 9,760.09
	GN-1		
	GN-2	17,667	
	GN-3	22,486	
	TOTAL	40,153	

3	METER NUMBER	METER READINGS		DIFFERENCE	BILLING FACTOR	THERMS
	2345678	PREVIOUS	PRESENT			
		917920	955980	38060	1.055	40,153

BOX 1 is the service period on a monthly basis.

BOX 2 is the rate schedule and terms used.

Gas company rates are based on the following priority schedule:

- GN-1 is for residential and small industrial users consuming less than 100,000 cubic feet of gas per day.
- GN-2 is for industrial users consuming over 100,000 cubic feet per day and who have standby fuel capability.

Box 3 shows the actual months consumption in cubic feet of gas.

The billing factor is the actual heat content of the gas. (Can vary depending on location).

The final column is the amount of therms used for the month.

Meter units are 100 cu. ft. (i.e., example equals 3,806,000 cu. ft.)

Our hypothetical bill is interpreted as follows:

1. Gas consumption @ GN-2 rate = 17,667 therms
2. Gas consumption @ GN-3 rate = 22,486 therms
3. Total gas consumption = 40,153 therms
4. Difference in meter readings = 3,806,000 cu ft
5. BTU content of gas = 1,055 BTU/cu ft
6. Amount of therms used per
month = $\frac{3,806,000 \times 1,055}{* 100,000}$ = 40,153 therms

* 1 therm - 100,000 BTU

Actual BTU's consumed = $40,153 \times 10^5$ BTUs

IN PLANT METERING

The monthly gas utility bills show how many Btu's have been expended to produce a product, what the bill does not tell you is where the Btu's were used in a particular gas consuming process.

As the nation's energy requirements grow, the Foundry Industry can expect to pay even more for gas in future years. Foundries that will remain dependent upon gas for their production processes will be placing even greater emphasis on in-plant conservation efforts in order to achieve maximum production efficiency from this increasingly expensive fuel.

Cost allocations, within departments, and fuel surcharges to customers will become commonplace. Close monitoring of allocated supplies will become a necessity in energy management.

The basic and most important tool in energy management is an energy monitoring system. Before energy can be saved, an accurate metering system must be established in the foundry to determine exactly how and in what quantities, energy is being used, considerable savings can be realized almost immediately from the data derived from an energy audit using in-plant metering.

Gas consumption monitoring can also be advantageously used to control oven or furnace temperatures and prevent over-temperature damage. Also equipment problems can be detected before they cause emergency shut down.

Measuring fuel consumption alerts maintenance crews to a variety of potential problems such as:

- Leaking fuel lines

- Faulty temperature measuring devices
- Faulty relief valves
- Excessive burner cycling
- Warped furnace doors
- Deteriorating furnace insulation

A relatively low cost monitoring device is the "Annubar". This device is a primary flow sensor designed to produce a differential pressure that is proportional to flow. The flo-tap annubar can be inserted and removed from operation without system shut down.

Annubar can be interfaced with secondary devices, a standard flow meter is available for rate of flow indication. It can be used as a portable meter or permanently mounted.

Annubar connected to a differential pressure transmitter (Electric or Pneumatic) is used with a variety of standard secondary equipment for totalizing, recording or controlling complex systems.

OBTAINING A COMBUSTION ANALYSIS

In order to determine the operating efficiency of melt and heat treat furnaces it is imperative that a flue gas analysis be made. One of the best ways available for obtaining a flue gas analysis for CO_2 and O_2 is the use of a combustion analyzer.

In most actual combustion processes the determination of correct air-fuel ratio cannot be made by direct measurement of entering air, since various leakages through auxiliary openings will be responsible for a substantial increase in total air over that metering at the burner, thus for practical purposes the air-fuel ratio must be determined by calculation from data available, hence the combustion analyzer.

The flue gas data resulting from a combustion analysis are used with suitable charts (see Section 3) for determining the percent excess air and, together with the information on flue gas temperatures, to determine the heat lost in the stack.

(N.B. pages 2-28 and 2-29 have been deleted)

TEMPERATURE MEASUREMENTS

Accurate measurement of high temperatures is one of the most critical factors in determining equipment performance and process efficiencies of energy consumption in foundries, high temperatures are defined as those between 700 and 3,500° F.

Sensors used to measure elevated temperatures are classified as either contact or non-contact. Contact sensors include thermocouples, resistance temperature detectors, bimetallic thermometers, thermistors, and filled systems. Non-contactors include optical and radiation pyrometers. Thermocouples are used in a large number of the applications in industrial plants.

Portable thermocouples of various designs are available. The instruments are compact, lightweight, and battery powered, and they can easily be carried around the plant to measure process or equipment temperatures easily. Most models have a variety of interchangeable thermocouples sensors and multiple temperature selector switches to provide maximum versatility. (See table 2-1 for comparisons).

TABLE 2-1. COMPARISON OF COMMON THERMOCOUPLES

Type	Usable Temperature Range	Advantages	Restrictions
Type J (Iron-constantan)	-300 to 1600 F	Comparatively inexpensive. Suitable for continuous service to 1600 F in neutral or reducing atmospheres.	Maximum upper limit in oxidizing atmosphere is 1400 F, because of the oxidation of the iron. Protection tubes should be used above 900 F. Protection tubes should always be used in a contaminating medium.
Type K (Nickel, chromium-nickel, aluminum)	0 to 2500 F	Suitable for oxidizing atmospheres. In higher temperature ranges, provides a more mechanically and thermally rugged unit than platinum or rhodium-platinum, and longer life than iron-constantan.	Especially vulnerable to reducing atmospheres, requiring substantial protection when used.
Type T (Copper-constantan)	-300 to 700 F	Resists atmospheric corrosion. Applicable in reducing or oxidizing atmospheres below 600 F. Stability makes it useful at subzero temperatures. Has high conformity to published calibration data.	Copper oxidizes above 600 F.
Type E (Nickel, chromium-constantan)	-300 to 1600 F	Has high thermoelectric power. Both elements are highly corrosion-resistant, permitting use in oxidizing atmospheres. Does not corrode at subzero temperatures.	Stability is unsatisfactory in reducing atmospheres.

TABLE 2-I (CONTINUED)

Type	Usable Temperature Range	Advantages	Restrictions
Type S (Platinum, 10% rhodium-platinum)	0 to	Usable in oxidizing atmospheres. Provides a higher usable range than Type K.	Easily contaminated in other than oxidizing atmospheres.
Type R (Platinum, 13% rhodium-platinum)	2700 F	Frequently more practical than noncontact pyrometers. Has high conformity to published calibration data.	
Type B (Platinum, 30% rhodium-platinum, 6% rhodium)	1600 to 3100 F	Better stability than Type S or R. Increased mechanical strength. Usable at higher temperatures than Type S or R. Reference-junction compensation is not required if junction temperature does not exceed 150 F.	Available in standard grade only. High-temperature limit requires the use of alumina insulators and protection tubes. Easily contaminated in other than oxidizing atmospheres.

BURNER COMBUSTION EFFICIENCY

Conserving fuel in melting, heat treating and ladle heating operations is a complex operation. It requires careful attention to the following:

- Refractories and insulation
- Scheduling and operating procedures
- Preventative maintenance
- Burners
- Temperature controls
- Combustion controls

Providing the correct combustion controls will increase combustion efficiency measurably. Complete combustion of Natural Gas Yields:

- (a) Carbon dioxide
- (b) Water vapor

If gas is burned with the chemically correct amount of air, an analysis of the products of combustion will show it contains about 11 to

12% CO₂ @ 20-22% water vapor. The remainder is nitrogen, which was present in the air and passed through the combustion reaction essentially unchanged.

If the same sample of natural gas is burned with less than the correct amount of air ("rich" or "reducing fire"), flue gas analysis will show the presence of hydrogen and carbon monoxide, products of incomplete combustion. Both of these gases have fuel value, so exhausting them from furnaces is a waste of fuel. (See Figure 2-9)

If more than the required amount of air is used (lean or oxidizing flame), all the gas will be burnt but the products of combustion will contain excess oxygen. This excess oxygen is an added burden on the combustion system - it is heated and then thrown away thereby wasting fuel.

The following steps should be taken to upgrade burner and combustion controls:

1. Use sealed-in burners. Make all combustion air go through the burner - open cage type burners are very inefficient.
2. Use power burners. Inspirator or atmosphere burners have very poor mixing efficiency at low inputs, especially if gas pressure is low.
3. Install a fuel/air ratio control system.

PREMIX BURNER SYSTEMS

Premix burner systems commonly use a venturi mixer known as an aspirator or proportional mixer. Air from the blower passes through the venturi, creating suction on the gas line and drawing in the correct amount of gas at reduced firing rates, air flow is cut back, reducing suction on the gas line, and the amount of gas drawn into the mixer drops in proportion to air flow. Aspirator systems are fairly simple to adjust and maintain accurate fuel/air ratios over wide turndown ranges, but their use is limited to premix burners. (Figure 2-10)

NOZZLE MIX BURNERS

Nozzle mix burners used with a Ratio Regular System is widely used for industrial furnace applications. Orifices are installed in the gas and air lines to a burner and then adjusted so that air and gas are in correct burning proportions when pressure drops across the orifices are equal. Once the orifices are set, they will hold the correct air/gas ratio as long as the pressure drop remains the same, no matter what firing rate. Ratio Regulator systems have good accuracy and are fairly easy to adjust. (Figure 2-10)

On large furnaces where fuel consumption is extremely high, or on furnaces where very close control of the atmosphere is required, extremely accurate fuel/air ratio control is vital, both for fuel economy and product quality. On these installations hydraulic or electronic flow controls are often used.

FIGURE 2-9 PERCENT EXCESS AIR FROM CO₂ READING

FIGURE 2-10 TYPICAL GAS/AIR REGULATOR HOOK-UP

These systems feature fixed orifices in both gas and air streams, and these orifices are sized to pass proportional amounts of gas and air at equal pressure drops, pressure drop signals are fed to a ratio controller which compares them. One of the outstanding features of this system is that the fuel/air ratio can be adjusted by turning a dial. Since a burner can be thrown off correct gas ratios by changes in ambient air temperature and humidity, this ratio adjustment feature permits the operator to set the burner back to peak operating efficiency with very little effort.

On multiple burner furnaces, the combustion products of all burners mix together before they reach the flue gas sampling point (Furnaces should have manifolded flue gas outlets in order to obtain common sampling point for flue gas analysis). If, for example, some of the burners are unintentionally set lean, and others rich, the excess air from the lean burners could consume the excess fuel from the rich burners, producing flue gas with ultimate CO_2 and practically no free oxygen or combustibles. Samples of these gases could be misleading and show correct air/gas ratio, when in fact they are not. Also if a burner is set rich and the excess combustibles in the flue gases find air in the stack and burn there, flue gas analysis will again suggest that the burner is properly adjusted.

To overcome the problem of misleading flue gas analysis in multi-burner furnaces, metering orifices should be installed on the gas lines to each burner. If pressure drops across all orifices are identical, gas flow to each burner will be the same.

FURNACE PRESSURE CONTROLS

Furnace Pressure Controls will afford additional energy savings, particularly on top-flued furnaces. If a furnace operates under negative pressure, cold air is drawn into it through badly fitted doors and cracks. This cold air has to be heated, adding to the burden on the combustion system and wasting fuel. If the furnace operates at high positive pressure, flames will sting out through doors, site ports and other openings, damaging refractories and buckling shells. Ideally a neutral furnace pressure overcomes both these problems.

Automatic furnace pressure controls maintain a pre-determined pressure at hearth level by opening or closing dampers in response to furnace pressure fluctuations.

In summation; good fuel/air ratio control equipment and automatic furnace pressure controls are two useful weapons for combating gas energy wastage in heating operations.

Properly applied, they also offer the side benefits of improved product quality and shortest possible heating cycles.

FURNACE EFFICIENCY

Conventional refractory linings in heating furnaces can have poor insulating abilities and high heat storage characteristics. Basic methods available for reducing heat storage effect and radiation losses in melt and heat treat furnaces are:

1. Replace standard refractory linings with vacuum-formed refractory fiber insulation material.
2. Install fiber liner between standard refractory lining and shell wall.
3. Install ceramic fiber linings over present refractory liner.

The advantages of installing refractory fiber insulation are:

- Refractory fiber materials offer exceptional low thermal conductivity and heat storage. These two factors combine to offer very substantial energy savings in crucible, reverberatory and heat treat furnaces (documented savings - 35% or better).
- With bulk densities of 12-22 lbs./cu ft, refractory fiber linings weigh 8% as much as equivalent volumes of conventional brick or castables.
- Refractory fibers are resistive to damage from drastic and rapid changes in temperature.
- Fiber materials are simple and fast to install.
- The density of fiber refractory is low, so there is very little mass in the lining, therefore much less heat is supplied to the lining to bring it to operating temperature. This results in rapid heating on the start-up. Conversely, cooling is also rapid, since there is less heat stored in the lining.
- More comfortable working environment is attainable due to lower shell surface temperatures.

The basic design criteria for fiber lined crucible furnaces are the same as used for furnaces lined with dense refractories. Two rules should be followed:

1. The midpoint of the burner should be at the same level as the bottom of the crucible, and the burner should fire tangentially into the space between the crucible and lining.
2. The space between the outside of the crucible, and the furnace lining near the top should be about 10% of the crucible diameter.

Crucible furnaces can be constructed using a combination of fiber with dense refractory or almost entirely out of fiber. Increasing the proportion of fiber will increase the energy savings and maximize the other benefits previously listed.

Fiber materials are available in varying thicknesses, suitable for a complete monolithic installation, and composition to handle 2,400° F, 2,600° F, and 2,800° F.

The higher temperature compositions contain high alumina fiber, which lowers the amount of shrinkage at elevated operating temperatures.

FURNACE COVERS

If preheating of combustion air utilizing furnace flue gas temperatures is contemplated, installation of furnace covers is mandatory. The difficulty in the past, in the fabrication and use of furnace covers, has been the problems of thermal shock and spalling, materials available today, such as refractory fiber, have eliminated these problems.

In addition to technological advantages of fiber insulations, industry has also developed the capability of vacuum forming these materials over a variety of metallic support structures. Fiber insulation can be formed over either expanded metal or angle iron frames, or both, with V-type anchors attached. The anchors are made from high temperature alloys, holding the fiber to the metallic support structures to provide an integral, fully secured assembly. No part of the anchor system is exposed to excessive temperatures, this eliminates attachment problems for ladle pre-heaters, crucible furnace covers, and induction furnace covers. Installation of furnace covers improves the thermal efficiency of the process by approximately 50%.

CRUCIBLE POT AND REVERBERATORY FURNACES

Non-Ferrous Foundries utilize three basic furnace types for melting and holding. They are:

- Gas fired crucible
- Gas fired reverberatory
- Electric reverberatory

The stationary crucible furnace is primarily used for aluminum, copper, and brass alloys. Its versatility in allowing alloy changes makes it a desirable furnace for small foundries where such metal changeover is necessary. Combustion burners are located so the flame is tangential to the crucible in order to avoid direct flame impingement against the crucible wall. Biggest disadvantage, other than thermal efficiencies, are short crucible life.

Fuel fired reverberatory furnaces are usually chosen when melt rate and/or capacity is such that a crucible would be too small. The reverberatory is direct fired from either the roof or sidewall with gas, propane, or oil burners (for the purpose of this study the relative cost per BTU is assumed as being equal). The heat is transferred to the bath by a combination of convection and radiation.

UPGRADING GAS FIRED FURNACES

1. Replace brick or castable refractory with vacuum-formed refractory fiber on gas fired crucibles.

Example -- Arrow Casting and Development Co., in Santee, California, installed fiber liners on two - 425 lb. crucibles - documented 35% saving in fuel. They can now produce a melt in one hour from cold start as compared to 2-1/2 hours with conventional refractory liner-payback period - 6 months.

Other advantages:

- Faster turn around time at reline time
 - Lower shell temperatures (500 to 350° F)
2. Add fiber insulated liner between standard refractory liner of shell casing.
 3. Update combustion controls (see burner combustion efficiency discussion)
 4. Install furnace covers (see furnace cover discussion)

5. Other miscellaneous changes that can be accomplished to improve furnace efficiencies.

- Reduce flue openings to a minimum, the correct design is 20-30,000 BTU per square inch
- Optimize burner equipment maintenance
- Maintain clean blower filters
- Keep flues and slag hole clear

HEAT TREAT FURNACES

Heat treating is the second most energy intensive operation in many foundries. A comprehensive energy management program is mandatory as gas and oil costs continue to grow and diminish in supply. (Some foundries perform no heat treating.)

It is safe to say that many heat treat facilities in the foundry industry are not in particularly good operating shape. Minimum attention is paid to combustion efficiency and refractory maintenance.

Upgrading heat treat furnaces in the following areas will yield tremendous fuel savings:

- Replace existing burners with a modern pre-mix burner system
- Install efficient burner controls
- Install furnace pressure controls
- Replace conventional refractory lining with fiber insulation
- Seal all cracks and openings in casing and doors
- Install combustion air pre-heat system

Each of the above categories is related and dependent upon the state of the others, but will show an energy savings when individual improvements are made. Energy savings can be considered additive when an all out improvement program is implemented.

Process Operation and Control

Heat treat operations fall into two major categories - continuous and batch type. Ignoring specific casting requirements, restricting one process over the other, the continuous operation is favored from an energy conservation standpoint. With continuous operation, the furnace remains at equilibrium and is not heated and cooled and reheated with every new batch processed. The heat required to bring refractory up to various furnace temperatures and the heat lost through the furnace walls to the

surrounding ambient temperature, based on varying thicknesses of refractory, is illustrated:

TABLE 2-II HEAT STORAGE AND LOSSES BTU SQ. FT.

WALL THICKNESS	TYPE REFRACTORY	HOT FACE TEMPERATURE °F					
		1,200		1,600		2,000	
		H. ST.	H.L.	H. ST.	H.L.	H.ST.	H.L.
9"	Composite 2,000° insulation and firebrick	13,700	285	19,200	437	24,800	615
13-1/2"	Composite 2,000° insulation and firebrick	22,300	335	31,400	514	40,600	718
22-1/2"	Composite 2,000° insulation and firebrick	43,200	182	61,000	281	79,200	392
6"	Ceramic fiber	842	208	1,170	432	1,490	672

Condensed from mark's handbook

H.ST --- Amount of heat stored

H.L. --- Amount of heat lost (Btu/Sq Ft)

The following information on present operating characteristics is necessary in order to evaluate present furnace efficiencies:

- Fuel flow rate in cubic feet per hour (gas) and gallons per hour (oil).
- Gas or oil usage (by metering) per operating day or week (preferably from fire-up to shut down).
- Casting through-put in tons per hour for the same period.
- Fuel cost in dollars per million BTU's.
- Operating cycle, hours per load, and casting load in tons.
- Furnace operating temperature, waste flue gas temperature, and outside shell temperature.
- Types of existing burners, ratings, and percent of excess air (determined by flue gas analysis).

The above information can be used to determine existing heat input in BTU's per pound of castings processed and, calculate the anticipated heat input after replacement or renovation of existing furnaces. Such

calculations form the basis of return on investment calculations that will permit a decision based on economical justification.

LADLE HEATING

The third largest gas consuming process in the foundry industry is ladle preheating. Most foundries use open ladles with Torch Type Gas Burners. Upgrading present ladle heating methods utilizing the following recommended procedures will result in substantial gas energy savings:

- Change unregulated Torch Type Burners to gas/compressed air type regulators.
- Install insulated covers.
- Add insulating lining between conventional refractory and shell.

Ladles come in numerous sizes and shapes, lined with castable or brick refractory or a combination of both. They are first heated slowly to expel moisture, without damaging refractory, until they are dry, then the heating rate is increased to allow refractory surface temperature to reach 2,000° to 2,400° F, primarily to reduce thermal shock to the lining and reduce temperature losses of the metal during pouring. Ladle practices vary largely from one cast metal facility to another. The practice is always energy intensive and what used to be good practice of a well operated shop, to have clean-heated ladles on standby at all times, is poor practice from the standpoint of energy management. The situation of high energy losses becomes progressively more serious when foundries use ancient, dilapidated, or homemade gas torches versus the latest state-of-the-art combustion equipment.

Ladle heating Equipment may be oil or gas fired or a combination of both; electric ladle heating is discussed under "Major Process Changes". See Section H Part 2.

Generally, more efficient heating and drying systems and practices are possible in shops using large ladles where fixed ladle heating stations with covers or hotwalls with fully piped burners are being used. The following diagrams show examples of fixed and wall type ladle stations.

FIGURE 2-11 FIXED TYPE LADLE HEATING STATION

FIGURE 2-12 WALL TYPE LADLE HEATING STATION

With many small foundry operations, the logistics and number of ladles handled make it difficult to maintain fixed burner stations using full air/gas controls. Often portable torches are propped up on the ladle rim, gas flow rates are regulated by means of manual ball or gate valves. Gas consumption can be reduced by two thirds if regulated compressed air is added.

A foundry in the midwest installed regulated compressed air in a 500 pound ladle for drying and heating, they now use 220 cu. ft. of natural gas per hour compared with 660 cu. ft. when using open gas torch only.

The other option for smaller foundries is to substitute electric ladle heaters - see Section 2 Part H for further discussion relative to electric versus gas ladle heating.

Potential indirect energy reduction, due to control of metal temperature in the ladle by utilization of insulation and covers is possible due to control of pouring defects from cold metal and reduction in super heat necessary for metal to be available at optimum pouring temperature when tapped from the furnace.

The possibilities of such savings and increased production make it worthwhile to carefully analyze hot metal handling systems and ladle selections, with the aim of eliminating excessive losses of temperature caused by unnecessary transfers of metal, improper distribution schedules, and inadequate ladle insulation.

In some instances, ladle preheating may be eliminated entirely with the use of insulating fiber ladle linings. See Section 2, part H for further discussion.

COKELESS CUPOLA

A new technology that is creating a great deal of interest is the so called "cokeless" cupola. The basic concept of the cokeless cupola is the replacement of coke as the fuel for melting with a gas or oil fired burner. The charge material is supported by a bed of either refractory spheres or broken refractory products such as bricks. This whole mass rests on a water cooled grate. This concept was originally developed by Taft in England, and further commercialized by several German cupola manufacturers. Approximately fourteen installations exist in Europe and Canada, ranging in capacity from 2 to 20 tons/hour.

A number of advantages are claimed over the use of regular cupolas. The use of gas rather than coke eliminates the pick-up of sulfur from the fuel. This is particularly advantageous for the production of ductile iron. Also, the elimination of coke results in less dust and fume that must be collected in order to meet environmental regulations. It is doubtful, however, that pollution control equipment can be completely eliminated as is the case in some of the Eastern Bloc countries where the cokeless cupola has been more widely accepted.

Another consideration is the cost of the refractory bed material. The Taft style of cokeless cupola used refractory spheres that may or may not be carbon coated to provide carbon to the melt. These are gradually consumed (dissolved) during the operation and represent a significant cost item. Recent work published by the natural gas industry estimates the cost at \$17.00 per ton of iron produced. Another type of cokeless cupola, developed in West Germany, uses broken brick as the bed material which reduces the cost. However, the carbon must be added in a separate operation which offsets some of the savings.

The problem of most concern is the difficulty in achieving a sufficiently high iron temperature to allow further processing. If the burners are operated at a fuel/air ratio that would result in the required temperatures, the furnace atmosphere becomes excessively oxidizing which results in iron quality problems. The usual approach is to use a channel induction holding furnace for temperature adjustment and maintenance.

A pilot sized cokeless cupola was built and operated a number of years ago under the sponsorship of the Gas Research Institute. Work on this unit was discontinued and the results not reported to the industry.

The cokeless cupola has considerable potential for the iron foundry, particularly when used in conjunction with a channel induction holder. Further technical and economic evaluations are necessary before the cokeless cupola finds its proper place in the list of options available to the foundryman.

C. COKE AND SUPPLEMENTAL FUELS

USE IN FOUNDRIES

Cupolas are coke-fired counterflow heat exchangers for melting iron. Energy statistics published by the AFS and other organizations show that, on the average, iron foundries using cupolas consume approximately half of their total energy in the cupola. Based on material input to the melting operation, Figure 2-17 and Table 2-III show energy use in the cupola (National Basis) per net ton of good castings.

FIGURE 2-13 MATERIALS AND ENERGY USED I CUPOLAS

TABLE 2-III ENERGY USE IN CUPOLA (NATIONAL BASIS)

	Million Btu per net ton of good castings shipped(a)
Coke (13% of metallics)(b)	7.76
Transport	0.08
Natural gas	1.60
Electricity(c)	1.05
Scrap	0.00
Transport	0.17
Pig iron	4.17
Transport	0.06
Limestone	0.02
Transport	0.01
FeSi	2.28
Transport	0.01
FeMn	0.75
Transport	0.01
Refractories	0.50
Transport	0.01
Oxygen	0.11
Transport	0.01
TOTAL	18.60

(a) 60% yield from molten iron to good castings shipped.
 (b) 33 million Btu/net ton of coke.
 (c) 10,500 Btu/kwh.

FOUNDRIY COKE

Foundry coke is a solid, cellular residue obtained when certain bituminous coals are heated, out of contact with air, above temperatures at which active thermal decomposition occurs. Coke formed by heating above 1,652° F is called high temperature coke.

Typical foundry coke blends:

TABLE 2-IV. SOME TYPICAL FOUNDRIY COKE BLENDS AND COKING CONDITIONS

Plant	Blend, %			Pulv'n ¹	Coking Time ² in./hr	Flue Temp. Ave. °F	Coke Temp. ³ °F
	Low Vol. Coals	High Vol. Coals	Inert ⁴				
A	30.5	56.5	13	80	1.1	2,500	1,800
B	34	60	6	85	0.7	2,200	1,860
C	32	59	9	80	1.1	2,610	1,800
D	50	50	0	88	0.65	1,800	1,750
E	38	56	6	90	1.1	2,300	--

¹ Percentage passing 1/8-in screen.
² Oven width in inches divided by coking time in hours.
³ Average coke temperature calculated from hydrogen content (see "Chemical Tests" in this chapter).
⁴ Selected anthracite fines meeting foundry coke size and gravity specifications¹⁵.

SUPPLEMENTARY FUELS

Anthracite coal is a dense, hard, natural product ranging in fixed carbon content from 85-87% compared to 90-93% for coke.

TABLE 2-V. MAJOR MATERIAL PROPERTIES

	Anthracite	Coke
Ash	8 - 10%	6 - 8%
Volatiles	4.5 - 5.5%	0.4 - 0.7%
Sulfur	0.4 - 0.65%	0.60 - 0.70%
Heat content (Btu/lb)	13,000 - 13,900	12,500 - 13,500
Material density lbs/ft ³	53 - 58	26 - 32

The greater density gives more energy per volume of space occupied by the coal in the cupola; however, the nonporous nature causes slower burning.

Usage of anthracite coal up to 25% of the total fuel has been reported with some modification necessary to cupola operation and careful control of material size.

If oxygen enrichment is also available, the use of greater than 25% coal may be feasible.

STORAGE

It is common practice at many foundries to store coke in the open. No appreciable deterioration results in mild weather, but when exposed to alternate freezing and thawing, the size can be degraded due to water freezing in the coke fissures. Also, moisture content of coke increases if not stored under cover resulting in increased energy usage to dry the coke charged in the cupola.

OTHER FUELS

Supplementary cupola charge fuels are in use. Coke breeze is used as briquettes or direct injection through the tuyeres.

Table 2-VI shows typical analysis and sizing of the injection grade coke fines being used in a typical injection system. The substitution of injected coke fines for charge coke has resulted in reduction of charge coke by as much as 20%. Replacement ratios of coke removed versus fines injected range from 1:1 and 1.5:1, that is to say, more coke is removed than fines injected with the corresponding cost reduction for materials.

TABLE 2-VI. COKE FINES SPECIFICATIONS

<u>SIZING:</u>	10 MESH X 0	
<u>PROXIMATE ANALYSIS:</u>	Fixed Carbon	88.0%
	Ash	11.0%
	Volatile	1.0%
	Sulfur	0.60%
	Moisture	-1.0%

TABLE 2-VII. COKE SUBSTITUTION VALUES FOR THREE CUPOLA OPERATIONS USING COKE FINES TUYERE INJECTION

CUPOLA	CUPOLA DIAMETER	BLAST TEMP °F	OXYGEN ENRICHMENT	SCFM BLAST RATE X 1,000	MELT RATE TONS/HOUR	% COKE CHARGED	% SUBSTITUTION OF CHARGED COKE	SUBSTITUTION RATIO	
								POUND(S) OF COKE REMOVED TO EACH POUND OF COKE FINES INJECTED	
A	122"	1,200	2%	25-27	50-60	12%	13%	1.3	1
B	108"	950	INTERMITTENT	18	35	15.8%	11.4%	1.6	1
C	46	NO	YES		10	19.5%	10.3%	1.25	1

CUPOLA MODIFICATIONS

Hot Blast and Divided Blast Cupolas. The application of the preheated air blast (hot blast) has improved the combustion efficiency and flexibility of cupola operations. Engineering developments have produced gas fired external heater systems capable of 1000-1200° F blast. Most modern installations incorporate recuperative heating into the design in order to utilize the combustion potential of the off-gas. The hot blast accelerates the combustion reactions and can increase temperature and carbon pick-up thus permitting the use of a higher percentage of steel scrap in the charge, or it can increase melt rate with a lower coke consumption.

Divided blast cupolas utilize a second row of tuyeres to proportionally distribute the combustion air between two levels to obtain increased combustion efficiency and reduced coke consumption.

Oxygen Enrichment

The use of oxygen for cupola melting has been successful on both a continuous and intermittent basis. The amount of oxygen added is usually from 1 to 4%. The application of oxygen enrichment results in increased melt rate, higher temperature and increased flexibility.

D. WASTE HEAT RECOVERY SYSTEMS

GENERAL CONSIDERATIONS

The first step in heat recovery analysis is to survey the foundry and take readings of all recoverable energy that is being discharged to atmosphere. The survey should include analysis of the following conditions:

- Exhaust stack temperatures
- Flow rates through equipment
- Particulates, corrosives or condensible vapors in the air stream

Ventilation, process exhaust and combustion equipment exhausts are the major sources of recoverable energy.

Table 2-VIII illustrates typical energy savings achieved by preheating combustion air with hot exhaust gases from process or furnaces.

TABLE 2-VIII. FUEL SAVINGS REALIZED BY PREHEATING COMBUSTION AIR*

Fuel savings, percent, when combustion air preheat temperature, F, is:

Furnace outlet temperature, F	400	500	600	700	800	900	1000	1100	1200	1300	1400
2600	22	26	30	34	37	40	43	46	48	50	52
2500	20	24	28	32	35	38	41	43	45	48	50
2400	18	22	26	30	33	36	38	41	43	45	47
2300	17	21	24	28	31	34	36	39	41	43	45
2200	16	20	23	26	29	32	34	37	39	41	43
2100	15	18	22	25	28	30	33	35	37	39	41
2000	14	17	20	23	26	29	31	33	36	38	40
1900	13	16	19	22	25	27	30	32	34	36	38
1800	13	16	19	21	24	26	29	31	33	35	37
1700	12	15	18	20	23	25	27	30	32	33	35
1600	11	14	17	19	22	24	26	28	30	32	34
1500	11	14	16	19	21	23	25	27	29	31	33
1400	10	13	16	18	20	22	25	27	28	30	--

* Natural gas with 10 percent excess air; other charts are available for different fuels and various amounts of excess air.

Regardless of the amount or temperature of the energy discharged, recovery is impractical unless the heat can be effectively used elsewhere in the foundry. Also, the recovered heat must be available when it is needed; if not, some sort of heat storage equipment is necessary which will increase the capital cost expenditure and minimize the return on investment.

Waste heat recovery can be adapted to several applications:

- Space heating
- Make-up air heating
- Water heating
- Process heating
- Combustion air preheating
- Boiler feed water heating
- Process cooling or absorption air conditioning
- Charge preheat
- Scrap preheating

An overview of the various heat recovery available will be presented which will cover:

- Air to air heat exchangers
- Air to liquid heat exchangers
- Liquid to liquid heat exchangers

TYPES OF HEAT RECOVERY EQUIPMENT

Choosing the type of heat recovery device for a particular application depends on a number of factors. For example air-to-air equipment is the most practical choice if the point of recovery and use are close coupled. Air-to-liquid equipment is the logical choice if longer distances are involved.

This study addresses five types of heat recovery equipment:

- Economizers
- Heat pipes
- Shell and tube heat exchangers
- Regenerative units

Recuperators

Economizers

Economizers are air-to-liquid exchangers. Their primary application is to preheat boiler feed water. They may also be used to heat process or domestic water, or to provide hot liquids for space heating or make-up air heating equipment.

The basic operation is as follows: Sensible heat is transferred from the flue gases to the deaerated feed water, as the liquid flows through a series of tubes in the economizer, which is located in the exhaust stack.

Most economizers have finned tube heat exchanges constructed of stainless steel while the inlet and outlet ducts are carbon steel lined with suitable insulation. Maximum recommended waste gas temperatures for standard units is 1,800° F.

According to economizer manufacturers, fuel consumption is reduced approximately 1% for each 40° F reduction in flue gas temperature. The higher the flue gas temperature the greater potential for energy savings.

Heat Pipes

The heat pipe thermal recovery unit is a counter flow air-to-air heat exchanger. (See Figure 2-14)

Hot air is passed through one side of the heat exchanger and cold air is passed through the other side in the opposite direction.

FIGURE 2-14. TYPICAL HEAT PIPE CONFIGURATION

Heat pipes are usually applied to process equipment in which discharge temperatures are between 150° and 850° F. There are three general classes of application for heat pipes:

- (a) Recycling heat from a process back into a process (process-to-process)
- (b) Recycling heat from a process for comfort and make-up air heating (process-to-comfort)
- (c) Conditioning make-up air to a building (comfort-to-comfort)

Heat pipes recover between 60 to 80% of the sensible heat between the two air streams. A wide range of sizes are available, capable of handling 500 to 20,000 cu ft of air per minute. The main advantages of the heat pipe are:

- No cross contamination
- Operates without external power
- Operates without moving parts
- Occupies a minimum of space

Shell and Tube Heat Exchangers

Shell and tube heat exchangers are liquid-to-liquid heat transfer devices. Their primary application is to preheat domestic water for toilets and showers or to provide heated water for space heating or process purposes.

The shell and tube heat exchanger is usually applied to a furnace process cooling water system, and is capable of producing hot water approaching 5° to 10° F of the water temperature off the furnace.

To determine the heat transfer capacity of the heat exchanger the following conditions of the operation must be known:

- The amount of water to be heated in gallons per hour
- The amount of hot process water available in gallons per hour
- Inlet water temperature and final water temperature desired
- Inlet process water temperature

Regenerative Unit (Heat wheel)

The heat wheel is a rotary air-to-air energy exchanger which is installed between the exhaust and supply air duct work in a make-up or air heating system. It recovers 70 to 90% of the total heat from the exhaust air stream.

Glass fiber ceramic heat recovery wheels can be utilized for preheating combustion air with exhaust flue gases as high as 2,000° F.

Heat wheels consist of: rotating wheel, drive mechanism, partitions, frames, air seals and purge section. Regeneration is continuous as energy is picked up by the wheel in the hot section, stored and transferred to the colder air in the supply section as the wheel rotates through it.

Recuperators

Recuperators are air-to-air heat exchangers built to provide efficient transfer of heat from hot exhaust gases to a cooler air stream.

Recuperators are generally used in the following processes:

- Preheating combustion air
- Preheating scrap metal
- Provide hot blast at cupola's
- Recovery heat from hot gas to supplement or replace the primary heat source in process or comfort heating applications.

There are many different types of recuperator designs available today. The recuperator illustrated in Figure 2-15 is primarily used for combustion air preheating. It consists of three basic cylinders, the hot gases flow up through the inner cylinder, cold combustion air enters at the bottom of the outer cylinder, flows upward and down through the middle cylinder, exiting from the bottom of the middle cylinder.

Heat energy from exhaust gases is transferred through the inner cylinder wall to the combustion air by a combination of conduction and radiation heat transfer. The net effect is preheated air temperatures as high as $1,000^{\circ}\text{F}$ with inlet exhaust gases entering at $2,000^{\circ}\text{F}$ and exiting at $1,300^{\circ}\text{F}$.

FIGURE 2-15. OPERATING PRINCIPLE
OF RECUPERATOR

E. PROCESSES OF SECONDARY IMPORTANCE

As previously stated, approximately 20% of the plants energy input is consumed in secondary processes - no attempt has been made to quantify energy savings in these areas except where actual percentages can be quoted from other sources.

CLEANING AND FINISHING

Material handling, welding, grinding, inspection, and painting processes comprise the minor energy using activities remaining after heat treatment. Areas where additional energy can be conserved:

1. Compressed air tools and hoists require frequent servicing to maintain efficiency. Adequate lubrication is essential to reduce friction in high velocity air motors.
2. Air hoses should be sized for minimum pressure drop to air tools, a 10% drop from designed supply air pressure of 90 psi results in 15% reduction in production output.
3. Replace air driven equipment with induction motors where practical. A high speed induction motor can produce 5 cfm at 100 psi pressure; an equivalent vane type air motor would consume 25 cfm at the same pressure requirement.
4. Check and replace worn sand blast air nozzles to reduce air consumption. 5/16" nozzle worn to 3/8" diameter will consume an additional 55 to 70 cfm.
5. Welding units of the motor generator type should be shut down when not in use. Smoke detector activated exhaust fans over welding area will reduce unnecessary loss of in-plant heated air and power consumption. When using coated electrode-metal arc welding, use the largest diameter electrode possible to improve efficiency.

EXAMPLE

<u>Rod size</u>	<u>Current</u>	<u>kW</u>	<u>Deposition</u>	<u>Welded Efficiency</u>
1/8"	110a.	5.6	0.87#/hr.	47%
3/16"	150a.	7.65	1.32#/hr.	51%
1/4"	250a.	13.65	2.50#/hr.	55%

6. Paint lines should use airless spray guns. It requires 9.5 HP to atomize 1 gpm using air spray, compared to approximately 1.3 HP for airless type.
7. Consider direct fired paint drying ovens instead of indirect. The heat transfer coefficient for direct fired is about 97% vs. 60% for indirect.

8. Install insulation on paint line heated wash and pretreatment tanks. For instance, an uninsulated vessel at 200° can waste up to 315 BTU/hr/sq. ft. Investigate using recovered process heat as source for paint line heating requirements. Schedule paint line for continuous period of operating rather than frequent shut downs and start ups. Robot painting manipulators can be programmed to start and stop the cycle as required.
9. Fork truck idling time and use of oversize vehicle for job wastes energy. Install door opening and closing devices operable by truck driver in the operating seat. If possible, install double air-lock doors. In large facilities use portable radios to direct fork trucks to next assigned area to reduce empty trips.
10. Improve work flow to reduce handling and movement.

MOLD AND CORE MAKING

The following modifications, changes, and additions to mold and core making operations to effect energy savings are:

1. Install manual shut-off valves on each gas distributing line on shell core making machines.

Example: A foundry in the midwest installed valves to control the flow of gas to each row of burner tips. Their objective was to use only as many gas tips as were required to heat the core box. By cutting off one row of burner tips, their energy savings amounts to 256×10^6 Btu per year.

2. Convert from hot box phenolic resin cores to cold box cores.

The same foundry as in (1) above saved gas in the amount of 1.170 Btu per pound of core or 675×10^6 Btu per year. In addition, they produced the cold box cores about three times as fast as the bottom box cores.

POURING AND SHAKEOUT

The following modifications, changes and additions to pouring and shakeout operations to effect energy savings are:

1. Excessive lighting levels over areas of mold cooling and incandescent lights used at work stations can be changed to reduce energy. Reported improvements of up to 15% were obtained by switching to high-pressure sodium lighting at a New Haven foundry.

2. Movement of clean waste heat to where it is needed can be profitable by recovery of heat from molds and cooling areas for process heat in other areas.

3. Pouring yield, that is, the effective weight of castings per mold relative to gross metal poured into the mold, is an important statistic indicating efficiency of pattern layout and gating techniques.

An improvement in pouring yield from 40% to 45% reduced energy in remelting the returns approximately 9% at Hayes Albion and even at 60% yield, about 40% of melt energy is still being dissipated by recycling of metal within the foundry. Yield improvement will be discussed further in Section 2, Part G.

4. Shakeout systems operating with no load and excessive sand to metal ratios consume energy with no increase in production.

COMPRESSED AIR SYSTEMS

A number of simple guidelines, if effectively followed, can save foundries significant amounts of energy through conservation of compressed air.

Conservation measures are especially needed to increase the efficiency of pneumatic cylinders. Some foundries have oversized cylinders and longer than necessary strokes. Only one cylinder size is correct for any given application and knowledgeable suppliers can provide the information necessary to determine the correct cylinder for any specific operation.

Use of higher pressure than those required wastes considerable compressed air; limiting pressures to the desired level with quality regulators quickly repays the initial investment. Figure 2-16 shows effect of different line pressures.

FIGURE 2-16. HOW LINE PRESSURE AFFECTS AIR CONSUMPTION

A large percent of cylinder and rotary actuator applications require maximum thrust in one direction only and the return stroke can be made with greatly reduced pressure -- this is true with jolting, squeezing, stamping, swaging, clamping, and cutting operations -- see Figure 2-17.

WITHOUT REGULATOR	
Advance stroke	90 psi
Retract stroke	90 psi
Air consumed	156 cu.in./cycle
WITH REGULATOR	
Advance stroke	90 psi
Retract stroke	20 psi
Air consumed	112 cu.in./cycle
Air saved	28%

FIGURE 2-17. HOW PRESSURE REGULATION SAVES ENERGY

Air Leaks

Leaks occur from defective hoses, couplings, fittings, valves, tubes, and actuators. Even leaks that cannot be detected audibly contribute to substantial energy losses. The cost of energy loss through misapplication and leakage in pneumatic systems is so appreciable that it often results in foundries purchasing unnecessary air compressor capacity. Unnecessary expenditures combined with wasted air can be curbed with effective energy management.

Example of loss in energy due to leaks:

- 1/16 inch diameter air leak uses about 2,520 kwh/year
- 1/8 inch diameter air leak uses about 10,100 kwh/year

DUST AND FUME COLLECTION

Dust collection equipment (baghouses, scrubbers, etc.) and its associated exhaust fans and miscellaneous accessories consume relatively large amounts of electricity.

Foundries generate a lot of dust and fumes in many phases of production. In order to satisfy the Environmental Protection Agency (EPA) and local air pollution control agencies, large volumes of air need to be exhausted. Often, exhaust air must be replaced with pre-heated make-up air, adding to overall energy consumption.

The energy savings potential for dust or fume collection equipment is minimal providing the system is operated and maintained correctly. The following checklist should be implemented to minimize electrical power consumption.

1. Install well designed ventilation hoods to keep air volume to a minimum.
2. Keep pressure drops across filters within initial design parameters.
3. Develop and maintain strict preventative maintenance procedures. (Check for leaks and infiltration.)
4. Turn system off when not needed.

Recent work indicates that the use of Adjustable Speed Drives (ASD) can provide significant energy savings over motors operated at constant speed.

HEATING, VENTILATION, AND AIR CONDITIONING

The need for comfort heating, ventilation and air conditioning can be significant in some areas for offices, pattern shops, laboratories, and the like.

Investment casting facilities generally have fairly large process air conditioning systems with stringent humidity requirements. Interior design conditions are usually 72° F dry bulb temperature and 45° relative humidity which requires both summer dehumidification and winter humidification.

Due to the many types of system variations and equipment applications in investment casting facilities it is impossible, and beyond the scope of this study, to recommend energy conservation measures in specific terms. Facilities with air conditioning systems larger than 20 tons (240,000 Btu/hr) should engage qualified professionals to optimize system performance.

The following list points out some areas where energy could be conserved either by retrofit, changes and/or modifications to existing systems:

- Add additional insulation to roofs, ceilings, or walls where practical.
- Install solar film on windows to cut cooling loads.
- Install weather stripping around windows and doors.
- Install higher efficiency lighting systems where possible.
- Recalibrate all controls.
- Lock thermostat to prevent resetting by unauthorized personnel.
- Install enthalpy controls to optimize use of outside air for natural cooling.
- Retest, balance and adjust systems.
- Turn off air conditioning machinery during unoccupied hours.
- Optimize system startup times.
- Reduce outdoor air and system air volumes.
- Replace forced air heaters with infrared heaters.
- Insulate piping and ductwork in unconditioned spaces.
- Reclaim process exhaust energy and utilize it for space heating and absorption cooling.
- Install solar-assisted heat pumps.
- Replace constant volume air systems with variable volume type.
- Use proper water treatment to reduce fouling of heat transfer surfaces in chillers and heat exchangers.
- Maintain all equipment for peak efficiency.
- Storm doors and windows.

PROCESS WATER

Some foundries utilize "once through" process cooling water systems for melt furnace and quenching operations.

Water recovery in the foundry is a valuable source of increasing operating economics, and can lend itself to energy recycling. Cooling for

hydraulic presses, air compressors, melting furnaces, and quenching operations is generally accomplished with water. As much as 98% of otherwise wasted water can be recovered by installing a "closed loop" recirculating water system. The evaporative cooler, commonly referred to as a cooling tower is normally used for this purpose.

PLANT LIGHTING SYSTEMS

Foundries utilizing incandescent lighting systems can save significant amounts of energy by replacing existing units with high pressure sodium units. For example: If a foundry replaced 365 - 1,000 watts incandescent units with 185 - 400 watt high pressure sodium units (HPS) the resulting decrease in electrical load would be 288 kilowatts with no significant change in light level. Assuming the lights burned 250 days per year, and 8 hours per day and the cost of electricity was 5 cents per KWH the energy cost savings would amount to:

$$288 \text{ kW} \times 250 \times 8 \times 0.05 = \$28,800 \text{ per year.}$$

In addition to conserving electrical energy, further saving can be realized in replacement costs due to the longer life of the HPS System.

PART F

LONG TERM PROCESS CHANGES

CHARGE PREHEATING

Preheating of charge material is considered to be cost-effective, however, total use of energy may increase.

Overall energy reduction would be possible with gas preheating provided that waste heat is recovered for combustion air heating.

The percent heat distribution in melting iron from 70° F temperature to 2,700° F is as follows:

Form	Temperature	Sp. heat Btu/lb./°F	Heat Content Btu/lb.	Percent Heat Required	Stage
Solid	70° F	0.130	10	65%	Preheat
Solid	1,000° F	0.140	140		
Solid	1,200° F	0.147	176		
Solid	2,300° F	0.161	370	22%	Melt
Liquid	2,300° F	0.214	492		
Liquid	2,600° F	0.209	543	13%	Superheat
Liquid	2,700° F	0.208	562		
				100%	

FIGURE 2-18. THERMAL PROPERTIES OF IRON

The percent heat required column indicates that major energy is used to preheat the metal.

The methodology used for comparing gas preheating versus all electric melting is as follows:

Heat required for preheating is expressed as

$$\text{Btu/lbs. of metal} = (t_1 - t_2) \times \text{specific heat}$$

Where :

$$t_1 = \text{final preheat temperature (1,000° F)}$$

$$t_2 = \text{initial cold temperature (70° F)}$$

Specific heat of iron (0.140)

Therefore: Heat required to raise to 1,000° F is:

$$(1,000 - 70) \times 0.140 = \underline{135.8 \text{ Btu/lb.}}$$

COGENERATION

Cogeneration, in simplistic terms, is a process of "energy cascading" by utilization of waste heat from various foundry operations (i.e., heat treat furnaces, melt furnaces, etc.).

The first step (or top cycle) of a cogeneration system is the generation of electricity which is used for in-plant electrical base load or peaking load service. The electricity produced replaces, in part, that which is normally purchased from the utility company. The last step (bottom cycle) in the thermodynamic cycle is the use of waste steam for industrial processes and/or environmental conditioning (see Figure 2-19 below).

FIGURE 2-19. COGENERATION BLOCK DIAGRAM

Cogeneration in a typical foundry is an intermittent operation, electricity production is possible only when equipment that is developing waste heat is operational.

Referring to cogeneration block diagram, Figure 2-19, the following major equipment is required for on-site power generation:

- Waste heat recovery boiler; these are available in water tube or fire tube design.
- Steam turbine
- Electrical generator
- Automatic synchronization equipment

Generation of on-site power by utilization of plant waste heat is extremely costly to install and maintain. Also, generation of high pressure steam could possibly require a full-time Class "A" boiler operator.

The complexity and initial expense of cogeneration, when applied to the typical foundry, is not cost-effective at this time. A detailed and comprehensive analysis would be required to justify the use of on-site power generation in a foundry of suitable size to warrant such a system.

PART G

MANAGEMENT ACTIONS

YIELD IMPROVEMENT PROGRAMS

Improvement in mold yield, to increase good castings relative to total poured metal, has a direct impact on energy usage by reduction of total melted metal required for a fixed weight of good castings.

Yield is made up of several parts comprising the effects of:

- Melt loss due to oxidation
- Slag
- Spill metal
- Pigged metal
- Pouring system, (gating, risers, excess casting weight)
- Scrap losses, grinding and machining losses

The typical foundry overall yield is 50% which results in required energy to melt double the finished casting weight. One percent yield improvement for 100-pound casting, from 50% to 51%, reduces metal melted by 4 pounds. (Yield varies with metal melted and processes used.)

Melt Losses:	Occur in all melting processes and range from 1-2% in electric furnaces to 7-10% in cupolas or higher in direct gas-fired furnaces. Selection of raw materials and redesign of melting unit and method changes can minimize the loss.
Slag:	Generated from impurities in the metal and oxidation, includes a percentage of pure metal, operating practices to restrict excess metal entrapment in the slag are necessary.
Spill:	Inaccurate pouring and poor transfer techniques result in metal melted that is not available for casting.
Pigged Metal:	Can amount to 1-2% of total metal melted. The correct measurement of ladle quantities is necessary in order to avoid skulls remaining after pouring. Correct sizing of ladles to prevent exceeding the workable pouring temperature range, before all the metal is utilized, will reduce pigging losses.

Pouring Systems: Ratio of poured metal to gross castings is the base yield figure. Improvements to runner systems, small risers or exothermic/insulators on the riser are required in an ongoing program to attain good yields.

Lightening of castings, if acceptable by the customer, will also reduce metal melting requirements and total energy used. The change may be in design of casting section thickness or closer tolerance to produce a casting with mold wall movement and "swell". The effect of weight reduction is shown in Figure 2-20.

FIGURE 2-20. EFFECT ON MELT ENERGY OF REDUCING CASTING WEIGHT
(Hayes Albion)

Scrap:

Reduction of scrap is of utmost importance in all foundries for overall cost reduction and energy savings. Figure 2-21 shows the melt energy savings when scrap is reduced from 10 percent to zero. There is an approximately linear relationship of energy reduction to scrap reduction; i.e., one percent scrap reduction saves one percent in energy input.

FIGURE 2-21. EFFECT ON MELT ENERGY BY REDUCING SCRAP

COMBINED EXAMPLE					
	Sales Weight	Scrap	Yield	Melt Weight	Percent Energy Reduction
BASE	100%	8%	4.5%	241.5%	0
IMPROVE YIELD	100	8	[50]	217.4	8
REDUCE SCRAP	100	[6]	[50]	212.8	1.9
REDUCE SALES WT.	[85]	[6]	[50]	202.1	5.4
					[15.3]

FIGURE 2-22. EXAMPLE OF EFFECT ON MELT ENERGY WITH COMBINED IMPROVEMENTS IN YIELD, SCRAP AND CASTING WEIGHT

Grinding and Machinery:

Losses due to machining away parts of the casting and grinding to remove ingate pads etc. must be minimized by design and careful positioning of ingates on the casting. Cooperation between customer's design engineer, on initial casting configuration, and the pattern maker is essential.

ESTABLISH ENERGY MANAGEMENT PROGRAM

For an energy management program to be fully effective foundry management should establish the position of "Director of Energy Conservation". The functions of this office would be:

- Establish the total energy cost per unit for each department or division.
- Perform in-plant inspections to identify energy conservation opportunities.
- Establish and maintain an on-going energy conservation program in each department.
- Establish an in-house training program for department supervisors.
- Analyze future energy requirements.
- Assist in establishing plans and capital investment requirements for implementation of conservation programs.
- Provide personal contact between various utility companies.

A single person cannot physically handle all the above assignments; the Director of Energy Conservation must form a committee comprised of top level management people and other members of virtually all departments of the foundry such as melting, heat treating, mold and pouring, cleaning and finishing, and maintenance. The committee thus formed must coordinate a total energy management program to determine what is to be done to reduce the amount of energy used.

After determination of energy reduction measures the committee must follow through with the modifications and changes, to equipment and processes, necessary to accomplish the end results.

Implementation of a full scale energy management program coupled with comprehensive preventive maintenance procedures will, by refining proven and successful foundry management concepts, derive major energy and cost savings.

Efforts to improve foundry profitability by reducing equipment and process downtime, increasing yield through reducing casting weight, reducing scrap and improved scheduling will also payoff in conservation of energy and related cost savings.

All out efforts to reduce energy consumption will significantly reduce the cost per ton of shipped casting, which will improve sales and profits. These challenges and opportunities are present in all foundries and should be carefully addressed by foundry management.

OPERATING PROCEDURES

Management approach must be to plan for operating with minimum energy usage. Improved scheduling in terms of when to run partial loads or reduce melting to fewer days but longer hours per day are very basic decisions.

It is not intended that all equipment operate 24 hours per day; careful scheduling can provide for metal to be melted up to pouring temperature at the time it is required, early melting will waste energy due to holding at temperature for long periods.

Changes in processes can be justified in energy savings, for example: shell or hot box core making conversion to cold box or no-bake methods.

General control of heating and high energy using equipment is necessary to see that it is only running when needed. Heat treat furnaces operated on a condensed schedule of several loads back to back will reduce the total energy required to initially heat up the mass of refractory.

Demand limiters for electric power and shifting the production or melting program to take advantage of off-peak power rates is also covered elsewhere.

Advantages of energy efficient conversions from direct fuel fired equipment to electricity may also be considered in terms of quality control refinements, improved operating conditions, with noise and exhaust requirements reduced. In nonferrous melting operations the cost advantage of reduced melt losses with electric melting frequently offsets the added energy cost.

A checklist of practical energy conserving suggestions covering plant operations for management to investigate is included in Section 4.

PART H

MAJOR PROCESS CHANGES

MELTING (GAS VERSUS ELECTRIC)

Foundries engaged in the planning of new melt facilities or contemplating major changes to existing facilities should analyze gas versus electric melting, particularly from the standpoint of fuel availability in the future. The following tables and graphs illustrate the differences in energy consumption and costs for various types of melting practices.

TABLE 2-IX. COST OF ENERGY (EXAMPLES*)

Energy Source	Energy Cost per unit Delivered	Conversion Factor	Energy Cost per Therm (100,000 BTU)
Electricity	\$.04/KWH	3415 BTU/KWH	\$ 1.172
Natural Gas	\$2.50/1000 CF	1000 BTU/CF	\$.250
Fuel Oil	\$.45/Gal	144,000 BTU/Gal.	\$.312
Propane	\$.35/Gal	93,000 BTU/Gal.	\$.376
Coke	\$.075/Lb.	12,690 BTU/Lb.	\$.590
Coal (Bituminous)	\$.0175/Lb.	14,030 BTU/Lb.	\$.124

Note: Costs of fuels have wide variations with regards to location and governmental control. The reader should research his particular situation with fuel costs. Moreover, availability of fuels rather than costs is emphasized in this paper.

Energy usage by alternate fuels is shown on the following Table 2-X.

TABLE 2-X. ENERGY REQUIREMENTS FOR MELTING AT 100% POWER UTILIZATION

ENERGY CONSUMPTION IN KWH PER TON					
METAL	TEMPERATURE (°F)	HEAT CONTENT KWH/TON	THEORETICAL OIL-FIRED	GAS AND COKE-FIRED	ELECTRIC (****)
Aluminum	1,400	295	1,406*-2,138**	N.U.	500
Copper	2,300	190	1,523*	N.U.	334
Gray Iron	2,750	340	N.U.	801***	500
Steel	3,000	363	N.U.	N.U.	606

References:

- *Crucible Handbook, Crucible Institute.
- **Stahl Specialty Company (Reverberatory Furnace).
- ***Cupola Handbook, AFS, 1965, P.292.
- ****Published Data by Induction and Arc Furnace Companies.

Example: Assume a requirement to operate six 2,000 lbs/hr aluminum melters with overall yearly utilization of 70 percent (no preheat).*

Furnace	Melting Therms Per Ton/Yr	Holding Therms Per Ton/Yr	Therms/Ton Per Year	Cost/Year
Gas/Oil Reverb.	304,760	72,489	377,249	94,300/117,700
Gas/Oil Crucible	288,000	-	288,000	72,000
Coreless Induction	101,798	6,231	108,022	126,306
Channel Induction	71,744	3,232	74,976	87,722
Elect. Reverb.*1	88,965	1,100	90,065	105,376

*Note: Above costs should be adjusted for particular situation and user energy rates. Also if 860° F preheat is utilized, gas/oil costs may be reduced approximately \$24,500. Preheating for electric melt reduces costs approximately \$13,000.

Energy only cost differences shows advantage for channel induction and gas crucibles, however, for cost justification analyses, other factors such as capital cost, maintenance, melt loss due to oxidation and general process variable should be taken into account on an individual basis.

MELTING (COKE VERSUS ELECTRIC)

Coke Fuel for Melting in Cupolas

The most efficient cupola system is a highly utilized large scale, uninterrupted operation. This will present the best metal to coke ratio. Provided that the coke ratio does not change during melting, the only additional coke charges made are to compensate for variations in operation.

The length of campaign will also be reflected in bed coke usage, with ratios as low as 1:1 for short daily melting cycles, also delay in blast-on time, after igniting the coke bed, allows excessive burn-out and waste.

Distribution of energy from cupola coke is shown as follows:

	<u>Percent</u>
Heat in melted iron	40
Latent heat in stack gas	35
Sensible heat in stack gas	13
Other (slag, losses)	<u>12</u>
	100

Modifications to the conventional cupolas to recover much of the stack loss is feasible by use of the recuperative hot blast techniques, but a foundry may decide against this method because of excessive capital costs and tending to plug. Divided blast systems, where the tuyeres are located in two rows, separated by approximately 36 inches, is proven to increase top temperatures and reduce coke. Coke savings is also possible by enrichment of the blast air by 2.0 to 4.0 percent oxygen.

Injection of coke breeze to reduce fuel cost plus use of Anthracite coke and shredded auto tires, as an energy and carbon pick up source, are other methods of savings, however, in all cases the degree of savings is proportional to the capital cost and/or operating problems incurred. These energy reduction methods are all in use, but the total combination of savings is only available under experimental situations. Capital costs of over 1.0 million dollars is reported to be involved in upgrading cupolas for full maximization of energy savings.

Electric Furnace Melting

Furnaces for melting with electric power are available as follows:

- Direct Arc
- Coreless Induction
- Channel Type Induction
- Resistance Type - Reverberatory Furnaces

The efficiency of electric melting is highest where a full bath of metal at liquid stage is being heated. Ability to maintain temperature within close tolerance and melt on a continuous or intermittent basis is of major advantage in electric melting. Other applications of electric power usage, as applied to the melting of metal, is covered elsewhere in this study.

COST COMPARISON COMPUTER ANALYSIS

Computer models have been developed to determine cost comparisons between induction and cupola melting for iron, and between induction, electrical resistance, and gas-fired melting for non-ferrous metals. These models can be accessed through the EPRI Center for Materials Production, Pittsburgh, Pennsylvania; or the CMP Foundry Office, Arlington Heights, Illinois.

LADLE PREHEAT (GAS VERSUS ELECTRIC)

Electric ladle drying and preheating costs can be cut as much as 50%, depending on utility rates, by use of electric silicon carbide glo-bar type elements utilized in conjunction with correctly designed ladle covers and controls.

The high thermal efficiency of electric ladle heaters, as compared to gas combustion devices in which a very large part of the available heat is wastefully vented to atmosphere, will afford maximum energy savings. As an added feature automatic programmed temperature control will provide close temperature control without overheating.

Figure 2-23 shows attainable curing and preheating cycles for 2,000-pound, 30-inch diameter ladle with a 65 kW heater.

FIGURE 2-23. ELECTRIC LADLE PREHEATER PERFORMANCE (30" DIAMETER LADLE)

Units available to suit ladle sizes are as follows:

kW	Ladle Size	Capacity-Pounds
25	17-1/2 - 21-1/2	500 - 1,000
40	21-1/2 - 27	1,000 - 2,000
65	27 - 34-1/2	2,000 - 4,000
100	34-1/2 - 43-1/2	4,000 - 8,000

Insulating Board Linings

A recent innovation in ladle lining practice is the use of disposal insulating board linings. The boards resemble conventional wall board in consistency, and are produced from either silica or magnetite refractory grains bonded with an organic resin. The boards are supplied as segments that are fitted together to form the walls of a ladle lining, and are backed by a permanent refractory safety lining. The gaps between the boards and the safety are filled with dry sand. A separate board ladle bottom is also often used. These same insulating materials are available in pre-shaped complete linings for small ladles as well.

The main advantage is that these linings do not require preheat and are used as "cold linings". Although the cost of these linings is high, energy savings can often compensate. These linings are designed to be used only once and then replaced in order to insure the highest quality of castings. Use of the boards for more than one heat (fill) causes rapid breakdown of the refractory and results in deterioration of casting quality.

SECTION 3

ANALYSIS OF ENERGY CONSUMPTION

This section provides all necessary charts, graphs, tables, and mathematical formulas for the development of energy savings in quantitative form for:

- Electric power and cost savings relative to the melting of metal in all available types of furnaces. By utilizing hypothetical mathematical models it will be shown how to cut energy cost and/or consumption by improving power factors, installing demand limit controls, changing to "off-peak" melting and demand shifting.
- Gas energy reduction relative to melting, heat treating, and ladle preheating. By utilizing hypothetical mathematical models it will be shown how to reduce energy cost and/or consumption by improving combustion efficiencies, installation of ceramic fiber lining, installation of covers, and adding combustion air preheating.
- Reduction of coke usage in cupola melting by upgrading equipment such as adding hot blast via stack gas recuperation divided blast and oxygen enrichment. Also shown is the comparative energy usage for cupola versus electric melting.

A. ELECTRIC MELTING

GENERAL

As stated previously in Section 1 of this report, approximately 34% of the total energy input (all fuels) to a typical steel foundry is in the form of electricity. Of this 34% approximately 60% is attributed to the melting of metal. This section deals with energy and cost savings in electric melting operations and covers the following areas.

- Furnace operation
- Energy usage
- Demand
- Demand control
- Off-peak melting
- Demand shifting
- Power factor correction

INPUT DATA

The required input data needed to analyze present melting operations, from the standpoint of energy consumption is:

- Electric utility bills for the past twelve months
- Kilowatt demand load profile
- Rate schedule for summer and winter "Time of Day" billing

The electric energy usage for a typical calendar year for a hypothetical foundry is shown in Table 3-I. The kilowatt demand load profile covers a period of 48 hours and represents an electrical demand requirement for electric melting (See Figure 3-1). The load profile was developed from the kilowatt demand printout (See Table 3-II). From Table 3-II, it should be noted that the kilowatt demand for each five-minute interval for each 24-hour period is listed.

TABLE 3-1. ELECTRICAL POWER USAGE

BILLING PERIOD	ENERGY KWH	BILLING DEMAND	POWER FACTOR	ENERGY CHARGE	FUEL ADJUSTMENT CHARGE	DEMAND CHARGE	GROSS BILL	NET BILL
JANUARY	376,800	2,291	.97	11,570	(638)	5,394	17,602	\$ 16,964.00
FEBRUARY	386,400	2,255	.98	10,757	(647)	5,318	16,722	16,075.00
MARCH	367,200	2,279	.99	10,136	(648)	5,361	16,145	15,497.00
APRIL	415,200	N/A	N/A	N/A	N/A	N/A	N/A	16,728.00
MAY	376,800	2,266	.98	10,443	(548)	5,341	16,332	15,784.00
JUNE	376,800	N/A	N/A	N/A	N/A	N/A	N/A	15,900.00
JULY	228,000	2,281	.90	6,646	(450)	5,373	12,469	12,019.00
AUGUST	384,000	2,262	.99	10,748	(476)	5,333	16,557	16,081.00
SEPTEMBER	434,400	2,404	.99	12,117	(509)	5,634	18,260	17,751.00
OCTOBER	432,000	2,443	.98	12,650	(505)	5,717	18,872	18,367.00
NOVEMBER	468,000	2,500	.98	14,149	(521)	5,838	20,508	19,987.00
DECEMBER	427,200	N/A	.99	N/A	(256)	N/A	15,029	14,772.00
TOTALS	4,672,800							\$195,925.00

FIGURE 3-1. ELECTRICAL LOAD PROFILES

TABLE 3-II. KILOWATT DEMAND PRINTOUT

Start
Time
12:05am
Column

[illegible]Kilowatt
Demand
Column

Finish
Time
12:00pm
Column

LOAD PROFILE DEVELOPMENT

Foundries with a separate electrical service to their melting furnaces can develop their own in-house kilowatt load profile in the following manner. Prepare a chart, using graph paper with one-tenth of an inch/to one inch divisions, recording time along abscissa axis and kilowatt demand along ordinate axis. Along the abscissa axis set out the "time of day" billing hours. Setting up the graph in this manner will indicate if the high kilowatt demands are occurring during the "on peak" hours (See Figure 3-2). From the kilowatt demand printout, record the thirty minute kilowatt demands for chosen time periods. When all 30-minute kilowatt demands have been recorded, connect all points to obtain profile of load. The procedure for developing a winter kilowatt load profile is the same as "summer", but the "time of day" billing hours change (See Figure 3-3).

Foundries that are not provided with a kilowatt demand printout for their electric melting operation or have only one electrical service for both melting and general plant service will need to install submetering of the service feeders.

Using a three-phase tap-type recording ammeter and a clipon type power factor meter the necessary data can be obtained to find the kilowatt demand.

Example

If the ammeter recorded 400 amperes with a 0.80 power factor the kilowatts would be as follows:

$$\frac{I \times E \times 1.73 \times PF}{1000}$$
$$\frac{400 \times 480 \times 1.73 \times .80}{1000} = 265 \text{ kilowatts}$$

From the above reading the kilowatt load profile can be developed.

KILOWATT DEMAND PROFILE (SUMMER)

Figure 3-2

KILOWATT DEMAND LOAD PROFILE (WINTER)

Figure 3-3

OFF-PEAK METAL MELTING

By utilizing "off-peak" hours for metal melting, substantial cost savings can be realized through lowering the demand and energy charges.

Figure 3-4 illustrates a total demand load of 2,300 kilowatts, of this amount approximately 59% or 1,357 kW is attributed to melting of metal, the remainder is base plant electrical load.

The following sample calculations illustrate the electrical cost for demand, energy and fuel adjustment charges for melting in on-peak and off-peak hours.

FIGURE 3-4

SAMPLE CALCULATION (On-Peak Period) (Figure 3-4 — "Before")

Demand Charges:

On-peak per kilowatt of maximum demand

Total on-peak 1369 kW at \$2.50 \$ 3,422

Plus "partial peak" per kilowatt of maximum demand

Total partial peak 1363 kW at \$0.30 \$ 408

Plus off-peak, per kilowatt of maximum demand

Total off-peak 1358 kW no charge \$ 0

Subtotal \$ 3,830

Energy Charges:

On-peak, per kilowatt hour: 12:30 pm to

6:30 pm 4-5 hrs/day

Total kilowatt hours 98,571 x ¢0.022/kWh \$ 2,168

Partial peak, per kilowatt hour: 8:30 am to

12:30 pm and 6:30 pm to 10:30 pm 8 hrs/day

Total kilowatt hours 145,135 x ¢0.019/kWh \$ 2,757

Off-peak, per kilowatt hours: 10:30 pm to

8:30 am 10 hrs/day

Total kilowatt hours 183,875 x ¢0.010/kWh \$ 1,839

Subtotal \$ 6,764

Fuel Adjustment Charges:

Total kilowatt hours = 427,582 x ¢0.04063 \$ 17,372

Grand total for (demand, energy and fuel
adjustment charges) \$ 27,966

Above calculations are based on normal day shift working hours and summer "time of day" billing rates for a 30-day period. Figures are abstracted from power company metered print-outs.

Off-Peak Melting (Figure 3-4 — "After")

Demand Charges:

"On-peak" per kilowatt of maximum demand

Total on-peak none at \$2.50 \$ 0

Plus "partial peak" per kilowatt of maximum demand

Total partial peak none at \$0.30 \$ 0

Plus "off-peak" per kilowatt of maximum demand

Total off-peak 1239 at no charge \$ 0

Subtotal \$ 0

Energy Charge:

"On-peak", per kilowatt hours: 12:30 pm to 6:30 pm 6 hrs/day

Total kilowatt hours none x ¢0.022/kWh \$ 0

"Partial peak" kilowatt hours: 8:30 am to 12:30 pm
and 6:30 pm to 10:30 pm 8 hrs/day

Total kilowatt hours none x ¢0.019 kWh \$ 0

"Off-peak" kilowatt hours: 10:30 pm to 8:30 am 10 hrs/day

Total kilowatt hours 427,582 x ¢0.010/kWh \$ 4,275

Subtotal \$ 4,275

Fuel Adjustment Charges:

Total kilowatt hours = 427,581 x ¢0.04063 \$ 17,372

Grand total for (demand, energy and fuel
adjustment charges) \$ 21,647

Potential cost savings by shifting to off-peak melting would be
\$27,966 - \$21,647 = \$6,319 or 22.5% savings for the 30-day period.

DEMAND SHIFTING AND DEMAND CONTROL

If night melting is not possible, demand shifting and control will permit metal melting during normal "on-peak" day time hours and still save substantial costs. Demand shifting will extend the melting period; this permits the sequential operation of the furnaces, thereby reducing the peak maximum demand.

With uncontrolled operation, large kilowatt demands are developed which produces low demand factors and low efficiency of power usage. Figure 3-5 is representative of an uncontrolled operation of power input to several furnaces. Figure 3-6, indicates how the kilowatt demand can be reduced by extending the hours of melting operations with the demand limit set at 1,700 kilowatts. The sample calculations illustrate the potential cost savings if demand shifting and control is utilized. To insure complete control of a set maximum demand an automatic demand controller should be installed, this controller automatically regulates or limits operation in order to prevent a set maximum demand from being exceeded. With the monitored information, the controller can calculate when an overload of the set demand will occur. The controller will delay any shed action to allow time for loads to shed normally. When it is determined that it will be necessary to shed one or more loads to keep from exceeding the set kilowatt demand, the controller will shed the necessary load. This means that shedding will occur only once during a demand interval and maximum use of available power will be realized.

FIGURE 3-5. ELECTRICAL LOAD PROFILE (UNCONTROLLED)

FIGURE 3-6. ELECTRICAL LOAD PROFILE (CONTROLLED)

Sample Calculations (Uncontrolled Operation - Figure 3-5)

Demand Charges:

"On peak" per kilowatt of maximum demand

Total on peak 1,0333 kw at \$2.50 \$ 2,507

Plus partial peak per kilowatt of maximum demand

Total partial peak 998 kw at \$0.30 \$ 299

Plus "off-peak" per kilowatt of maximum demand

Total off-peak 994 kw no charge \$ 0

Subtotal \$ 2,806

Energy Charge:

"On peak", per kilowatt hour: 12:30 pm to
6:30 pm 6 hrs/day

Total kilowatt hours 98,571 x \$0.022/kWh \$ 2,168

"Partial peak" kilowatt hour: 8:30 am to
12:30 pm and 6:30 pm to 10:30 pm 8 hrs/day

Total kilowatt hours 15,135 x \$0.019/kWh \$ 2,757

"Off-peak" per kilowatt hour: 10:30 pm to
8:30 am 10 hrs/day

Total kilowatt hours 183,875 x \$0.010/kWh \$ 1,839

Subtotal \$ 6,764

Fuel Adjustment Charges:

Total kilowatt hours = 427,582 x \$0.04063 \$ 17,372

Grand total for (demand, energy and fuel
adjustment charges) \$ 26,942

Sample Calculations (Controlled Operation - Figure 3-6)

Demand Charges:

"On peak" per kilowatt of maximum demand

Total on peak none kw at \$2.50 \$ 0

Plus partial peak per kilowatt of maximum demand

Total partial peak 998 kw at \$0.30 \$ 299

Plus "off-peak" per kilowatt of maximum demand

Total off-peak 994 kw no charge \$ 0

Subtotal \$ 299

Energy Charge:

"On-peak", per kilowatt hour: 12:30 pm to
6:30 pm 6 hrs/day

Total kilowatt hours none $\times$ \$0.022/kwh \$ 0

"Partial peak" kilowatt hour: 8:30 am to
12:30 pm and 6:30 pm to 10:30 pm 8 hrs/day

Total kilowatt hours 145,135 $\times$ \$0.019/kwh \$ 2,757

"Off-peak" per kilowatt hour: 10:30 pm to
8:30 am 10 hrs/day

Total kilowatt hours 282,446 $\times$ \$0.010/kwh \$ 2,824

Subtotal \$ 5,581

Fuel Adjustment Charges:

Total kilowatt hours = 427,582 $\times$ \$0.04063 \$ 17,372

Grand total for (demand, energy and fuel
adjustment charges) \$ 23,252

DEMAND CONTROL

With a power demand controller installed on the power system supply to the furnaces, maximum kilowatt demand can be controlled.

The controller automatically regulates or limits operation in order to prevent a set maximum demand from being exceeded. The controller predetermines the demand limit and the demand interval. The sequence of operation is similar to that described under "load shifting and control".

Figure 3-7, illustrates the new load profile with demand set at 1,700 kW. Cost savings are the same as those computed under "Load Shifting and Control."

FIGURE 3-7. ELECTRIC LOAD PROFILE (DEMAND CONTROL)

POWER FACTOR CORRECTION

The electrical efficiency of the coreless induction furnace is approximately 76-81 percent with a power factor of approximately 90-98 percent, the channel furnace is approximately 94-96 percent with a power factor of 94-98 percent. With these high power factors designed into the furnaces, no additional correction is necessary.

On the other hand arc furnaces have an approximate power factor of 70% if capacitors are not installed on furnace transformers. It should be noted that power factor improvement will not save in-plant energy or reduce the customer's power bill, but will save energy at the utility company power plant thereby reducing the nation's dependence on oil.

IMPROVED FURNACE DESIGN

Induction Furnaces

An improved profile of the power coil reduces the magnetic flux lines penetrating through the outside corners, which in turn minimizes eddy current loss, thereby improving furnace efficiency.

Use of castable backup refractory will eliminate the need for cooling coils and save the energy that would otherwise enter into the cooling water. The efficiency of the furnace can be increased as much as 10% with these improvements. A foundry producing 25 tons a day can save approximately per year. Using representative figures for this example the savings compute as follows:

Total energy required to melt 25 tons of metal per day =

$$\frac{25 \times 500 \text{ kwh/ton}}{0.76\% \text{ efficiency}} = 16,500 \text{ kwh}$$

10% improvement = $16,500 \times 0.10 = 1,650 \text{ kwh savings/day}$

Savings/year at 240 days = $1,650 \times 240 = 400,000 \text{ kwh}$

Average power at \$0.0427 = \$17,000 savings/year

Arc Furnaces

The installation of water-cooling on the sidewalls of the furnace will reduce downtime necessary for refractory replacement. With installation of water-cooled blocks there is about 10% increase in total furnace productivity; other benefits are:

- 80% decrease in sidewall brick consumption
- Reduction of power "on-time" by 13%
- 3% energy savings
- 8% reduction in electrode consumption

The installation of solid-state furnace controls provides for automatic positioning of the electrodes within the furnace. The control maintains the arc setpoint more accurately which gives constant power input and longer refractory life. Constant arc stability provides for a higher through-put, with a higher input power usage. The energy savings that can be realized are approximately 10 percent.

Electric Resistance Reverberatory Melting Furnace (ERMF)

Installation of furnace covers over the charging and dipout wells and the bath will save energy.

Sample Calculation

Potential energy savings in covering a four-square-foot opening based on radiation losses of 20,000 Btu's/SF/hr for covered furnaces.

Four Ft² Area

Losses without cover	= (4 x 20,000)	=	80,000 Btu/hr
Losses with cover	= (4 x 500)	=	2,000 Btu/hr
Net reduction		=	78,000 Btu/hr
Losses per 10-hr day	= (78,000 x 10)	=	780,000 Btu
kwh saved (780,000 . 3412)		=	228 kwh
Annual savings (240 dys x 228 x \$0.042)	=		<u>\$ 2,298.00</u>

Graphite Rod Holding Furnace

As the graphite rod holding furnace is not a primary melting furnace, this furnace will not be addressed with regards to lost energy. The efficiency and utilization of energy input for metal holding is high. The power factor is maintained at near unity with this type of unit.

TABLE 3-III. SUMMARY OF COST SAVINGS

POTENTIAL ANNUAL COST SAVINGS FOR ELECTRICAL ENERGY AND DEMAND ^{1/}					
ITEM	PRESENT CONDITIONS		POTENTIAL CONDITIONS		POTENTIAL ANNUAL COST SAVINGS \$
	ENERGY CONSUMED KWH	ENERGY AND DEMAND COST \$	ENERGY CONSUMED KWH	ENERGY AND DEMAND COST \$	
Off-Peak Melting	5,130,984	335,592	5,130,984	259,764	75,828
Demand Shifting and Demand Control	5,130,984	323,304	5,130,984	279,024	44,280
Demand Control Only	5,130,984	335,592	5,130,984	323,304	12,288
Furnace Covers	56,272	2,363	1,406	65	2,298
Improved Furnace Design	3,960,000	169,092	3,564,000	152,182	17,000

^{1/} Developed from sample calculations shown previously in this text.

1. Potential annual cost savings are based on 240 operating days per year.
2. Energy consumed per year is based on furnace loads only. Does not include plant base loads.

B. NATURAL GAS MELTING

GENERAL CONSIDERATIONS

This section deals with energy savings in gas melting operations:

Formulas, calculations, and graphs have been simplified within the Scope of the Project to reflect constant conditions during the process.

To investigate any process in depth, it is essential to establish parameters, calculate the data and plot results on a continuous basis to establish the limits of the operation and equipment, and identify any trends.

The work sheet lists the expected parameters for furnaces, burner and ancillary equipment and operational data to complete a "one shot" energy audit. This constitutes a base for any further improvements. A tape measure, thermometer, flue gas analyzer and flow meters will be the tools needed.

TABLE 3-IV. GAS FURNACE DATA INPUT

Metal type:	Aluminum	Annual tons	1,500
Pouring or tap temperature	1380	°F	
* Heat content Btu/lb	497	Shifts/day	One
Melting period hrs.	8	Holding period hrs.	16
Method of Melting	Crucible	Reverb	
Metal melted/hr. lbs.	2,000	2,000	
Burner rating Btu/hr	3.6×10^6	4.85×10^6	
Total gas usage/hr CFH	3,600	4,850	
Capacity of furnace lbs.	2,000	5,000	
Crucible diameter	36"	-	
Area of metal radiation sq. ft.	4.0	4.0	
Area of refractory wall:			
Below metal sq. ft.	110	40	
Above metal sq. ft.	-	40	
Thickness of wall ins.	6	6	
Door open area or dip well sq. ft.	-	-	
Mean temperature of walls °F	-	-	
Outer temperature of wall T_1	100°F	100°F	
Inner temperature of walls T_2	3,000°F	2,000°F	
Present refractory K value	N/A	6	
Proposed refractory K value	-	-	
Rs value for refractory	-	-	
CO ₂ flue gas reading	5% CO ₂		
Combustion air cfm	N/A	N/A	
Combustion air wg	N/A	N/A	
Flue gas temperature	1,150°F	1,600°F	
Ambient temperature °F	-	-	
Time of day used	-	-	
Days/year used	240	240	
Energy cost/therm \$	\$0.30		

* See Figure 3-8 for input data.

GRAPHS, TABLES AND CHARTS

The following graphs, tables and charts illustrated here are to be utilized for performing sample calculations for anticipated energy reduction measures.

Heat Content of Metals

The following graph (Figure No. 3-8) shows the heat content of numerous metals and alloys for various temperature ranges:

FIGURE 3-8. HEAT CONTENT OF METALS

Example of use: With a 1400° F metal temperature, the heat content of aluminum die casting alloy is approximately 500 BTU/lb.

PERCENT EXCESS AIR FROM CO₂ READING

FIGURE 3-9. BURNER CHARACTERISTICS

Source: North American Combustion Handbook.

Example of Use: A combustion analysis shows 6% CO₂ content of the flue gas, with natural gas burning equipment the excess air is approximately 90%.

FIGURE 3-10. PERCENT AVAILABLE HEAT

From North American Combustion Handbook

This chart is only applicable to cases in which there is no unburned fuel in the products of combustion.

The average temperature of the hot mixture just beyond the end of the flame may be read at the point where the appropriate "% Excess Air" curve intersects the zero available heat line.

Example of use: With a flue gas temperature of 1100° F and an excess air requirement of 90%, the amount of heat available for metal melting (including heat lost by radiation) is approximately 52%.

TABLE 3-V. TYPICAL THERMAL PROPERTIES OF
REFRACTORY AND INSULATING CONCRETES

Aggregate.	Fired density, lb. per cu. ft.	Heat capacity, B.t.u. per (cu. ft.) (deg. F.)	Thermal conductivity, B.t.u. per (hr./sq. ft.) (deg. F. per in.)	Thermal diffusivity, (sq. ft. per hr.)
Vermiculite ..	35	9	1.2	0.011
Diatomite ..	55	14	1.7	0.010
Crushed H.T. Insu- lating brick ..	85	21	3.2	0.013
Expanded clay ..	90	22	3.5	0.013
Crushed firebrick ..	115	29	6	0.017
Molochite ..	120	31	8	0.021
Sillimanite ..	135	33	10	0.025
Carborundum ..	145	40	50	0.103
Calcined bauxite ..	160	45	12	0.022
Magnesite ..	160	45	20	0.037
Chrome-magnesite ..	165	37	8	0.014
Fused magnesia ..	170	50	24	0.04
Fused alumina ..	175	52	10	0.026
Bubble alumina ..	95	22	6	0.023

Example of use: Read "K" (thermal conductivity) for type of lining in use.

PHYSICAL PROPERTIES*

	2100	2400	2600	2800	3000
Maximum Recommended Use Temperature	2100°F (1150°C)	2400°F (1315°C)	2600°F (1425°C)	2800°F (1540°C)	3000°F (1650°C)
Density (PCF)	12.15	18.22	18.22	18.22	18.22
Thermal Conductivity - k (BTU · In./S.F. · °F · Hr.)	Same k values for these compositions.				
Mean Temperature of					
600°F	0.26	0.29			
800°F	0.36	0.35			
1000°F	0.48	0.41			
1200°F	0.62	0.48			
1400°F	0.77	0.57			
1600°F	0.93	0.67			
1800°F	1.08	0.79			
2000°F	1.24	0.93			
2200°F	-	1.10			
2400°F	-	1.30			

Ref. Industrial Insulations, Inc.

TABLE 3-VI. THERMAL PROPERTIES

Example of use:

Determine mean temperature from formula; $\frac{t_1 - t_2}{2} = \text{Mean wall temp.}$

Read "K" thermal conductivity under maximum recommended use temperature.

FIGURE 3-11

Composite refractory- and insulating-
concrete lining of a propane-fired furnace

Example of K values for above material

Fused alumina,	K = 16
Crushed Firebrick,	K = 6
Vermiculite,	K = 1.2
Diatomite Brick,	K = 1.7

TABLE 3-VII. HEAT STORAGE AND LOSSES BTU/SQ. FT.

WALL THICKNESS	TYPE REFRACTORY	HOT FACE TEMPERATURE °F					
		1,200		1,600		2,000	
		H. ST.	H.L.	H. ST.	H.L.	H. ST.	H.L.
9"	Composite 2,000° insulation and firebrick	13,700	285	19,200	437	24,800	615
13-1/2"	Composite 2,000° insulation and firebrick	22,300	335	31,400	514	40,600	718
22-1/2"	Composite 2,000° insulation and firebrick	43,200	182	61,000	281	79,200	392
6"	Ceramic fiber	842	208	1,170	432	1,490	672

H. ST. - Heat Stored
H. L. - Heat Lost. BTU/Hr.

FIGURE NO. 3-12

Example of use: Read gas saved in percent against furnace temperature curve for combustion air temperature obtained.

At 1600° F furnace temperature, and 1200° F air temperature, the gas saved is approximately 26 percent.

FIGURE 3-13

Example of use: Read net radiation (kw/m^2) against surface temperature and radiation curve.

e.g. at 800°C , radiated power is approx. 100 kw/m^2 .
 Where $800^\circ\text{C} = 1472^\circ\text{F}$.
 $100 \text{ kw/m}^2 = 30,000 \text{ BTU/sq. ft.}$

IMPROVING COMBUSTION EFFICIENCY

Example: A crucible furnace melts 2,000 lbs. of aluminum per hour, flow meter readings indicate that 3,500 cu. ft. of gas per hour (3.5×10^6 BTU/hr.) is used.

Flue gas temperature was measured at 1150° F and the flue gas analysis showed a CO_2 content of 5%. Find present combustion efficiency and probable efficiency, by installation of a nozzle mix burner and fuel/air ratio controls, if CO_2 content was corrected to 11% and excess air reduced to 10%. For this example it has been assumed that furnaces are equipped with covers.

Present Combustion Efficiency

Heat required to melt aluminum,

- Heat content of metal is 500 BTU/lb (Figure No. 3-8)
- Amount of metal heated per hour is 2,000 lb.

Therefore, heat to product is $500 \times 2000 = \underline{1,000,000 \text{ BTU/hr.}}$

Heat lost to exhaust.

- From Figure No. 3-9 with 5% CO_2 in flue gas the excess is approximately 130%.
- From Figure No. 3-10 with a flue gas temperature of 1150° F and 130% excess air, the percent of gross fuel input available to do work (including radiation losses) is approximately 40%.

Therefore, of the 3,500,000 BTU/hr. energy input only ($3,500,000 \times 0.4$) 1,400,000 BTU/hr (minus the radiation losses) is utilized.

Probable Combustion Efficiency

Heat lost of exhaust

- From Figure No. 3-9 with 11% CO_2 in flue gas the excess air is 10% approximately.
- From Figure No. 3-10 with a flue gas temperature of 1150° and 10% excess air, the percent of gross fuel input available to do work (including radiation losses) is approximately 65%.

Therefore, of the 3,500,000 BTU/hr. energy input ($3,500,000 \times 0.65$) 2,275,000 BTU/hr. is available for melting the metal.

As previously stated the amount of heat required to melt 2,000 lbs. of aluminum is 1,000,000 BTU/hr. Present combustion efficiency calculations show that 1,400,000 BTU/hr. was available to melt the metal. Therefore: $1,400,000 - 1,000,000$ results in 400,000 BTU/hr. being lost by radiation effects. By increasing the available fuel to 65% it can be readily seen that a smaller burner could be used to accomplish the same work.

$$\frac{875,000 \text{ BTU/hr.} \times 100}{350,000 \text{ BTU/hr.}} = 25\% \text{ less fuel}$$

Summary

Item	Present Energy	Probable Energy
Heat to product	1,000,000 BTU/hr.	1,000,000 BTU/hr.
Heat loss to Stack	2,100,000 BTU/hr.	1,225,000 BTU/hr.
Heat loss (Radiation)	400,000 BTU/hr.	400,000 BTU/hr.
Gross Input	3,500,000 BTU/hr.	2,625,000 BTU/hr.

Process Energy Flow Diagrams

PRESENT CONDITION

PROBABLE CONDITION

Process Energy Flow Diagrams

PRESENT CONDITION

PROBABLE CONDITION

Yearly Energy Cost Savings

Assuming, using the above example, that the furnace melted 8 hours per day, 5 days per week, 50 weeks per year then the energy and cost savings would be:

$8 \times 5 \times 50 \times 875,000 \text{ BTU/hr.} = 1750 \times 10^6 \text{ BTU}$ or 17500 therms/year,
at \$0.30 per therm, yearly savings would be \$5,250

COMBUSTION AIR PREHEATING

For typical gas fired furnace with flow rate of $3.5 \times 10^6 \text{ BTU/hr.}$, improved efficiency can be attained by preheating the combustion air with the use of a hot gas recuperator.

Example Calculations

With flue gas temperature of 1600° F, if combustion air is pre-heated to 1200° F, energy savings of approx. 26% are available as obtained from Fig. 3-12. Thus heat savings can be calculated for the typical gas fired furnace as follows:

$$2.625 \times 10^6 \text{ BTU/hr.} \times 0.26 = 0.68 \times 10^6 \text{ BTU/hr.}$$

Annual energy reduction based on 8 hours/day, 240 days per year is

$$\frac{0.68 \times 10^6 \times 8 \times 240}{100,000 \text{ BTU/therm}} = 13,100 \text{ terms/yr. @ \$0.30 per therm, cost}$$

$$\text{reduction} = \underline{\$3,930/\text{year}}$$

Item	Present Energy	Probable Energy
Heat to Melt	1,000,000 BTU/hr.	1,000,000 BTU/hr.
Stack Losses*	1.225,000 BTU/hr.	545,000 BTU/hr.
Radiant Losses*	400,000 BTU/hr.	400,000 BTU/hr.
Gross Input	2,625,000 BTU/hr.	1,945,000 BTU/hr.

*Stack and radiant losses from previous example after improvements

REFRACTORY MATERIALS - CRUCIBLE FURNACE

Sample Calculation -

A crucible furnace with composite refractory and insulating - concrete lining is compared to same furnace with ceramic fiber sleeve insulating material. Diagram of typical furnace with composite lining is shown in Fig. 3-11.

The heat loss through composite material is determined by calculation of "Q".

$$Q \text{ per sq. ft.} = \frac{t_1 - t_2}{R_1 + R_2} \text{ etc.}$$

Where t_1 = Hot Face Wall Temperature.
 t_2 = Cold Face Wall Temperature.
 R = Resistance, which is the wall thickness divided by "K", the conductivity of the material.

"K" for various materials is obtained from table of typical thermal properties (Table 3-V). Thus $R_1 + R_2$ etc. for various thicknesses is:

$$R_1 = \frac{2}{16} \text{ (fused alumina)} = 0.125$$

$$R_2 = \frac{3}{6} \text{ (crushed firebrick)} = 0.333$$

$$R_3 = \frac{1}{1.2} \text{ (vermiculite)} = 0.833$$

$$\text{Total } R_1 + R_2 + R_3 = 1.291$$

Area of side walls estimated to be 110 sq. ft.

Thus heat loss through composite material = Q_a

$$\therefore Q_a = \frac{(3,000 - 100) 110}{1.291} = 247,000 \text{ BTU/hr.}$$

NOTE: The above calculation demonstrates the methodology used for computing sample radiation losses. Actual radiation losses used throughout the preceding examples is 400,000 BTU/Hr.

Replace 6" composite material with 6" ceramic fiber sleeve of 3,000° F maximum use temperature. The calculation of mean temperature =

$$\frac{t_1 - t_2}{2} = \frac{3,000 - 100}{2} = 1450^\circ \text{ F}$$

K value for mean temperature of 1450° F (from Table 3-VI) is prorated between 0.57 and 0.67 to be 0.60

$$\text{thus } R \text{ (ceramic fiber)} = \frac{6}{0.60} = 10$$

Thus heat loss through ceramic fiber sleeve = Q_b

$$\therefore Q_b = \frac{(3,000 - 100) 110}{10} = 31,900 \text{ BTU/hr}$$

$$\text{Change in heat loss } Q_a - Q_b = 247,000 - 31,900 = 215,100 \text{ BTU/hr}$$

Based on a melt program of 8 hours/day, 240 days per year, the annual gas usage reduction is as follows:

$$\frac{215,100 \text{ BTU/hr} \times 8 \times 240}{100,000 \text{ BTU/therm}} \times \$0.30 = \$1,240/\text{year.}$$

If original energy input is 1.945×10^6 BTU/hr., the furnace efficiency is improved from 51.4 per cent to approximately 57.8 percent, or 6.4% increase in efficiency.

Summary

Item	Present Energy	Probable Energy
Heat to Melt	1,000,000 BTU/hr.	1,000,000 BTU/hr.
Radiation Loss*	400,000 BTU/hr.	185,000 BTU/hr.
Radiant Losses*	545,000 BTU/hr.	545,000 BTU/hr.
Gross Input	1,945,000 BTU/hr.	1,730,000 BTU/hr.

*Stack and radiant losses from previous example after improvements of combustion equipment.

TYPICAL ENERGY FLOW DIAGRAM

FURNACE COVERS

Ladle and furnace covers eliminate most of the radiation loss which is the major area of energy loss from uncovered ladles and metal surfaces. Net radiated heat loss from a metal surface, emissivity, depends on the amount of slag. Emissivity of clean iron is relatively small but the thin slag layer usually present increases emissivity. Energy loss can be obtained by reference to Fig. 3-13 by reading net radiated power at metal temperature from the chart.

Example, at metal temperature of 800°C (1472°F), read for radiation at $E = 1$, net radiated power = 100 kw/m^2 ($0.03 \times 10^6 \text{ BTU/sq.ft.}$)

Where: $1 \text{ m}^2 = 10.76 \text{ sq.ft.}$

$1 \text{ kw} = 3412 \text{ BTU.}$

Sample Calculation-

Consider a gas fired furnace holding aluminum at 1400°F with dip well area 4 sq. ft. without a cover and calculate the energy savings with a ceramic fiber cover in place.

Radiation losses, at 1400°F (760°C) from Fig. 3-13 = 60 kw/m^2
= $19,000 \text{ BTU/sq.ft.}$

Thus $4 \text{ sq.ft.} \times 19,000 \text{ BTU} = 76,000 \text{ BTU/hr.}$

Heat loss from dip well with cover, based on thickness of two inches for ceramic fiber cover, is:

$$Q = \frac{t_1 - t_2}{R_1 + R_2} \text{ etc.}$$

where t_1 = hot face temp. 1400°F .

t_2 = cold face temp. 200°F .

R = Resistance which is the thickness of the cover divided by the conductivity K .

K for cover material can be obtained from Table 3-V where mean temperature of the material is given by

$$\text{Mean temp.} = \frac{t_1 - t_2}{2} = \frac{1400 - 200}{2} = 600^{\circ}\text{F}$$

Thus K from Table 3-V at $600^{\circ}\text{F} = 0.26 \text{ (BTU/sq. ft. per ins - }^{\circ}\text{F/hr.)}$

$$\therefore Q = \frac{(1400 - 200)}{2/0.26} 4 \text{ sq. ft.} = \frac{4800}{7.7} = 600 \text{ BTU/hr.}$$

Savings in energy loss = $76,000 - 600 = 75,400$ BTU/hr.

With cover in place during 16 hours holding period per day, the reduction in energy for 240 days per year is:

$75,400 \times 16 \times 240 = 289 \times 10^6$ BTU year @ \$0.30 per therm, the cost savings is:

$$\frac{289 \times 10^6 \times 0.3}{100,000} = \$870 \text{ per year}$$

Summary

Item	Present Energy	Probable Energy
Heat to Melt	1,000,000 BTU/hr.	1,000,000 BTU/hr.
Radiation Loss*	185,000 BTU/hr.	109,600 BTU/hr.
Radiant Losses*	545,000 BTU/hr.	545,000 BTU/hr.
Gross Input	1,730,000 BTU/hr.	1,654,600 BTU/hr.

*Stack and radiant losses from previous example for present conditions after improvements.

PRESENT CONDITION -

PROBABLE CONDITION -

OVERALL FURNACE EFFICIENCY

The following table summarizes the probable cost and energy savings by carrying out all of the possible improvements previously covered in the examples.

Summary (Energy and Cost Savings)

Item	BTU/hr. Reduction	Efficiency Percent Increase	Annual Gas Therms.	Savings Cost \$
Combustion Efficiency	875,000	25.0%	17500	5250
Preheat Comb. Air	680,000	26.0%	13100	3930
Refractory Upgrade	215,000	6.4%	4130	1240
Furnace Covers	75,000	2.6%	2900	870
Total	1,845,000	31.8	37,630	\$11,290

$$\text{Overall Thermal Efficiency} = \frac{1.0 \times 10^6}{(3.5 - 1.845) 10^6} \times 100 = 60.4\%$$

$$\text{Present Efficiency (Approximate)} = 28.6\%$$

$$\text{Increased Efficiency} = 60.4 - 28.6 = 31.8\%$$

$$\text{Percent Energy Saved} = \frac{1,845,000}{3,500,000} = 53\%$$

REVERBERATORY FURNACES

Energy savings and efficiency improvements can be developed for reverberatory furnaces. For combustion efficiency and burner preheating the previous examples are repeated and applied to reverberatory furnace summary analysis.

REFRACTORY MATERIALS - REVERBERATORY FURNACES

Sample Calculation -

Assume a reverberatory furnace melts 2,000 lbs of aluminum per hour. The area of refractory below metal is 40 sq. ft. and the area of refractory above metal is 40 sq. ft. Thickness of refractory is 6 inches. Metal is at 1380° F and combustion gas temperature above the metal is 3000° F. To find heat loss with conventional refractory, the thermal conductivity k for the material is determined from Table 3-V to be 6 BTU/hr. per sq. ft. (deg. F per inch.) for crushed firebrick.

$$\text{Heat loss } Q = \frac{t_1 - t_2}{R_1 + F_2} \text{ etc.}$$

Where t_1 = Hot Face Wall Temperature.
 t_2 = Cold Face Wall Temperature.
 R = Resistance, which is the wall thickness of the lining divided by the conductivity of the material K.

Mean temperature $\frac{t_1 - t_2}{2}$ is required to select K

Thus the mean temperature for area above the metal, based on a combustion gas temperature of 3000° F = $\frac{3000 - 100}{2} = 1450^\circ \text{ F}$

Mean temperature for area below the metal = $\frac{1380 - 100}{2} = 690^\circ \text{ F}$

∴ Q_a (above the metal) = $\frac{3000 - 100}{6/6} = 2900 \text{ BTU/Hr/Sq. Ft.}$

= $2900 \times 40 = 116,000 \text{ BTU/hr.}$

∴ Q_b (below the metal) = $\frac{1380 - 100}{6/6} = \frac{1280}{1} = 1280 \text{ BTU/hr/sq/ft.}$

= $1280 \times 40 = 51,200 \text{ BTU/hr.}$

∴ Total heat loss through the refractory walls

= $Q_a + Q_b = 116,000 + 51,200 = \underline{167,200 \text{ BTU/hr.}}$

To find the heat loss with ceramic lining used for insulation between the refractory and the outer shell, the added R, resistance, must be calculated.

The thermal conductivity K for ceramic fiber is determined from Table 3-V for 1 inch thick material to be 0.26 BTU/hr. per sq. ft. (deg. F per inch.)

Note - Mean temperature assumed between refractory and shell,
 $t = 200^{\circ} \text{ F.}$

$$\begin{aligned} \therefore \text{ New heat loss } Q_a + Q_b &= \frac{(t_{1a} - t_2) 40}{6/6 = 1/0.26} + \frac{(t_{1b} - t_2) 40}{6/6 + 1/0.26} \\ &= \frac{(3000 - 100) 40}{1 + 3.84} = \frac{(1380 - 100) 40}{1 + 3.84} = 23,970 + 10,600 \\ &= \underline{34,570 \text{ BTU/hr.}} \end{aligned}$$

Change in heat loss through lining by adding 1 inch of ceramic fiber insulation = 167,200 - 34,570 = 132,630 BTU/hr. reduction, equivalent to 79.3% savings.

Based on a melt program of 8 hours per day, 240 days per year, the annual gas cost reduction is as follows:

$$\frac{132,600 \text{ BTU/hr.} \times 8 \times 240}{100,000 \text{ BTU/therm}} \times \$0.30 = \underline{\$760}$$

Summary

Item	Present Energy	Probable Energy
Heat to Melt	1,000,000 BTU/hr.	1,000,000 BTU/hr.
Radiation Losses*	250,000 BTU/hr.	117,000 BTU/hr.
Combustion and Stack Losses*	2,045,000 BTU/hr.	2,045,000 BTU/hr.
Gross Input	3,295,000 BTU/hr.	3,162,000 BTU/hr.

* Combustion and stack losses from previous example after improvements are listed in this case for present energy use.

Energy flow diagrams for all improvements by progression from original condition to ultimate condition are as follows:

Energy Flow Diagrams - Reverberatory Furnace Example

ORIGINAL CONDITION:

COMBUSTION IMPROVEMENT & BURNER AIR PRE-HEAT

REFRACTORY & METAL COVERS IMPROVEMENTS

OVERALL FURNACE EFFICIENCY

The following table summarizes the probable cost and energy saving available by carrying out all of the possible improvements in common with the crucible furnace per previous examples.

TABLE 3 - VIII. SUMMARY (ENERGY AN COST SAVINGS)

ITEM	BTU/HR REDUCTION	% ENERGY SAVING	ANNUAL GAS THERMS	SAVINGS COST \$
Combustion Efficiency*	875,000	25.0%	17,500	5,250
Preheat Combustion Air	680,000	26.0%	13,100	3,930
Refractory Upgrade	132,000	4.0%	2,550	760
Furnace Covers	75,000	2.1%	2,900	870
TOTAL	1,762,000		36,050	\$10,810

$$\text{Overall percent energy reduction} = \frac{1,762,000}{4,850,000} = 36.3\%$$

$$\text{Overall thermal efficiency} = \frac{1.0 \times 10^6 \times 100}{(4.85 - 1.762 \times 10^6)} = 32.3\%$$

$$\text{Present efficiency (approximate)} = 20.6\%$$

$$\text{Increased efficiency} = 32.3 - 20.6 = 11.7\%$$

<u>ECONOMIC EVALUATION</u>		<u>CRUCIBLE FURNACE</u>	<u>REVERBERATORY FURNACE</u>
1.	Replace existing burner system with a combination nozzle mix burner system-recuperator package with completely pre-wired control system Equipment Cost _____	\$ 30,000.00	30,000.00
2.	Replace conventional refractory lining with ceramic fiber material _____	\$ 2,000.00	500.00
3.	Metal covers in ceramic fiber material _____	\$ 200.00	200.00
4.	Labor to install Item 1 _____	\$ 17,000.00	17,000.00
5.	Engineering Costs _____	\$ 5,000.00	5,000.00
TOTAL		\$ 45,000.00	43,000.00

$$\text{Payback period} = \frac{\text{Capital Investment}}{\text{Energy Savings \$ / YR}} = \text{Years}$$

Therefore payback period (present day costs)

$$\text{Crucible Furnace} = \frac{45,000}{11,290} = 3.98 \text{ years}$$

$$\text{Reverberatory Furnace} = \frac{43,000}{10,850} = 3.98 \text{ years}$$

NOTE: The above costs are for example only, actual equipment costs are to be obtained for specific furnace item as part of normal engineering procedure. Labor costs for lining installations are assumed to be covered by normal maintenance expense budget.

HEAT TREATING

General Considerations

This section, dealing with the energy savings obtainable in the Heat Treat Furnace operation, will concentrate generally on the major areas for energy savings attributed to:

- Process operation and control
- Refractory materials
- Combustion equipment
- Heat recuperation

Formulas, calculations, and graphs have been simplified with the Scope of the Project to reflect constant conditions during the process.

To investigate any process in depth it is essential to establish parameters, circulate the data and plot results on a continuous basis to establish the limits of the operation and equipment, and identify any trend.

The work sheet lists the expected parameters for furnace shell, blower, burner and ancillary equipment, and operational data to complete a "one shot" energy audit and constitute a base for any future improvements. A tape measure, thermometer, flue gas analyzer and flow meters will be the tools needed.

FIGURE 3-14. HEAT TREAT DATA INPUT

HEAT TREATING UNIT NO.1			
FURNACE MAKE <u>ANY</u> MODEL <u>ANY</u> SIZE <u>10' x 20' x 8' HIGH</u> CAPACITY <u>20,000</u> LBS. TYPE OF LINING <u>Conventional</u> WALL THICKNESS <u>13½</u> INCH BLOWER MAKE _____ MODEL _____ SIZE _____ CFM. PRESS _____ "WG VOLT _____ HP _____	BURNER MAKE <u>ABC</u> MODEL <u>ABC</u> TYPE <u>Pre mix</u> SIZE _____ BTU/HR FUEL <u>Natural Gas</u> RECUPERATOR MAKE <u>None</u> MODEL _____ TEMP _____ °F TYPE _____ SIZE _____ CONTROLS MAKE <u>None</u> TYPE _____		
TYPE OF HEAT TREAT CYCLE _____ ALLOY _____			
HEAT TREAT CYCLE - HEATUP _____ HRS - SOAK _____ HRS -COOL DOWN _____ HRS CYCLES PER WEEK _____ TEMPERATURE <u>1,650</u> °F AVERAGE LOAD _____ LBS CASTING _____ LBS BASKETS _____ LBS STOOLS _____ LBS LOAD DENSITY _____ LBS/WFT QUENCH <u>AIR</u> , <u>H2O</u> , <u>OIL</u> QUENCH TEMPERATURE _____ °F	FUEL/AIR RATIO <u>Un-controlled</u> HIGH LOW FLUE TEMPERATURE <u>1650</u> °F _____ °F SHELL MEAN TEMPERATURE _____ °F FURNACE PRESSURE <u>Negative</u> "WC FLUE ANALYSIS (HIGH) <u>N/A</u> % CO <u>N/A</u> % O ₂ <u>5</u> % CO ₂ FUEL CONSUMPTION <u>116</u> THERMS/CYCLE		

MISCELLANEOUS

WALL AREA 880 SQ.FT.
WALL TEMPERATURE HOT FACE T₁ 1650 °F
WALL TEMPERATURE COLD FACE T₂ 160 °F
AMBIENT TEMPERATURE 80 °F
EXTERNAL SURFACE AREA 880 SQ.FT.
HOT SURFACE AREA 570 SQ.FT.
ENERGY COST/THERM \$ 0.30

HEAT TREAT LOADS/DAY _____
HEAT TREAT LOADS/YEAR _____

Note: Data Recorded is only that needed to perform sample calculations.

TABLES, GRAPHS AND CHARTS

TABLE 3-IX

APPROXIMATE THERMAL CONDUCTIVITIES OF FIRECLAY BRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference,
for One-Inch Thickness

Kind of Brick	Den- sity*	Mean Conductivity at T°F.												
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600 2800
147	9.7	9.7	9.7	9.7	9.8	9.9	10.0	10.2	10.3	10.5	10.7	10.9	11.1	11.3
146	8.7	8.8	9.0	9.1	9.3	9.4	9.6	9.7	9.9	10.0	10.2	10.4	10.5	....
136	8.4	8.5	8.7	8.8	9.0	9.2	9.3	9.5	9.6	9.8	9.9	10.1	....	....
127	7.1	7.3	7.4	7.6	7.8	8.0	8.1	8.3	8.5	8.7	8.8	9.0	....	....
125	5.8	6.2	6.5	6.9	7.3	7.6	8.0	8.3	8.7	9.0	9.4	9.8	....	....

*Pounds per Cubic Foot.

NOTE: For brick of the same type, class, composition, and burn, the conductivities are approximately proportional to the bulk densities (weights in pounds per cubic foot).

TABLE 3-X

APPROXIMATE THERMAL CONDUCTIVITIES OF INSULATING FIREBRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference,
for One-Inch Thickness

Den- sity*	Thermal Conductivity at T°F													
	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
36	1.06	1.20	1.34	1.48	1.63	1.77	1.91	2.05	2.19	....	....	....	....	....
38	1.26	1.40	1.54	1.68	1.83	1.97	2.11	2.25	2.40	....	....	....	....	....
46	1.44	1.59	1.75	1.91	2.06	2.22	2.38	2.53	2.69	2.85	3.00	....	....	....
31	0.78	0.86	0.94	1.02	1.09	1.17	1.25	1.33	1.41	1.48	1.56	....	....	....
49	1.83	1.98	2.13	2.28	2.43	2.58	2.73	2.88	3.03	3.18	3.33	3.48	....	....
56	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90
60	2.20	2.35	2.50	2.65	2.80	2.95	3.10	3.25	3.40	3.55	3.70	3.85	4.00	4.15

*Pounds per Cubic Foot

FIGURE 3-15. THERMAL CONDUCTIVITY OF CERAMIC FIBER INSULATION

Thermal Conductivity vs Mean Temperature (per ASTM C-177)**

**All heat flow calculations are based on a surface emissivity factor of .90, an ambient temperature of 27°C (80°F), and zero wind velocity, unless otherwise stated. All thermal conductivity values for Fiberfrax materials have been measured in accordance with ASTM Test Procedure C-177. When comparing similar data, it is advisable to check the validity of all thermal conductivity values and ensure the resulting heat flow calculations are based on the same condition factors. Variations in any of these factors will result in significant differences in the calculated data.

Heat storage and losses can be approximated based on the following
Table 3-XI.

TABLE 3-XI. HEAT STORE AND LOSSES BTU/SQ. FT.

WALL THICKNESS	TYPE REFRACTORY	HOT FACT TEMPERATURE °F					
		1,200		1,600		2,000	
		H. ST.	H. L.	H. ST.	H. L.	H. ST.	H. L.
9"	Composite 2,000° insulation and firebrick	13,700	285	19,200	437	24,800	615
13-1/2"	Composite 2,000° insulation and firebrick	22,300	335	31,400	514	40,600	718
22-1/2"	Composite 2,000° insulation and firebrick	43,200	182	61,000	281	79,200	392
6"	Ceramic fiber	842	208	1,170	432	1,490	672

H. ST. - Heat Stored
H. L. - Heat Lost Btu/hr

FIGURE 3-18. EFFECT OF AIR INFILTRATION

FIGURE 3-18A

FIGURE 3-18B

Courtesy of American Gas Association

Above table to be used for calculating air infiltration through cracks.

FIGURE 3-19. PREHEATING OF COMBUSTION AIR*

*From AGA Catalog

SAMPLE CALCULATIONS

Upgrading Furnace Linings

Heat loss through various refractory linings can be calculated by the use of the following mathematical formula:

$$\text{HEAT LOSS "Q"} = \frac{T_1 - T_2}{R_1 + R_2} \text{ etc.}$$

WHERE:

- t_1 = Hot face wall temperature
- t_2 = Cold face wall temperature
- R = Resistance, which is the thickness of the lining divided by the conductivity of the material "K"

Typical values of "K", thermal conductivity in Btu/hr, per square foot, per degree "F" temperature difference, for one inch thickness are listed in Tables 3-IX and 3-X for fire clay and brick refractories.

"K" values for ceramic fiber linings are shown in Figure 3-15.

The heat required to get refractories up to furnace operating temperature (heat storage effect) is listed in Table 3-XI.

To obtain "K" factors from Tables 3-IX, 3-X, and Figure 3-15, it is necessary to calculate the mean temperature. This is accomplished by adding t_1 and t_2 and dividing by 2. Thus mean temperature for this set of conditions is:

$$\frac{1650^{\circ}\text{F} - 160^{\circ}\text{F}}{2} = 905^{\circ}\text{F.}$$

Example: Determine heat loss through furnace walls lined with:

- (a) Conventional brick refractory lining
 - (b) Laminated ceramic lining
 - (c) Full ceramic fiber lining
- (a) Conventional refractory lining is composed of the following materials:
- 9" fire brick with a density of 147 lbs/cu. ft.
 - 4-1/2" insulated brick with a density of 31 lbs/cu. ft.

Therefore:

$$\text{Heat loss} = \frac{1650 - 160}{.91 + 4.24} = 289 \text{ Btu/hr/F}^2$$

To find resistance "R" for insulated brick, enter Table 3-X at 905° F (mean temperature) and read down to the 31 lb. density column, the resultant "K" factor is approximately 1.06,

$$\text{Therefore } R = \frac{4-1/2}{1.06} = 4.24$$

Total heat loss through furnace walls:

$$= 289 \text{ Btu/hr/ft}^2 \times 570 \text{ sq. ft.} = \underline{164,730 \text{ Btu/Hr.}}$$

(b) Laminated refractory lining is composed of:

- 9" fire brick with a density of 147 lb/cu. ft.
- 4-1/2" insulated brick, density of 31 lbs/cu. ft.
- 1" ceramic fiber lining, density of 8 lb/cu. ft.

Therefore:

$$\text{Heat Loss} = \frac{1650 - 160}{.91 + 4.24 + 1.43} = 226 \text{ Btu/hr/F}^2$$

Total heat loss through furnace walls:

$$= 226 \text{ Btu/Hr/F}^2 \times 570 \text{ sq. ft.} = \underline{128,820 \text{ Btu/hr.}}$$

(c) Full ceramic fiber lining composed of the following:

- 12" ceramic fiber at 8 lbs. density/cu. ft.

Therefore:

$$\text{Heat Loss} = \frac{1650 - 160}{17.14} = 87 \text{ Btu/hr/F}^2$$

To find resistance "R" for ceramic fiber, enter Figure 3-15 at 905° F., extend up to the 8 lb. density column and read 0.7 at the left hand side of the graph, therefore:

$$R = \frac{12}{0.7} = 17.14$$

Total heat loss through furnace walls:

$$= 87 \text{ Btu/hr/Ft}^2 \times 570 \text{ Sq. Ft.} = \underline{49,590 \text{ Btu/hr.}}$$

TABLE 3-XII. SUMMARY - HEAT LOSS FOR VARIOUS LININGS

ITEM	Btu/hr	% Savings over Basic Refract.
Conventional Refractory	164,730	-0-
Laminated Refractory	128,820	22%
Ceramic Fiber	49,590	70%

Equivalent total gas usage reduction, utilizing ceramic fiber lining, is $164,730 - 49,590 = 115,140$ Btu/hr or 1.15 Therms per hour.

Based on a continuous heat treat operation (with furnace in equilibrium) of 16 per day, 5 days per week-50 weeks per year, the total yearly gas savings would be as follows:

$$\frac{115,140 \text{ Btu/Hr} \times 16 \times 5 \times 50}{100,000 \text{ Btu/Therm}} \times \$0.3 = \underline{\$1,382.00 \text{ per year}}$$

Batch type heat treat operation is very costly in terms of gas usage due to the input energy required to heat the refractory mass up to furnace operating temperature, the following table illustrates the amount of energy required to heat the refractory to 1,600° F. versus that required for ceramic fiber:

TABLE 3-XIII. EFFECT OF USE OF CERAMIC FIBER INSULATION

ITEM	1/Heat Capacity Stored - Btu	% Savings over Basic Refractory
Conv. Refractory (13-1/2")	17,898,000	
Ceramic fiber (12")	1,333,800	92.5%

*Based on 570 sq. ft. inside furnace area and heat storage figures from Table IV.

Operating batch furnaces on a rapid change-over schedule will realize substantial fuel savings, also consideration must be given to the product to be processed. The scheduling effort to load to design capacity will be more than offset by the fuel savings obtained by reduced heating of the lining.

Quantitative figures for overall savings, as a percentage of gas input to furnace, for upgrading conventional lining cannot be stated due to the many variables encountered in actual heat treat practices as applied to individual foundry operations. Savings shown in the example calculations, for lining replacements is attributed to radiation loss savings only.

Improving Combustion Efficiency

A Heat Treat Furnace has the following characteristics (from input data sheet);

- Furnace size: 20' x 10' x 8 ft. high.
- Furnace capacity: 20,000 lbs.
- Operating temperature: 1,650° F.
- 5% CO₂ in flue gas.
- Flue gas temperature: 1,650° F.
- Natural gas flow rate: 116 Terms/Hr. or 11,600 cu. ft.
- Furnace physical condition: 1/4" crack visible all around door.

Calculate present combustion and furnace efficiency and probable furnace efficiencies if the furnace was upgraded as follows:

- Install nozzle mix burners with flue/air ratio controls.
- Install furnace pressure controls.
- Install hot gas recuperator for preheating combustion air.
- Repair furnace door and seal cracks.

Example No. 1: Calculate present excess air and available heat.

Excess air through burner system with 5% CO₂ in flue gas (from Figure 3-9) is 130%.

Therefore, available heat to do work, (from Figure 3-10) with 130% excess air and 1,650° F. flue gas temperature, is 20% of 11,600 cu. ft./Hr. of natural gas which is:

$$11,600 \text{ cu. ft./Hr} \times 0.20 = 2,320 \text{ cu. ft./Hr or } 2,320,000 \text{ Btu/Hr}$$

Example No. 2: Calculate secondary excess air infiltration due to door leakage.

From Figure 3-16A with an average furnace temperature of 1,650° F., the furnace negative pressure due to chimney effect is 0.011" WC per foot of furnace height.

Therefore, total negative pressure is $0.011 \times 8 = 0.088$ " WC.

From Figure 3-16B with a total furnace negative pressure of 0.088, the air infiltration is approximately 280 cubic feet per hour per square inch of crack opening.

Therefore, total crack opening is, based on 28 linear feet of door circumference, $336 \text{ inches} \times 1/4" = 84 \text{ sq. inches}$.

From Figure 3-16A with an average furnace temperature of $1,650^{\circ} \text{ F.}$, approximately 35 Btu is necessary to heat each cubic foot of infiltrated air, therefore, total heat required is:

$$35 \text{ Btu} \times 84 \text{ sq. inches} \times 280 \text{ cu. ft/Hr/Sq. inch} = 823,200 \text{ Btu/Hr.}$$

Present Combustion Efficiency

From Example 1. Available heat = 2,320,000 Btu/hr.

From Example 2. Heat Lost (Infiltration) = 823,200 Btu/hr.

Net Heat Available = 1,496,800 Btu/hr.

$$\text{Efficiency} = \frac{1,496,800}{11,600,000} \times 100 = 12.9\%$$

Example No. 3: Calculate probable combustion efficiency after installing new burner system and sealing furnace cracks. CO_2 content corrected to 11% and positive pressure maintained in furnace.

Available heat to do work (from Figure 3-10) with 10%.

Excess air is $53\% \times 11,600,000 \text{ Btu/hr} = 6,148,000 \text{ Btu/hr}$

Net increase in heat content available is:

$$6,148,000 \text{ Btu/hr} - 1,496,800 \text{ Btu/hr} = 4,651,200 \text{ Btu/hr}$$

or 75.65% increase

Based on 5 days per week, 50 weeks per year heat treat operation with heat-up time averaging 6 hours, the yearly energy savings would amount to:

$$\frac{4,651,200 \text{ Btu/hr} \times 5 \times 50 \times 6}{100,000 \text{ Btu/Therm}} = 69,000 \text{ Therms per year.}$$

At \$0.30 per therms, dollar savings would be \$20,700/year

Combustion Air Preheating

From the preceding examples approximately 5,452,000 Btu/hr (11,600,000 - 6,148,000) is lost through the exhaust stack and radiation losses through the furnace walls. By preheating the combustion air with the use of a hot gas recuperation, the following additional energy savings can be realized.

Example No. 4: With flue gas temperature of 1650° F, calculate the energy savings if combustion air is preheated to 1200° F.

From Figure No. 3-12 the resultant fuel savings will amount to approximately 28%.

Therefore, additional heat saved per hour

$$= 0.28 \times 11,600,000 \text{ Btu/hr} = 3,248,000 \text{ Btu/hr}$$

Annual energy savings, using same operating time as stated in example 3, is:

$$\frac{3,248,000 \text{ Btu/hr} \times 1,500 \text{ Hrs.}}{100,000 \text{ Btu/Therm}} = 48,000 \text{ Therm/yr}$$

At \$0.30 per therm, dollar savings would amount to \$14,400

Overall Furnace Efficiency

The following table summarizes the possible cost and energy savings by upgrading existing furnace.

TABLE 3-XIV. SUMMARY OF COST AND ENERGY SAVINGS

Item	Btu/hr Saved	ENERGY SAVINGS PERCENT	Annual Gas Savings	
			Gas (Therms)	Cost
Furnace Radiation Losses	115,140	70%	4,600	\$1,382
Improve Comb. Efficiency	4,651,000	53%	69,000	\$20,700
Pre-heat Combustion Air	3,248,000	28%	48,000	\$14,400
Total	8,014,140		121,600	\$36,482

$$\text{Overall Energy savings} = \frac{8,014,140}{11,600,000} \times 100 = 69\%$$

Note: The foundry industry, in general, is experiencing between 50 to 60% actual Energy Savings by upgrading their present heat treat furnaces. Energy calculations in Section 3 of this study are based on 56% savings.

Summary

It must be restated that this analysis has been oversimplified to illustrate the need for improving existing thermal efficiency. The examples used can be a valuable tool in estimating potential savings. A full heat balance and thermal analysis should be made by an expert in this field before a major conversion is made. The energy savings are there if product requirements can be adjusted toward that goal.

Economical Evaluation

(a)	Replace existing burner system with a combination nozzle mix Burner system - recuperator package with completely pre-wired control system. (Equipment cost).....	\$90,000
(b)	Replace conventional refractory lining with 12" thick ceramic fiber insulation - material cost.....	\$15,000
(c)	Labor to install item No. 1*.....	\$40,000
(d)	Engineering costs.....	<u>\$10,000</u>
	Total.....	\$155,000

$$\text{Pay Back Period} = \frac{\text{Capital Investment}}{\text{Energy Savings Cost}} = \text{_____ yrs.}$$

$$\text{Therefore: Pay Back} = \frac{\$155,000}{36,482} = 4.25 \text{ years}$$

The above pay back period does not take into account future cost of natural gas which could increase as high as 15% per year, or government tax credits for installation of energy saving devices.

*Installation labor does not include the relining of the furnace. It is assumed that this labor would be performed by foundry maintenance personnel and expensed.

LADLE HEATING

General

Ladle Heating is a very necessary requirement in any foundry operation. It is a large user of natural gas and probably represents the greatest abuse of gas energy in foundries today. This Section will examine the requirements for upgrading or replacing existing equipment for ladle drying and heating, covering the following:

- Ladle covers
- Burner efficiencies
- Improved insulation

Formulas, calculations, and graphs have been simplified within the scope of the project to reflect constant conditions during the process.

To investigate any process in depth it is essential to establish parameters, calculate the data and plot results on a continuous basis to establish the limits of the operation and equipment and identify any trends.

FIGURE 3-18

OPERATIONAL DATA FACT SHEET

LADLE PREHEAT DATA

LADLE CAP TONS 1.0 HEAT CYCLES/DAY 3
LADLE AREA INSIDE 12 SQ FT. LINING THICKNESS 2.5 ins.
COVERED No TYPE OF LINING Firebrick
INSIDE TEMP 1560 °F OUTER SHELL TEMP 300 °F
AMBIENT TEMP N/A °F
GAS USAGE/HR 550 CU FT. CO₂ READING N/A
COMBUSTION AIR N/A CFM PRESSURE -- WG
PREHEAT CYCLE TIME 1.0 HRS FLUE TEMP -- °F
REFRACTORY K VALUE 6 RS VALUE 0.33
BLOWER HP N/A RECUPERATOR EFFCY --
FUEL COST/THERM \$ 0.3 ANNUAL USE N/A BTU x 10⁶
NUMBER OF UNITS IN USE 1

GRAPHS, TABLES AND CHARTS

Figure 3-19 shows typical relationship of time versus temperature to fuel input for uncovered and covered ladles both with tight fitting and raised covers.

FIGURE NO. 3-19. EFFECT OF LADLE COVERS

- 1/ Temperatures both in °C and °F at the inside bottom of the ladle.
- 2/ Figures shown as gas flow rates in liters per min. and cubic feet per hour.

Example of use: Curve is developed for specific ladle size with measured gas flow rates.

Read elapse time from intersection of curve with temperature.

For covered ladle at 275 cu. ft./hour gas flow, the time to attain required temperature 850°C, is approximately 50 minutes.

FIGURE 3-20
HEATING CHARACTERISTICS

FIGURE 3-21
FUEL CONSUMPTION

Reference: Hotwork Mfg. Inc.

Example of use:

Figure 3-20: Read elapsed time hours at intersection of temperature with approved burner graph line; then,

Figure 3-21: Obtain fuel usage for improved burner by reading up from elapsed hours to intersection with graph line and across to fuel usage.

For example: At temperature requirement of 1300° F, read approximately 0.25 hours (for improved burner) from Figure 3-20.

Transfer hours (0.25) onto Figure 3-21 and read approximately 400 cu. ft. fuel used by improved burner.

TABLE 3-XI. THERMAL PROPERTIES OF CONCRETES

B - Typical Thermal Properties of Refractory and Insulating Concretes (Mix proportions approx. 1 vol. cement: 3 - 4 vols. aggregate).

Aggregate.	Fired density, lb. per cub. ft.	Heat capacity, B.t.u. per (cub. ft.) (deg. F.)	Thermal conductivity, B.t.u. per (hr./sq. ft.) (deg. F. per in.)	Thermal diffusivity, (sq. ft. per hr.)
Vermiculite	35	9	1.2	0.011
Diatomite	55	14	1.7	0.010
Crushed H.T. insulating brick	85	21	3.2	0.013
Expanded clay	90	22	3.5	0.013
Crushed firebrick	115	29	6	0.017
Molochite	120	31	8	0.021
Sillimanite	135	33	10	0.025
Carborundum	145	40	50	0.103
Calcined bauxite	160	45	12	0.022
Magnesite	160	45	20	0.037
Chrome-magnesite	165	37	8	0.013
Fused magnesia	170	50	24	0.04
Fused alumina	175	52	16	0.026
Bubble alumina	95	22	6	0.023

TABLE 3-XVI. THERMAL CONDUCTIVITY OF CONCRETES

	2100	2400	2600	2800	3000
Maximum Recommended Use Temperature	2100°F (1150°C)	2400°F (1315°C)	2600°F (1425°C)	2800°F (1540°C)	3000°F (1650°C)
Density (PCF)	12.15	18.22	18.22	18.22	18.22
Thermal Conductivity - k (BTU · In./S.F. · °F · Hr.)	Same k values for these compositions.				
Mean Temperature °F					
600°F	0.26	0.29	"k" measurements made at Refractories Research Center, Ohio State University.		
800°F	0.36	0.35			
1000°F	0.48	0.41			
1200°F	0.62	0.48			
1400°F	0.77	0.57			
1600°F	0.93	0.67			
1800°F	1.08	0.79			
2000°F	1.24	0.93			
2200°F	-	1.10			
2400°F	-	1.30			

* Ref. Industrial Insulations Inc.

SAMPLE CALCULATIONS

Ladle Covers:

Heat loss during pre-heat of ladle relates to time in attaining required temperature measured at the inside bottom of the ladle.

Typical burner sizes for average ladle capacities of 1 ton (iron) is 1.0×10^6 Btu/hr. Therefore energy savings for any capacity ladle can be prorated based on pre-heat time for any size burner.

Example:

Burner size 1" (1.0×10^6 Btu/hr) shows a gas flow rate of 275 cu.ft./hr.

The elapsed time to attain 850°C (1560°F) with the tight-cover ladle, is approximately 50 minutes, reference Figure 3-19.

$$\text{Thus gas usage} = \frac{50}{60} \times 275,000 = 0.230 \times 10^6 \text{ Btu.}$$

The elapsed time to attain 850°C (1560°F) with a raised cover ladle utilizing gas flow rate of 275 cu.ft./hr, is approximately 50 minutes, reference Figure 3-19.

$$\text{Thus gas usage} = \frac{60}{60} \times 275,000 = 0.275 \times 10^6 \text{ Btu}$$

The elapsed time to attain 850°C (1560°F) with an open ladle utilizing gas flow rate of 550 cu.ft./hr is approximately 60 minutes, reference Figure 3-20.

$$\text{Thus gas usage} = \frac{60}{60} \times 55,000 = 0.55 \times 10^6 \text{ Btu}$$

Relative savings for the alternate arrangements is:

Item	Btu's	Change in energy
Uncovered ladle	550,000	-0-
Raised cover ladle	275,000	- 50.0%
Tight cover ladle	230,000	- 58.0%

In quantitative terms the covered ladle (tight cover) results in gas usage reduction of:

$$550,000 \times 0.58 = 320,000 \text{ Btu/hr}$$

$$\text{At } \$0.30 \text{ per therm, cost reduction} = \$0.96/\text{hr}$$

Based on 20% utilization, 8 hours/day, 240 days per year, the annual cost reductions:

$$0.96 \times 8 \times 240 \times 0.2 = \$370$$

It should be noted that the example is worked for one ladle only whereas generally more than one ladle is in use daily. Also size of ladle and therefore burner size will have impact on total possible savings.

COMBUSTION SYSTEMS

High efficiency burners reduce drying and preheating time which translates into increased ladle utilization and energy reduction.

Comparison between a conventional burner (high intensity) and a high efficiency burner is shown in Figure 3-20 and Figure 3-21.

Example: Time required to raise ladle refractory to 1300° F is 1 hour, using conventional burner.

Indicated time for improved burner with high efficiency characteristics, is shown on Figure 3-20 to be approximately 0.25 hours. With fuel usage of 1,000 cu. ft. and 400 cu. ft. respectively as indicated on Figure 3-22.

Thus efficiency improvement is calculated from

$$\frac{\text{Fuel usage reduction} \times 100}{\text{Original fuel usage}} = \text{percent}$$

$$\text{Therefore: } \frac{(1,000 - 400) \times 100}{1,000} = 60.0\%$$

Equivalent energy reduction for ladle preheating in previous example using 230,000 Btu/hr, the gas usage reduction is:

$$230,000 \times 0.60 = 138,000 \text{ Btu/hr.}$$

At \$0.30 per therm, the cost reduction =

$$\frac{138,000 \text{ Btu/hr} \times 0.3}{100,000 \text{ Btu/Therm}} = \$0.414/\text{hr}$$

Based on 20% utilization, 8 hours/day, 240 days per year, the annual cost reduction is:

$$\$0.414 \times 8 \times 240 \times 0.2 = \$160$$

INSULATION

Ladle insulation and covers increase heating efficiency which leads to quicker heating and thus less time for losing energy by conduction and radiation through the ladle walls. Improved wall insulation saves energy in two ways, first by reduction in pre-heat gas requirements and second by minimizing the metal temperature loss during the pour, thus lowering the initial superheat required by the melter and extending the usable pouring period of the ladle with the possibility of reducing scrap castings by pouring less cold metal.

Example of energy savings by installing 1/2 inch insulation between the 2 inch refractory and the shell. The heat lost during ladle preheating is to be calculated and compared to lining without insulation.

Area of lining 30" dia. x 30" deep = 12 sq. ft.

Heat loss through conventional lining material is calculated from

$$Q = \frac{t_1 - t_2}{R_1 + R_2} = \text{Btu/Sq.Ft/hr}$$

Where $R = \frac{\text{Thickness of Lining}}{\text{"K" value}}$

t_1 = hot face temperature (1300° F)

t_2 = cold face temperature (200° F)

K = thermal conductivity of lining material from Figure 4 and Figure 5

$$\text{Thus } Q_a \text{ (no insulation)} = \frac{(1300 - 200)}{R_1} 12 \text{ sq.ft.}$$

$$R_1 \text{ (high alumina cement)} = \frac{2.5 \text{ inches}}{K} = \frac{2.5}{6} = 0.42$$

$$Q = \frac{1100 \times 12}{0.42} = 31,400 \text{ Btu/hr}$$

$$Q_b \text{ (with insulation)} = \frac{(1300 - 200)}{R_1 + R_2} 12$$

$$R_1 = \frac{2 \text{ inches}}{6} = 0.333$$

$$R_2 \text{ (ceramic fiber)} = \frac{0.5}{K} = \frac{0.5}{0.29} = 1.72$$

Note: Ceramic fiber layer assumed to have a mean temperature below 600° F.

$$Q_b = \frac{1100 \times 12}{0.333 + 1.72} = 6,400 \text{ Btu/hr}$$

$$\text{Reduction in heat loss} = 31,400 - 6,400 = 25,000 \text{ Btu/hr}$$

Equivalent to 79.6% savings in energy.

From previous example, net reduction in energy usage is:

$$31,400 \text{ Btu/hr} \times 0.796 = 25,000 \text{ Btu/hr}$$

At \$0.30 per therm, cost reduction

$$\frac{25,000 \times 0.3}{100,000 \text{ Btu/Therm}} = \$0.075/\text{hr}$$

Based on 20% utilization, 8 hours per day, 240 days per year, annual energy cost savings is = $0.075 \times 8 \times 240 \times 0.2 = \$28.80/\text{year}$.

SUMMARY (PROBABLE ENERGY SAVINGS)

The following table summarizes present and probable energy requirements for ladle heating as determined in sample calculations if all the improvements are carried out.

TABLE 3-XVII. PROBABLE SAVINGS

ITEM	BTU/HR SAVED	%SAVINGS	ANNUAL GAS THERMS	SAVINGS COST \$
Covers	320,000	58.0	1,233	370
Combustion System	138,000	60.0	533	160
Insulation	25,000	79.6	96	30
EQUIPMENT TOTAL	483,000	--	1,862	\$560

Actual overall energy saving between 50% and 60% is considered to be practical for the majority of ladle heating operations. Additional savings can be realized if ladle heater utilization is reduced to 15% of the typical 8 hour shift period.

ECONOMIC EVALUATION

<u>Item</u>		
1.	Provide insulated cover (material cost)	= \$ 500.00
2.	Replace burner with 'High Efficiency' unit with gas controls	= 4,000.00
3.	Add insulation to ladle lining 1/2" x 12 sq. ft. (material cost)	= 50.00
4.	Labor to install cover	= 450.00
SUBTOTAL		<u>\$ 5,000.00</u>
5.	10% Engineering cost	500.00
TOTAL		<u>\$ 5,500.00</u>

Payback period = $\frac{\text{Capital Investment}}{\text{Energy Savings}}$ = years

Thus payback = $\frac{5,500}{560}$ = 9.8 years

Note - installation of insulated lining is assumed to be carried out during normal reline schedule and labor cost is expensed. The above costs are "order of magnitude" only.

C. COKE FUEL MELTING - CUPOLA

GENERAL

Methods of melting to be analyzed in this section are:

- Lined Cold Blast Cupola
- Lined Cupola With 500° F Hot Blast
- Water Cooled Cupola With 1,000° F Hot Blast
- Divided Blast Cupola, Cold Blast
- Lined Cupola, Cold Blast With 2-4% Oxygen Enrichment

COKE USAGE

The conventional cupola is a vertical shaft type furnace with a refractory lining and equipped with a windbox and tuyeres for the admission of air. The sequential material charges, through the stack of the cupola, comprise alternate layers of metallica and coke with some fluxes added. The descending fuel replaces that burned from the original coke bed and maintains the height of this bed.

COKE BED CALCULATIONS

Example

Recommended coke bed height above the tuyeres is;

$$10.5 \times \text{sq. root of blast pressure (ounces)} + 6^*$$

Therefore if windbox pressure = 16 ounces

$$\text{Bed coke height} = (10.5 \times \sqrt{16}) + 6 = 48"$$

Thus the volume of bed coke required per melt campaign is obtainable by reference to Table 3-XVIII. Consider above example and determine weight of coke required in initial bed as follows:

Read Table 3-XVIII, for volume at 16 onz. pressure = 38.5 cu. ft., therefore at 30 lbs/cu. ft., weight of coke = 1155 lbs.

Additional coke may be required to be added to maintain bed height during initial melt period, to obtain full burning of the bed prior to the first charge of metal, and for starting the blast. Additional coke to fill the hearth up to tuyere level, must be made based on specific cupola design. Total energy required to operate the cupola, including bed coke and electric power, is to be calculated as shown on the work sheet as follows:

*6 is a suggested factor which may have to vary for a specific cupola.

STANDARD CALCULATION FORMAT FOR CUPOLA ENERGY DATA

Standard 48" Lined, Cold-Blast Cupola. (Desired melt rate 9.0 TPH)

Melt rate TPH. 9.0 X 2000 18,000 LBS/HR.

Metal to Coke ratio 10:1, Coke charged/hr 1,800 lbs.

CFM air Req'd. 4,100 @ Blast Pressure 18 ONZ

Fan HP 50.0

Skip Loader 7.5

Dust Collector 55.0

Misc. Power 5.0

Equivalent BTU/HR $\frac{117.5 \times .746 \times 3412}{1.73} = 172,878$

Coke Charged/HR 1800 LBS/HR

Bed Coke x 1/8 225

Equivalent BTU/HR $2,025 \times 12,500 = 25,312,500$

TOTAL BTU/HR = 25,713,410

AVERAGE BTU/TON OF METAL CHARGED = 2,831,700

OPERATION OF SPECIAL CUPOLAS

Comparison of current cupola operation with alternate systems, hot blast type, divided blast or oxygen enriched blast, can be made by reference to the model energy chart graphs at specific melt rate requirements.

It assumed that the cupola melt rate, in all cases, is based on conventional practice prior to improvements.

TABLE 3-XVIII. BED COKE REQUIREMENTS

NORMAL WINDBOX PRESSURE (OZ)	BED COKE ABOVE TUYERES (INCHES)	MELT DIAMETER (INCHES)	ZONE AREA (SQ IN)	VOLUME COKE (CU. FT.)
7	28-34	18	254	5.0
12	36-42	23	415	10.0
14	40-46	32	804	21.4
16	42-48	42	1,385	38.5
18	45-51	48	1,809	53.4
20	47-53	72	4,071	124.9

Assumption:
Density of Cupola Coke = 30 lbs/cu.ft.

GRAPHS, TABLES, AND CHARTS

TABLE 3-XIX. CUPOLA OPERATING CHARACTERISTICS

IRON TO COKE RATIO	COKE PER TON OF MELT LB	MELTING RATE TONS PER HOUR	METAL TEMPERATURE °F	APPROXIMATE THERMAL EFF., %
12 to 1	167	16.0	2,656	46.7
11 to 1	182	15.2	2,672	43.0
10 to 1	200	14.2	2,686	39.5
9 to 1	222	13.1	2,706	36.0
8 to 1	250	12.0	2,730	32.0
7 to 1	286	10.9	2,762	28.4
6 to 1	333	9.8	2,798	27.0

LINED CUPOLA - IRON MELTING

FIGURE 3-22

CUPOLA OPERATING CHARACTERISTICS - LINED CUPOLA - IRON MELTING

MELTING GRAY IRON

FIGURE 3-23

CUPOLA OPERATING CHARACTERISTICS - LINED CUPOLA, 500°F HOT BLAST

MELTING GRAY IRON

FIGURE 3-24

CUPOLA OPERATING CHARACTERISTICS - LININGLESS 1000°F HOT BLAST CUPOLA

MELTING GRAY IRON

FIGURE 3-25

CUPOLA OPERATING CHARACTERISTICS - DIVIDED-BLAST CUPOLA

FIGURE 3-26
CUPOLA OPERATING CHARACTERISTICS
LINED COLD BLAST CUPOLA WITH OXYGEN ENRICHED BLAST

FIGURE 3-27

RELATIVE MELT RATE/HOUR FOR 1,000°F
HOT BLAST LINING LESS WATER-COOLED CUPOLA

Figure 3-28

Reduction of charge coke consumption and increase in melting rate by operating cupola with two rows of tuyeres with divided-blast supply (Blast rate 1600ft³/min)

COKE TO METAL RATIO

The range of sizes and operating recommendations for conventional cupolas has been developed over a long period of time resulting in fairly standard data (see Table 3-XIX). Ratio of metal weight to coke charged, excluding the bed coke, determines the melt rate and/or temperature of iron as it leaves the cupola with conventional designed cupolas. Higher tapping temperatures involve a penalty in coke usage and melt rate.

Example

If metal is to be tapped from a cupola at 2,762° F, calculate the energy (coke) penalty compared to tap temperature of 2,686° F. From Table X-XIX, a cupola producing 10.9 tons per hour with iron to coke ratio of 7:1 for 2,762° F tap temperature, results in approximate thermal efficiency of 28.4% at 2,686° F.; the cupola would produce 14.2 tons/hour with iron to coke ratio of 10:1 and approximate thermal efficiency of 39.5%.

Thus at 7:1 ratio, coke usage = 286 lbs/ton melted

10:1 ratio coke usage = 200 lbs/ton melted

Reduction = 86 lbs/ton melted

∴ Penalty for 76° F super heat is equivalent to:

$86 \times 12,500 \text{ BTU/lb} = 1.075 \times 10^6 \text{ BTU/ton melted}$

At \$0.09 per lb for coke, the cost difference

$86 \times 0.09 = \$7.74 \text{ per ton melted}$

Annual energy reduction based on 15,000 tons per year of metal melted

$= 1.075 \times 10^6 \times 15,000 = \underline{16,125 \times 10^6 \text{ BTU}}$

Energy reduction = $\frac{86}{286} = 30.0\%$

Cost savings per year = $\$7.74 \times 15,000 = \underline{\$116,100}$

Thermal efficiency improvement = $39.5 - 28.4 = 11.1\%$

Note- In above example the coke bed height in each case is the same and does not effect the melting energy difference.

Tap temperature reduction may be impractical without other operational improvements such as insulation of launders, pouring ladles, etc. Control of production scheduling is required to minimize holding periods or delays prior to pour off; also, redesign of gating to enable lower casting pouring temperatures is another requirement.

SPECIAL CUPOLA MELTING CONDITIONS

To obtain increased melting or higher temperature and more efficient coke usage, refinements to the standard cupola are available.

Blast conditioning, through utilization of recuperative hot blast, can be provided using the waste heat from the cupola exhaust.

HOT BLAST SYSTEM

Model energy usage in BTU/ton of iron melted can be determined by reference to specific charts and by projecting a point on the graph, at known metal to coke ratio, from desired melt rate in tons per hour. (Figure 3-23 - 24)

Value determined from the graph can be compared to proposed operation under new conditions of operation, by calculation of actual energy usage difference for requirements, as per following example.

Example

In the previous example, the metal to coke ratio in a conventional cupola is 10:1. From Figure 3-22, graph line C, the energy required to melt is 2.85×10^6 BTU/ton. (Includes melt coke, bed coke and electrical energy.)

From Figure 3-27, for conditions of 1,000° F hot blast, a similar size 48" diameter cupola is indicated to be capable of melting 14.2 tons/hr. at 13:1 metal to coke ratio.

Thus reading energy required for 1000° F hot blast cupola at 13:1 metal to coke ratio, from Figure 3-25 is:

$$\text{Energy required} = 2.20 \times 10^6 \text{ BTU/ton}$$

$$\text{Reduction in energy/ton} = (2.85 - 2.20) \times 10^6 \text{ BTU/ton} = 650,000 \text{ BTU/ton}$$

$$\text{Which is equivalent to } \frac{0.65}{2.85} = 22.8\% \text{ improvement}$$

∴ Annual energy reduction based on 15,000 tons of metal melted

$$\text{per year} = \frac{650,000 \text{ Btu/ton melted}}{12,500 \text{ BTU/lb.}} = 52 \text{ lbs coke/ton}$$

$$\text{At \$0.09 per lb, cost reduction} = 52 \times 15,000 \times 0.09 = \underline{\$70,200 \text{ per year}}$$

DIVIDED BLAST CUPOLA

Provision of two rows of tuyeres enables higher metal tapping temperatures to be obtained for a given consumption of coke, or reduction of 20 to 30 percent coke with increased melt rate of 11 to 23 percent with a given blast rate and constant tapping temperature. Comparison of thermal balances for conventional (one row of tuyeres vs. divided blast operation) is as follows:

Item	Conventional	Divided
Coke charge %	12.0	12.0
Metal temp. °F	2655	2755
Top gas composition CO ₂ %	11.9	13.1
Top gas composition CO %	15.0	13.0
Combustion ratio $\frac{\text{CO}_2}{\text{CO}_2 + \text{CO}} \times 100$	44.2	49.8
Top gas temp. °F	860	970

Utilization of Heat Supplied

Sensible heat in metal at			
Top temp. (thermal efficiency)	%	34.7	35.7
Latent heat in top gas	%	38.9	35.0
Sensible heat in top gas	%	12.8	15.1
Other losses	%	13.6	14.2
TOTAL		100.00	100.00

Example

Show reduction of charge coke consumption and increase in melting rate by operating a cupola with two rows of tuyeres at a blast rate of 1,600 cu. ft/min, compared to the cupola operating under previous example conditions. At 13:1 metal to coke ratio, the charge coke is 7.7% addition. Read Figure 3-28 for reduction of coke with two rows of tuyeres (divided blast) at 2,686° F metal temperature and 7.7% charge coke.

∴ From graph line (Figure 3-28) for 2 rows of tuyeres, the reduction of coke consumption = 30%

Thus coke savings for divided blast cupola operation,

$$= 2,000 \times 0.077 \times 0.3 = 36.2 \text{ lbs/ton of melt}$$

$$\begin{aligned} & @ 12,5000 \text{ BTU/lb, energy saved per ton of melt} = 46.2 \times 12,500 \\ & = \underline{577,500 \text{ BTU}} \end{aligned}$$

Total energy requirements for cupola from previous example is approximately 2.20×10^6 BTU/ton melted at 13:1 metal to coke ratio.

Revised energy requirement: divided blast cupola, per ton
 $= 2.20 \times 10^6 - 577,500 = 1.62 \times 10^6$ BTU

By calculation, the new metal to coke ratio is equivalent to energy required at 15.8:1 metal to coke ratio or approximately 126 lbs of coke per ton of melt.

∴ Annual energy reduction based on 15,000 tons of melt required per year $= 577,500 \times 15,000 = 8662.5 \times 10^6$ BTU

$$\text{Percent energy reduction} = \frac{577,500}{2.20 \times 10^6} = 26.2\%$$

Cost reduction for 15,000 tons per year melt requirement

$$= 15,000 \text{ tons} \times 46.2 \text{ lbs/ton} \times \$0.09/\text{lb} = \underline{\$62,370}$$

OXYGEN ENRICHED BLAST SYSTEM

A minimum production rate of 15 tons/day and 3 days per week is generally needed to justify the use of oxygen to gain production increase. Also no major reduction in coke usage occurs above 10 tons per hour melt rate with 2 - 3% O_2 enrichment. Savings at lower production rates are obtained as follows:

Example

Increased melting rate and/or tap temperature can be obtained by oxygen enrichment of 2 - 3%.

The total energy required can be read from graph 'A' Figure 3-26 for production under 10 tons/hour.

$$\text{Thus energy at 9 tons/hour metal melted} = 1.85 \times 10^6 \text{ BTU/ton}$$

Energy reduction compared to say a divided blast cupola (ref. Figure 3-25) with metal to coke ratio of 13.5:1 (graph "E")

$$2.20 \times 10^6 - 1.85 \times 10^6 = 350,000 \text{ BTU/ton}$$

$$\text{Percent savings} = \frac{350,000}{2.20 \times 10^6} = 16\%$$

$$\text{Cost reduction based on reduction of coke} = \frac{350,000}{12,500} \text{ BTU/lb}$$

$$= 28 \text{ lbs/ton melted at } \$0.09 \text{ per lb, the annual savings in coke}$$

$$\text{energy for 15,000 tons melted} = 15,000 \times 28 \times 0.09 = \$37,800/\text{yr.}$$

OVERALL ENERGY SAVINGS

The following table summarizes the possible cost and energy savings by improvements to the cupola operation.

TABLE 3-XIX.
SUMMARY OF COST AND ENERGY SAVINGS

ITEM	BTU/TON SAVED	ENERGY % IMPROVEMENT	ANNUAL COKE THERMS	SAVINGS COST \$
Tap Temp. Reduction	1,075,000	30.0%	161,250	\$ 116,100
Hot Blast System	650,000	22.8%	97,500	70,200
Divided Blast System	577,000	26.2%	86,625	62,370
Oxygen Enrichment (Not Applicable)		-	-	-
TOTAL	2,302,000		345,375	\$ 248,670

ECONOMIC EVALUATION

The order of magnitude cost, to implement all improvements for the sample cupola considered, is used to emphasize the viability of large capital expenditures for energy conservation measures. The payback is further improved, if full tax credits are accounted for and adjustments made for impact of future energy cost.

Example

$$\text{Payback period} = \frac{\text{Capital Investment}}{\text{Energy Cost Savings/year}}$$

$$\therefore \text{Payback} = \frac{\$1,000,000}{248,670} = \underline{4.0 \text{ years}}$$

FIGURE 3-29. MELTING EFFICIENCIES

The following TABLE compares the three practical melting methods with respect to energy economics.

TABLE 3-XXI. MELTING METHOD COMPARISON

ITEM	CUPOLA	ELECT. INDUCTION	ELECT. ARC.
Cost to preheat	\$ 8.01	\$ 13.99	\$ 11.19
Cost to melt	2.71	4.73	3.79
Cost to superheat	13.74	2.80	6.72
TOTAL	\$ 24.46	\$ 21.52	\$ 21.70
BTU's required x 10 ⁶	3.65	1.84	1.85

Example

Cost to pre-heat one ton of metal by cupola to melt temperature;

$$\text{Btu required} = \frac{35.8 \text{ Btu/lb} \times 2000 \text{ lbs.}}{60\% \text{ Efficiency}} = \frac{0.72 \times 10^6}{0.60} = 1.196 \times 10^6$$

$$\text{Cost of energy @ \$6.70 /million Btu} = 1.196 \times 6.70 = \$8.01$$

On the basis of this analysis, the electric induction furnace is more energy efficient. However, the analysis can be applied to any combination of melting methods to obtain the most energy cost effective results (See Figure 3-29).

COKE VS. ELECTRICITY

COMPARATIVE ANALYSIS

Determining the best method involves consideration of a complex interrelationship of specific foundry needs, relative to furnace operation. Energy for melting is only one aspect and not necessarily the primary factor, however, this analysis deals with differences in costs of melting due to energy only.

Based on calculated cost of energy developed elsewhere in this study, the cost of potential heat by alternate methods is summarized as follows:

TABLE 3-XV.
COST SUMMARY - COKE AND ELECTRICITY

Item	Foundry Coke	Electricity (Ave.)
Cost of Energy	\$167.50/net ton *	\$ 0.0400/KW *
Potential Heat Content	12500 Btu/lb.	3415 Btu/KWH
Cost per million Btu	\$6.70	\$ 11.70

* representative values

Energy for pre-heating, melting and superheating 1 ton of cast iron to 2,700° F.

$$552 \text{ Btu/lb} \times 2000 = 1,100,000 \text{ Btu/ton}$$

Percent of energy requirement for each phase of the melting cycle is as follows:

Btu/lb.

Pre-heat to melt temp.	$552 \text{ Btu/lb} \times 65\% = 358.8$
Melt to liquid state	$552 \text{ Btu/lb} \times 22\% = 121.4$
Super heat to 2,700° F	$552 \text{ Btu/lb} \times 1.3\% = 71.8$

For melting efficiencies of different types of equipment used for melting cast iron (see Figure 3-29).

FIGURE 3-30. ENERGY COST COMPARISON FOR MELTING AND HOLDING

Subject to the practical feasibility of these combinations and not accounting for other capital or operating costs, the cupola to induction furnace approach at \$13.52 per ton melted is the least cost. Btu's required by this method based on previous calculations are:

Cupola	1.60×10^6
Induction	<u>0.24×10^6</u>
TOTAL	1.84×10^6 Btu/ton

Note: As mentioned in Section 2, a cost analysis computer model to evaluate cupola vs. electric melting is available through the EPRI Center for Materials Production.

D. GAS-FIRED CHARGE PREHEATING

GENERAL

Furnace charge preheating, up to 1000° F for iron or steel, results in energy and cost reductions of up to 25%.

This section deals with charge preheating by:

- Gas-fired burner units.
- Oxygen assisted burners.

Diagrams and tables indicate typical data and performance for equipment commercially available. Similar information should be reviewed from alternate sources prior to actual energy audit work being carried out.

Example

Required: Scrap preheat temperature of 1,000° F for batches of one ton size to be charged to an electric melting unit, operating 8 hours per day, 240 days per year at annual rate of say 3,000 tons of gray iron.

Increased melt production percentage is obtained by reference to Figure 3-31, reading for 'iron' at 1,000° F scrap temperature.

@ 1,000° F, resulting increase = 30%

Equivalent Energy Requirements:

Natural Gas-Fired Unit:

@ 1,000° F = 600 cu. ft/ton = 600,000 Btu (from Table 3-XXII).

Thus: Cost @ \$0.30/Therm x 6 Therms = \$1.80/ton

Electrical Energy Usage Reduction

@ 1,000° F = 117 kW/ton (from Table 3-XXII).

Thus: Cost @ \$0.042 per kW = \$4.91/ton

Net cost savings = (4.91 - 1.80) = \$3.11 per ton

Annual cost reduction = 3,000 x 3.11 = \$9,330

FIGURE 3-31. INCREASED MELT PRODUCTION

TABLE 3-XXII.

Furnace Charge Preheating Energy Comparison for Arc and Induction Melting of Iron, Aluminum and Brass

Efficiency Basis. Induction Furnace @ 70%/Fuel (Gas, Propane, Oil @ 47% to 93%, depending on Temperature).

Preheat Temp ° F.	KW Usage per Ton Cold Melt			Venella Usage per Ton/CF Natural Gas @ 1000 BTU/Cu. Ft.			Venella Usage per Ton/Gal. Propane @ 91,735 BTU/Gal.			Venella Usage per Ton/Gal. #1 or #2 Fuel Oil @ 138,000 BTU/Gal.		
	Iron	Alum	Brass	Iron	Alum	Brass	Iron	Alum	Brass	Iron	Alum	Brass
500	59	101	44	150	256	105	1.64	2.8	1.14	1.1	1.9	.8
600	70	121	53	216	365	151	2.4	4.0	1.65	1.6	2.6	1.1
700	82	141	62	276	469	193	3.0	5.0	2.1	2.0	3.4	1.4
800	94	161	70	372	640	261	4.1	7.0	2.8	2.7	4.6	1.9
900	106	181	79	480	808	332	5.2	8.8	3.6	3.5	5.9	2.4
1000	117	201	89	600	1012	417	6.5	11.0	4.5	4.3	7.3	3.0
1100	129			792			8.6			5.7		
1200	141			1008			11.0			7.3		
1300	152			1320			14.4			9.6		
1400	164			1680			18.3			12.2		

OXYGEN-FUEL ASSISTED MELTING

Oxy-fuel assisted melting involves supplying additional heat energy during melt down by introducing oxygen with the fuel to supplement or replace the electrical power input to the furnace. Oxy-fuel assisted melting practice has been applied successfully to most nonferrous and ferrous metals with the exception of brass which exhibits high zinc loss. Suitable stoichiometric firing rates are chosen for each metal to minimize oxidation.

Note: Wellman Alloys Limited of England used oxy-fuel (propane) burner - melting rate increased by 80% - energy savings in excess of 15%.

Example

Data based on various induction furnaces incorporating oxy-fuel indicates average of 26% improvement in power input, reference Table 3-XXIII.

TABLE 3-XXIII. OXY-FUEL ASSISTED MELTING IN INDUCTION FURNACES

Data Obtained From Various Induction Furnaces Incorporating Oxy-Fuel					Melt Down Time Tap to Tap, Min.			Furnace Electrical Power Input, kw/ton			Melting Rate, ton/hr			
Case No.	Furnace Capacity Ton (kg)	Furnace Rating kw	Material Melting	Fuel	Btu/ton x 10 ⁶ (kw/ton)	Normal	Assisted	Improvement %	Normal	Assisted	Improvement %	Normal	Assisted	Improvement %
1	.3 (305)	200	Ductile Iron	Propane	.775 (227)	73	51	30	897	828	30	.248	.354	44
2	.5 (509)	150	Ni Cr Alloy	Propane	.60 (178)	150	95	38	1040	720	31	.20	.318	58
3	1.0 (1018)	300	Carbon Steel	Propane	.3175 (93)	150	105	30	815	680	17	.42	.60	43
4*	1.0 (1018)	300	Ni Cr Alloy	Propane	.625 (183)	184	97	47	863	500	42	.325	.612	88
5	1.0 (1018)	600	Ni Cr Alloy	Butane	.592 (173)	90	60	33	733	630	14	.66	.89	31
6	2.0 (2034)	800	Alloy Steel	Nat. Gas	.503 (147)	175	135	23	778	610	22	.67	1.0	49
7	3.0 (3054)	800	Gray Iron	Propane	.730 (214)	190	125	34	770	625	32	.632	.978	54
8	3.0 (3054)	800	Gray Iron	Propane	.297 (87)	95	77	38	680	471	18	.840	1.364	62
*Case 4: Figures and Results are for Flat-Bottom, Courtesy Wellman Alloys Ltd., Ambleside, Sloughbridge, West Midlands, England.					Average Improvement			34.5	Average Improvement		28	Average Improvement		48.5

Extracted from Foundry M & T MPS - March 1978
by J. Allread / Grede Foundries, Milwaukee

SECTION 4

ENERGY AUDIT FORMS

A. ENERGY USE TABLES AND PRODUCTION STATISTICS

ELECTRICAL POWER USAGE

BILLING PERIOD	ENERGY KWH	BILLING DEMAND	POWER FACTOR	ENERGY CHARGE	FUEL ADJUSTMENT* CHARGE	DEMAND CHARGE	GROSS BILL	NET BILL
JANUARY								
FEBRUARY								
MARCH								
APRIL								
MAY								
JUNE								
JULY								
AUGUST								
SEPTEMBER								
OCTOBER								
NOVEMBER								
DECEMBER								
TOTALS								

AVERAGE POWER COST \$ _____ KWH = \$ _____ /KWH

REMARKS:

FORM 4-1

ANNUAL GAS CONSUMPTION

PERIOD	THERMS	BTU X 10 ⁶	COST
TOTALS			

HEAT CONTENT OF GAS = _____ BTU/CU FT (FROM BILL)

100,000 BTU = 1 THERM

COST OF GAS = \$ _____ = \$ _____ PER THERM
THERMS

REMARKS:

FORM 4-2

ANNUAL COKE CONSUMPTION

PERIOD	TONS	BTU X 10 ⁶	COST
TOTALS			

AVERAGE COST OF COKE = \$ TONS = \$ PER TON

1 LB. OF COKE = 12,500 BTU

REMARKS:

FORM 4-3

ANNUAL OIL CONSUMPTION

PERIOD	GALLONS	BTU X 10 ⁶	COST
TOTALS			

AVERAGE COST OF OIL = \$ = \$ PER GALLON
GALLONS

REMARKS:

FORM 4-4

ANNUAL PROPANE CONSUMPTION

PERIOD	GALLONS	BTU X 10 ⁶	COST
TOTALS			

REMARKS:

FORM 4-5

ANNUAL PRODUCTION

YEAR _____

METAL CAST _____

PERIOD	MELT TONS	SHIPPED TONS	HEAT TREAT TONS	SALES VALUE
JANUARY				
FEBRUARY				
MARCH				
APRIL				
MAY				
JUNE				
JULY				
AUGUST				
SEPTEMBER				
OCTOBER				
NOVEMBER				
DECEMBER				
TOTALS				

AVERAGE MELT TONS/DAY = _____

REPORTED % SCRAP _____

REPORTED % MELT LOSS _____

AVERAGE FOUNDRY YIELD % _____

FORM 4-6

[illegible]

4-8

DESCRIPTION AND FLOW RATES OF GAS-FIRED EQUIPMENT

EQUIPMENT	TYPE	BURNERS		OPERATION		AVERAGE CFH	MAXIMUM CFH
		NO.	TYPE	HRS/DAY	DAYS/MO		
TOTALS							

FORM 4-8

PRESENT ENERGY-EFFICIENCY RECORD

MONTH OR YEAR RECORDED _____

UNITS OF PRODUCTION _____

FUEL COSTS

- Electricity \$ _____
- Natural Gas _____
- Propane _____
- Oil _____
- Coke _____
- Other _____

TOTAL _____

ENERGY USED

- KWH _____ x 3,412 Btu = _____ Btu x 10⁶
- Mcf Gas _____ x 1/ _____
- Gal. Propane _____ x 91,600 Btu = _____
- Gal. Oil _____ x 140,000 Btu = _____
- Coke - lb. _____ x 12,500 Btu = _____
- _____ = _____

TOTAL BTU _____

ENERGY USED PER UNIT OF PRODUCTION

$\frac{\text{(Million Btu)}}{\text{(Units)}}$ = _____ Btu x 10⁶/Ton

COST PER MILLION BTU

$\frac{\text{(Energy Cost)}}{\text{(Million Btu)}}$ = _____ Cost/Btu x 10⁶

COST PER UNIT OF PRODUCTION

$\frac{\text{(Total Cost)}}{\text{(Units)}}$ = _____ Cost/Unit

1/ 1 Mcf = 1,000 cu.ft./hr - See Gas Bill for Btu content/cu.ft.

FORM 4-9

POTENTIAL ENERGY-EFFICIENCY RECORD

MONTH OR YEAR RECORDED _____

UNITS OF PRODUCTION _____

FUEL COSTS

- Electricity \$ _____
- Natural Gas _____
- Propane _____
- Oil _____
- Coke _____
- Other _____

TOTAL _____

ENERGY USED

- KWH _____ x 3,412 Btu = _____ Btu x 10⁶
- Mcf Gas _____ x 1/ _____
- Gal. Propane _____ x 91,600 Btu = _____
- Gal. Oil _____ x 140,000 Btu = _____
- Coke - lb. _____ x 12,500 Btu = _____
- _____ = _____

TOTAL BTU _____

ENERGY USED PER UNIT OF PRODUCTION

(Million Btu) _____
(Units) _____ = _____ Btu x 10⁶/Ton

COST PER MILLION BTU

(Energy Cost) _____
(Million Btu) _____ = _____ Cost/Btu x 10⁶

COST PER UNIT OF PRODUCTION

(Total Cost) _____
(Units) _____ = _____ Cost/Unit

1/ 1 Mcf = 1,000 cu.ft./hr - See Gas Bill for Btu content/cu.ft.

FORM 4-10

B. OPERATIONAL DATA FACT SHEETS

KILOWATT DEMAND LOAD PROFILE

FORM 4-11

KILOWATT DEMAND LOAD PROFILE (WINTER)

KILOWATT DEMAND LOAD PROFILE (SUMMER)

OPERATIONAL DATA FACT SHEET

ARC FURNACE DATA

Furnace make _____
Model _____
Shell Dia. _____ FEET
Bath Depth _____ INCHES
Capacity _____ TONS

Electrode Dia. _____ inches
Transformer _____ KVA
Primary _____ Volt
Taps 1st _____ Volt
2nd _____ Volt
3rd _____ Volt

Output _____ Ton/YR
Alloy _____
Melt cycle _____ minutes
Heat size _____ tons
Heats per day _____
Temperature _____ °F
No. of Back charges _____
No. of slag cycles _____
Blow down cycle O₂ _____ minutes

Type of fume collection:

Furnace pressure _____ oz
Exhaust _____ CFM
Water Cooling _____ GPM
Roof _____, Gland _____, Slag Door _____, Bazel _____,
Water temperature in _____ °F, out _____ of
Type of refractory lining.

REMARKS:

Form 4-13

OPERATIONAL DATA FACT SHEET
CORELESS INDUCTION FURNACE

Furnace make _____ Transformer KVA _____
Model _____ Primary Voltage _____
Capacity _____ Secondary Voltage _____

Output _____ tons/yr.
_____ tons/day

Alloy _____

Melt cycle _____ minutes

Tap Quantity _____ lbs.

Charge Quantity _____ lbs.

Tap temperature _____ °F

Holding temperature _____ °F

Slag cycle _____ minutes

Fume collection _____ CFM

Water cooling....GPM, Temp.....in °F.....Out °F

Type of Refractory _____

Energy consumption _____ KWH/YR

Energy Cost _____ \$/KW

REMARKS:

OPERATIONAL DATA FACT SHEET

GAS MELT FURNACE DATA

Metal type: _____ Annual tons _____
 Pouring or tap temperature _____ °F
 Heat content Btu/lb _____ Shifts/day _____
 Melting period hrs. _____ Holding period hrs. _____

METHOD OF MELTING

CRUCIBLE

REVERB

Metal melted/hr.lbs.	_____	_____
Burner rating Btu/hr	_____	_____
Total gas usage/hr	_____	_____
Capacity of furnace lbs.	_____	_____
Crucible diameter	_____	_____
Area of metal radiation sq.ft.	_____	_____
Area of refractory wall:		
Below metal	_____	_____
Above metal	_____	_____
Thickness of wall	_____	_____
Door open area or dip well sq.ft.	_____	_____
Mean temperature of walls °F	_____	_____
Outer temperature of walls T ₁	_____	_____
Inner temperature of walls T ₂	_____	_____
Present refractory K value	_____	_____
Proposed refractory K value	_____	_____
Rs value for refractory	_____	_____
CO ₂ flue gas reading	_____	_____
Combustion air cfm	_____	_____
Combustion air wg	_____	_____
Flue gas (or comb.) temperature	_____	_____
Ambient temperature °F	_____	_____
Time of day used	_____	_____
Days/year used	_____	_____
Energy cost/therm \$	_____	_____

FORM 4-15

OPERATIONAL DATA FACT SHEET

HEAT TREATING UNIT NO.	
FURNACE MAKE _____	BURNER MAKE _____
MODEL _____	MODEL _____
SIZE _____ WFT.	TYPE _____ SIZE _____ BTU/HR
CAPACITY _____ LBS.	FUEL _____
TYPE OF LINING _____	RECUPERATOR MAKE _____
WALL THICKNESS _____ INCH	MODEL _____ TEMP _____ °F
BLOWER MAKE _____	TYPE _____ SIZE _____
MODEL _____	CONTROLS MAKE _____
SIZE _____ CFM. PRESS _____ "WG	TYPE _____
VOLT _____ HP _____	
TYPE OF HEAT TREAT CYCLE _____ ALLOY _____	
HEAT TREAT CYCLE - HEATUP _____ HRS	FUEL/AIR RATIO _____
- SOAK _____ HRS	FLUE TEMPERATURE _____ HIGH _____ °F LOW _____ °F
-COOL DOWN _____ HRS	SHELL MEAN TEMPERATURE _____ °F
CYCLES PER WEEK _____	FURNACE PRESSURE _____ "WC
TEMPERATURE _____ °F	
AVERAGE LOAD _____ LBS	FLUE ANALYSIS (HIGH) _____ % CO
CASTING _____ LBS	_____ % O ₂
BASKETS _____ LBS	_____ % CO ₂
STOOLS _____ LBS	LOW _____ % CO
LOAD DENSITY _____ LBS/WFT	_____ % O ₂
QUENCH _____ AIR, _____ H ₂ O _____ OIL	_____ % CO ₂
QUENCH TEMPERATURE _____ °F	
	FUEL CONSUMPTION _____ THERMS/CYCLE

WALL AREA _____ SQ. FT.

WALL TEMPERATURE HOT FACE T_1 _____ °FWALL TEMPERATURE COLD FACE T_2 _____ °F

AMBIENT TEMPERATURE _____ °F

EXTERNAL SURFACE AREA _____ SQ. FT.

ENERGY COST/THERM \$ _____

HEAT TREAT LOADS/DAY _____

HEAT TREAT LOADS/YEAR _____

FORM 4-16

OPERATIONAL DATA FACT SHEET

BURN-OUT FURNACES

FURNACE MAKE _____		BURNER MAKE _____	
MODEL _____		NO. OF BURNERS _____	
SIZE _____		TYPE _____ SIZE _____ BTU/HR	
CAPACITY _____ LBS.		FUEL _____	
TYPE OF LINING _____		AFTER BURNER MAKE _____	
EXHAUST BLOWER MAKE _____		MODEL _____	
MODEL _____		TYPE _____ SIZE _____	
SIZE _____ CFM. PRESS _____ "WG		OPERATING HOURS	
VOLT _____ HP _____		MAIN BURNER _____	
		AFTER BURNER _____	
TYPE OF FURNACE CYCLE _____ N/A			
FURNACE CYCLE - HEATUP _____ HRS		FUEL/AIR RATIO _____ HIGH _____ LOW _____	
- SOAK _____ HRS		FLUE TEMPERATURE _____ °F _____ °F	
CYCLES PER WEEK _____		FURNACE PRESSURE _____	
TEMPERATURE _____		CO ₂ IN FLUE GAS _____	
LOAD DENSITY - _____		FUEL CONSUMPTION _____ Therms/Day	
REMARKS:			

FORM 4-17

OPERATIONAL DATA FACT SHEET

LADLE PREHEAT DATA

LADLE CAP TONS _____ HEAT CYCLES/DAY _____
LADLE AREA INSIDE _____ SQ FT. LINING THICKNESS _____
COVERED _____ TYPE OF LINING _____
INSIDE TEMP _____ °F OUTER SHELL TEMP _____ °F
AMBIENT TEMP _____ °F
GAS USAGE/HR _____ CU FT. CO₂ READING _____
COMBUSTION AIR _____ CFM PRESSURE _____ WG
PREHEAT CYCLE TIME _____ HRS FLUE TEMP _____ °F
REFRACTORY K VALUE _____ RS VALUE _____
BLOWER HP _____ RECUPERATOR EFFCY _____
FUEL COST/THERM \$ _____ ANNUAL USE _____ BTU x 10⁶
NUMBER OF UNITS IN USE _____

REMARKS:

FORM 4-18

OPERATIONAL DATA FACT SHEET

CUPOLA DATA

CUPOLA DIA SHELL _____ INS REFRACTORY THICKNESS _____
LINING _____ INS WATER COOLING GPM _____
HEIGHT OF TUYERES ABOVE HEARTH _____ INS
LAUNDER LENGTH _____ WIDTH _____
METAL TO COKE RATIO _____ BED COKE _____ LBS
MELT RATE _____ TPH COKE ADDITION/HR _____ LBS
BLAST RATE _____ CFM PRESSURE _____ ONZ
NUMBER OF TUYERES _____ DIAMETER _____ IN
NUMBER OF ROWS OF TUYERES _____ SPACING _____ IN
COOLING WATER USAGE _____ GPM $T_1 - t_2$ _____ °F
FAN HP _____ MISC. HP _____
HOT BLAST TEMP _____ °F RECUPERATOR CAP _____ BUT/HR
AFTER BURNER RATING BTU/HR _____
OXYGEN ENRICHMENT PERCENT ADDITION _____ %
MELTING PERIOD; BLAST ON _____ BLAST OFF _____
COKE BREEZE ADDITION, PERCENT OF COKE _____ %
ANTHRACITE ADDITION, PERCENT OF COKE _____ %

REMARKS:

OPERATIONAL DATA FACT SHEET

HEAT TREAT FURNACES (ELECTRIC)

FURNACE MAKE	_____	MODEL	_____
SIZE	_____	INSIDE	_____
		OUTSIDE	_____
CAPACITY	_____	LBS.	_____
		TYPE	_____
WALL THICKNESS	_____	TEMP. RANGE	_____ °F
HEATING ELEMENT	_____	VOLTS	_____
		AMPS	_____
		kw	_____
HEAT TREAT CYCLE -	HEAT-UP	_____	HRS
	SOAK	_____	HRS
	COOL DOWN	_____	HRS
CYCLES PER WEEK	_____		
ELECTRICAL CONSUMPTION	_____	KWH/CYCLE	
REMARKS:			

OPERATIONAL DATA FACT SHEET

GAS-FIRED SCRAP PREHEAT

METAL TYPE _____ DENSITY _____ LBS/CU.FT.

PREHEAT TEMPERATURE _____ °F. CYCLE _____ HRS

MELTING CAPACITY _____ TONS/DAY. MELT RATE _____ TONS/HR

FUEL AVAILABLE FOR PREHEAT _____ COST/THERM

CHARGE SIZE/WEIGHT PER BATCH _____ LBS

PREHEAT BURNER RATING BTU/HR _____

CO₂ FLUE GAS READING _____ TEMPERATURE _____ °F

COMBUSTION AIR CFM _____ PRESSURE _____ WG

AMBIENT TEMPERATURE _____ TIME OF DAY USED _____

SHIFTS PER DAY _____ DAYS/YEAR _____

REMARKS:

FORM 4-21

SECTION 5

ENERGY SAVINGS PROCEDURES CHECKLIST

Many energy savings opportunities exist in all foundries that can be instituted immediately without requiring large capital equipment investments. The checklist that follows presents these no cost/low cost energy savings ideas together with suggestion modifications and changes that will require medium to major capital investments:

	APPLIES	DOES NOT APPLY	COMMENTS
<p>Infiltration--Infiltration of cold air into the plant through cracks, openings, gaps around doors and windows, etc., increases the building's heat load and may be responsible for 20 to 25 percent of the yearly space-heating energy consumption. This waste can be eliminated, and an additional saving in heating realized, by taking the following steps:</p> <ol style="list-style-type: none"> ___ 1. Replace broken or cracked window panes. ___ 2. Caulk cracks around window and door frames. ___ 3. Weatherstrip windows and doors. ___ 4. Close windows while the building is being heated. ___ 5. Check sealing gaskets and latches for all operable windows to see that they are working properly. ___ 6. Close all rolling-type doors when they are not being used. ___ 7. Eliminate unnecessary windows and skylights. <p>Heating, Ventilating, and Air-Conditioning (HVAC) Systems--HVAC systems have a significant impact on the plant's total energy consumption. These changes in operational routine can cut HVAC energy use 5 to 15 percent:</p> <ol style="list-style-type: none"> ___ 1. Establish minimum temperature levels for the heating season and maximum levels for the cooling season. Establishing these levels requires consideration of occupied and unoccupied periods. ___ 2. Repair or replace all damaged or defective thermostats or control equipment; calibrate as necessary. ___ 3. Mount thermostats on inside walls and columns only. ___ 4. Lock all thermostats to prevent unauthorized personnel from tampering with them. ___ 5. Eliminate the use of mechanical cooling when the plant is unoccupied. Turn off heat or maintain a 50 F minimum in unoccupied areas. ___ 6. Inspect all outside air dampers to ensure that they establish an air-tight fit when closed. ___ 7. Establish startup and shutoff times for HVAC systems. ___ 8. Shut off or adjust HVAC systems during weekends and holidays. ___ 9. Minimize outdoor air intake. 			

	APPLIES	DOES NOT APPLY	COMMENTS
<p>Makeup-Air Units--Whenever air must be heated, inefficiencies are probable. The following modifications to makeup-air units can help conserve energy:</p> <ol style="list-style-type: none"> 1. Adjust burners for proper flame patterns. 2. Clean burner nozzles periodically to remove mineral deposits and corrosion buildup. 3. Observe the fire when the unit shuts down. A fire that does not cut off immediately could indicate a faulty control valve. Repair or replace the control valve as necessary. 4. Keep all heat-exchanger surfaces clean. 5. Inspect casings for air leaks. Seal them as necessary. 6. Clean or replace air filters regularly. 7. Keep fan blades clean. 8. Inspect and lubricate motor bearing regularly. 9. Inspect fan inlets and discharge screens to keep them free of dirt and debris at all times. <p>Insulation--Transmission heat losses and gains through walls, glass, roof, floor, etc., can be controlled with adequate insulation. The savings depend on the loss reductions achieved. A 5 to 10 percent saving is possible.</p> <p>Lighting--Lighting represents a major portion of electrical energy use. A reasonable effort should be made to use only the amount of lighting necessary for safety and efficiency. Taking the following steps could lower plant electrical energy consumption approximately 5 to 15 percent:</p> <ol style="list-style-type: none"> 1. Use daylight for illumination when possible. Turn off lights when sufficient daylight is available. 2. Turn off lights at night and in unoccupied areas during the day. 3. Install simple timers on light switches throughout the plant, including in offices. 4. Keep lighting equipment clean and in good working order. 5. Replace burned out or darkened lamps and clean all fixtures. 6. Increase the light-reflective quality of walls and ceilings with light colors. Such improvements may permit additional lighting reductions. <p>Boilers--In any boiler operation, the main source of energy waste is inefficient combustion. A 10 to 25 percent energy saving is possible by regularly following these simple checks and guidelines:</p> <ol style="list-style-type: none"> 1. Inspect boilers for scale deposits. 2. Keep all heat-transfer surfaces as clean as possible to reduce temperature differences. 3. Follow the boiler manufacturer's recommendations. 4. Follow the feedwater treatment and blowdown procedures recommended by the supplier. This measure will save fuel by minimizing scale formation. 5. Inspect door seals and other seal gaskets. Leaking gaskets waste fuel; doors may be deformed. 6. Check boiler stack temperature. If it is too high (more than 150 to 200 deg F above steam temperature), clean the tubes and adjust the burner. 			

- ___ 7. Adjust the burner so that the stacks are free of haze.
- ___ 8. Collect and analyze flue gas samples regularly to determine if combustion is efficient.
- ___ 9. Minimize the amount of excess air supplied for combustion.
- ___ 10. Operate only one boiler unless it cannot supply the load.
- ___ 11. Prevent short-cycle firing.

Steam Lines and Traps--Whether small or large, the leaks in steam piping, fittings, valves, and traps add up and can waste large amounts of energy. A detailed survey of all such piping should be made weekly or monthly and the following steps should be taken:

- ___ 1. Repair or replace defective or missing insulation.
- ___ 2. Inspect steam traps and replace those that are worn, inoperative, or improperly sized.
- ___ 3. Inspect pressure-reducing and regulating valves and their related equipment. Adjust, repair, or replace as necessary.
- ___ 4. Check pressure gauges and thermometers for recording accuracy.

Fans, Pumps, and Motors--Proper maintenance of fans, pumps, and motors can significantly improve their operational efficiency. The following steps can save energy at almost no cost:

Fans:

- ___ 1. Clean the blades.
- ___ 2. Inspect and lubricate bearings regularly.
- ___ 3. Inspect belts for proper tension.
- ___ 4. Keep inlet and discharge screens free of dirt and debris.

Pumps:

- ___ 1. Check packings for wear. Bad packings waste water and erode the shaft.
- ___ 2. Inspect bearings and belts regularly.

Motors:

- ___ 1. Keep motors clean.
- ___ 2. Prevent overvoltage and undervoltage.
- ___ 3. Eliminate excessive vibration.
- ___ 4. Correct loose connections, bad contacts, belts, pulleys, bearings, etc.
- ___ 5. Check for overheating and provide adequate ventilation.
- ___ 6. Prevent imbalance in power phase sources. This condition can cause inefficient motor operation.

Domestic Hot and Cold Water--Following these guidelines can maximize the efficiency of domestic water use:

- ___ 1. Inspect the water supply system and repair leaks, especially faucet leaks.
- ___ 2. Inspect insulation on storage tanks and piping. Repair as needed.
- ___ 3. Turn off the pump when the building is unoccupied, if hot water is distributed by forced circulation.
- ___ 4. Inspect and test hot-water controls. Regulate, repair, or replace as necessary.
- ___ 5. Disconnect all refrigerated water fountains, if acceptable to building occupants.

APPLIES DOES NOT APPLY		COMMENTS

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	APPLIES	DOES NOT APPLY	COMMENTS
12. Locate and repair all piping leaks. Typically, many manufacturing plants lose about 10% of their compressed air through leaks, usually from loose pipe fittings, valve packing, shut off valves, worn out filters-regulators-lubricators, quick couplers, and unused air tools. A 1/16" leak can waste 6.5 cfm, and in addition to wasting compressor horsepower, will cost @ \$8.00 per month. The hundreds of leaks in many industrial air systems can represent a tremendous energy waste.			
13. Be careful to size compressor capacity fairly closely to load, since a compressor's efficiency is highest at full load.			
14. Consider the installation of several smaller compressors rather than one large unit. Sequential operation will enable each compressor to operate at full load.			
15. Prohibit all use of compressed air operated fans or compressed air hoses for personal cooling.			
16. Remember that it requires about 1 horsepower to produce 5 CFM @ 100 PSI while a 1 horsepower vane type air motor requires about 25 CFM @ 90 PSI. Investigate replacing high usage air motors with electric motors where practical.			
17. Consider using solenoid valves to cycle punch press blow off nozzles for only a short interval. Many blow off nozzles have a 1/8" orifice and, if operated continuously, will consume about 25 CFM @ 100 PSI (the equivalent of 5 HP compressor).			
18. Consider reducing the operating speed/pressure on air operated paint pumps and paint agitators during off-shift hours. Depending on pigmentation and metallic content it may even be possible to stop all agitation or circulation of some enamels or lacquers during off hours.			
19. In addition to poor partial load mechanical efficiency, induction type compressor motors have extremely poor power factors at reduced outputs. For instance, a 250 HP induction motor has a .87 PF at full load and a .55 PF at 1/4 load. Significant low load operation can drastically raise utility power factor charges.			
20. For highest efficiency, be sure air tools are kept in good repair and are not excessively worn. For instance, a sand blast nozzle worn from 5/16" to a new diameter of 3/8" would consume an additional 65-70 CFM.			
21. Minimize low load compressor operation. If air demand is less than 50% of compressor capacity, consider converting smaller compressors from constant speed operation to start/stop operation.			
22. Install timers on desiccant type compressed air dryers to match dryer recharging cycles to actual system requirements.			
23. Match compressor operation to building hours. A time switch can permit close control of compressor hours and permit shut down of high unloaded horsepower compressors during meal breaks or shift changes.			

Welding Operations

- 1. Investigate converting heating equipment fuel from acetylene, natural gas, or propane to methylacetylene propadiene, stabilized (MAPP). This gas may result in the improved performance, higher cutting speeds and reduced oxygen consumption.
- 2. If product design is applicable, consider utilizing seam welding (RSEW) instead of coated electrode metal arc welding (SMAW), metallic inert-gas welding (GMAW), or submerged arc welding (SAW). Since high frequency seam welding only heats the actual welding zone, distortion is minimized. The process is also less energy intensive than most other applicable welding processes.
- 3. Consider utilizing electronic precipitators to "scrub" welding exhaust fumes and thereby eliminate building exhaust with its attendant heat loss.
- 4. Install solenoid valves on welder or water cooled torch supply lines to limit cooling water flow to actual welder operating periods.
- 5. Consider the installation of smoke detectors to control welding exhaust fans.
- 6. Investigate inertia welding for uniform tubular or solid sections and similar shapes. Inertia welding can often replace alternative welding methods with their related preparatory machining operation.
- 7. Investigate using bag type dust collectors/filters to reduce building exhaust.
- 8. If welding shop workload varies widely, investigate ordering any new transformer type welders with built-in power factor correcting capacitors.
- 9. If oxy-acetylene welding/cutting torches are frequently used throughout the day, consider installing weight actuated automatic torch valves. This should help insure that an unused torch is turned off when it is hung up.
- 10. Investigate the installation of automatic cutting torches, which normally operate at maximum speed, thus yielding maximum cutting for minimum gas consumption. Their cutting speed and accuracy can often replace more energy intensive alternative manufacturing methods.
- 11. Be sure gas welding equipment connections and hoses are tight. Leaks both waste expensive gas and are fire hazards.
- 12. Investigate using high frequency induction heating for brazing operations instead of hand-held torch or a furnace.
- 13. Consider operating automatic cutting torches on natural gas or propane instead of acetylene. Acetylene has a higher flame temperature than normally required for steel cutting.
- 14. Consider using hot air instead of direct gas flame soldering torches. Since hot air is supplied at lower temperatures, it conserves energy and improves product appearance, as well as reducing fire hazards.
- 15. Replace continuous pilot lights for gas welding torches with conventional flint lighters.

APPLIES		DOES NOT APPLY		COMMENTS

	APPLIES	DOES NOT APPLY	COMMENTS
<p>16. Be careful to avoid over-welding, either during design or manufacture.</p> <p>17. Use flame gouging instead of chipping hammers to remove tack welds, full welds, defects, blow holes, or sand inclusions.</p> <p>18. Consider using flame deseaming or scarfing instead of chipping hammers to remove cracks, seams, scabs, and crowsfeet. Hot scarfing can clean up forgings without the cooling and reheating required by chipping.</p> <p>19. In general, transformer type arc welders are more energy efficient than motor-generator welders. At full rated load, transformer type welders will consume slightly less power than a comparable motor-generator welder. At partial or no load, however, motor generator efficiency and power factor drop appreciably.</p> <p>20. Motor generator welders are valuable where ripple-free DC is required from single phase power. A transformer-rectifier welder cannot normally deliver well filtered DC from single phase power.</p> <p>21. Investigate "stack cutting" with automatic cutting torches. In many cases, a thicker cut uses proportionately less oxygen per piece than a thinner cut. Cutting accuracy is a maximum below 2" total thickness and gradually deteriorates until the normal maximum cutting thickness of 6" is attained.</p> <p>22. Shut down transformer type and motor-generator arc welders when not in use and during breaks and lunch. Savings will be minimal with transformer type welders but will become increasingly significant when motor-generator welders are stopped.</p> <p>23. Be sure unused automatic torches are turned off when not in use. Avoid excessive idle time.</p> <p><u>Process and Manufacturing Operations</u></p> <p>1. Evaluate all machine tool purchases carefully for operating efficiency. In some cases, an alternative manufacturing method may result in lower energy usage per piece.</p> <p>2. Consider installing electrostatic precipitators to minimize dust or particle exhaust, such as from welding operations.</p> <p>3. Investigate installing smoke detectors to operate exhaust fans.</p> <p>4. Interlock process ventilation equipment with the equipment it serves.</p> <p>5. Replace simplex or duplex steam pumps with motor driven pumps where feasible.</p> <p>6. Install timers on punch presses, press brakes, and hydraulic presses to shut down equipment if left idling for more than 10-12 minutes.</p> <p>7. Install solenoid valves on all machine air supply lines to limit air use to machine operating periods.</p> <p>8. Investigate using mechanical methods, such as a cam or solenoid to eject punch press parts instead of using compressed air.</p> <p>9. Install either automatic doors or insulated flaps on conveyor type heat treating ovens to reduce heat loss.</p>			

	APPLIES	DOES NOT APPLY	COMMENTS
10. Install solenoid valves on all water cooled equipment water lines to minimize water leakage.			
11. Redesign processes to eliminate process exhaust ventilation.			
12. Investigate the installation of reflecting shielding or thermal barriers around heat treating equipment to minimize cooling load on adjacent areas, particularly in metallurgical laboratories.			
13. All water pumping equipment will have to operate at less than full design flow, consider the installation of variable speed pumps to minimize reduced flow power consumption.			
14. Avoid severely oversizing production equipment. An oversized tool is normally heavier and requires more power than a smaller, correctly sized tool.			
15. Operate air tools on correct pressure. Most air tools are designed to operate on 90 PSI. Tool operation on lower pressures reduces output, while only a 10 pound pressure increase results in a 14% tool life expectancy reduction.			
16. Meter unusual gas or process chemical requirements. "Billing" a department for actual consumption can often result in phenomenal consumption reductions.			
17. Modify product test or analysis procedures to avoid high energy consumption tests. For instance, minimize test time on engine operated equipment.			
18. Investigate the feasibility of operating production machinery at 100% load for one shift rather than at partial load for two shifts. For instance, careful scheduling of vapor degreaser operation may permit full load operation for fewer hours.			
19. Attempt to reduce machine idle time as much as feasible to maintain high power factors.			
20. Assign specific plant personnel to be sure all production equipment is shut down after shift and during breaks and lunch.			
21. Operate melt furnace exhausts only during furnace charging or fluxing if feasible.			
22. Shut down process ventilation, building exhaust, and dust collection during breaks and lunch.			
23. If heat treating ovens are not required for immediate use, energy can be saved by reverting to a reduced temperature condition. Investigate constructing a cool down/reheat time chart for various furnace temperature. This will enable operating personnel to easily reduce furnace temperatures and still be able to have the furnace up to heat by the desired time.			
24. Consider operating heat treating ovens 24 hours/day to make maximum usage of energy.			
25. Use fixed cycle times for heat treating/annealing operations. Many actual oven times are far longer than actually required, with a resulting energy waste.			
26. Operate chip conveyors only when needed, not continuously.			

APPLIES		DOES NOT APPLY		COMMENTS

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	APPLIES	DOES NOT APPLY	COMMENTS
<p>15. Be careful not to overfill fork lift fuel tanks. Spilled gasoline or diesel fuel or vented LPG is both wasteful and hazardous.</p> <p>16. If a light load has to be moved a short distance, use a hand truck rather than a fork lift. Be sure fork lifts are used for material handling, not personal transportation.</p> <p>17. Be sure pneumatic fork lift tires are properly inflated. Underinflation both damages tires and wastes fuel.</p> <p>18. Avoid using a far larger fork lift than required. For instance, use a 2000 pound lift to maneuver oil barrels rather than a 6000 pound lift.</p> <p>19. Avoid excessive fork lift idling. Start a lift only when there is work to be done - and stop it as soon as it is completed.</p> <p>20. Avoid making a habit of using a drastically oversized crane for a drastically undersized load. If a machine frequently requires a crane to load small work pieces, consider installing a small jib crane with an electric hoist. This both frees up the main crane for heavier jobs and saves energy.</p> <p>21. Install automatic timers to shut down crane motor generators if no crane moves are made within ten minutes.</p> <p>Paint Line Operations</p> <p>1. Consider use of airless spray instead of air spray paint application. While it requires about 9.5 HP to atomize 1 GPM using air spray, it only requires about 1.3 HP to atomize 1 GPM using airless spray. Airless spray is particularly suited to large, heavy work pieces that must be painted with one coat, in place, such as heavy construction equipment, barges, structural steel, or railroad cars.</p> <p>2. Since natural gas is a decreasing resource, investigate the applicability of ultra-violet cured metal finishes to your product. Frequently, product redesign may enable the use of ultra-violet post coating or may permit using pre-coated coil stock. In many cases, coil coating uses only about 20% of the energy required for post painting.</p> <p>3. Consider installation of direct fired paint ovens instead of indirect fired. The heat transfer coefficient for direct fired is about 97% versus 60% for indirect fired, with comparable differences in fuel consumption.</p> <p>4. Investigate conversion to water base painting materials. Water base usually cuts energy consumption by reducing spray booth air flow, oven exhaust, air makeup requirements, and oven times. In some cases, finishing lines have reduced total natural gas consumption up to 45%.</p> <p>5. Research is currently being done to develop low temperature cure and air dry waterbase coatings. Current future forecasts often predict water base may account for up to 60% of the industrial finishing market by 1985.</p> <p>6. Consider utilizing gas fired washer combustion products to provide heat for dry off oven. This would be particularly applicable to direct fired washers.</p>			

	APPLIES	DOES NOT APPLY	COMMENTS
7. If your product configuration is applicable, consider converting to a high intensity infra-red curing which uses as little as 10% of the energy required for a comparable gas fired oven.			
8. Investigate converting paint ovens to the "Raw Oven Exhaust Recycle Process". This system returns part of the oven exhaust back to the oven after passing through an incinerator.			
9. Investigate conversion to airless paint drying from conventional oven baking. This system holds oven oxygen content to as low as 1%, with resulting reductions in oven exhaust and gas requirements.			
10. Reduce spray booth/makeup air temperature to 65° - 68°.			
11. Investigate installing electric ovens instead of gas or oil fired. Higher operating costs are somewhat reduced by better temperature control, constant one-fuel operation, and more readily controllable oven atmosphere.			
12. Consider insulating the entire paint line parts washer to reduce heat loss. Some plant operators estimate they have achieved up to 20% fuel reduction in metal pretreatment operations after insulating parts washers.			
13. If insulating the entire washer is not feasible, investigate insulating the heated portion of the washer.			
14. Consider additional paint oven wall insulation. Doubling the present thickness (usually only 2") will cut wall losses in half. Since most paint oven heat is lost through oven roofs, this portion in particular should be well insulated.			
15. Consider utilizing ambient temperature solvent flash off if possible. In many cases, a slightly longer or slower conveyor may be all that is required.			
16. Considerable heat is lost through oven "air seals", which are generally ineffective. Consider installation of bottom entry/exit oven, which better retain heated air within the oven.			
17. Consider installations of oil fired paint ovens instead of gas fired. New oven technology can minimize paint discoloration and soot problems if a light, low sulfur (1%), oil is used.			
18. Consider heat recovery equipment, such as "heat pipes", in spray booth and bake oven stacks. If heat recovery equipment is used, a regular maintenance program is required to minimize heat losses caused by paint residue build up.			
19. Consider switching to low or ambient temperature parts washer cleaners and phosphating compounds. For instance, iron phosphates are now being successfully used at 100-120°F. in some applications.			
20. Investigate staging spray booth air flow. If painters work only in the first section, with automatic spray equipment in the remaining zones, the booth air can flow into the first zone, and be exhausted to the other zones. In many cases, solvent concentration in the final zone would still be below the 25% LFL limit.			

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	APPLIES	DOES NOT APPLY	COMMENTS
21. Replacing manual spray with automatic paint spraying machinery may permit a reduction in spray booth air velocity with a resultant make up air reduction. Material flammability and toxicity must be investigated to determine if any reductions are feasible. This normally requires approval from insurance inspectors, fire inspectors, O.S.H.A., and any other applicable agencies.			
22. Investigate using process steam condensate as heat source for paint line parts washer tanks.			
23. Use a fixed orifice rather than an adjustable valve to meter water into process or paint line constant overflow tanks for minimum flow.			
24. Check booth velocity carefully to avoid over exhausting. Consider using electrostatic spray since this usually permits a reduction of booth velocity of about 40%.			
25. Investigate interlocking paint line conveyors with parts washers and bake ovens.			
26. Investigate the feasibility of operating fume incinerators at reduced temperatures.			
27. If paint line or process exhausts include extremely high solvent concentrations, investigate recovering and re-refining these otherwise wasted solvents. In some cases, solvents have been reclaimed at an energy cost 1/5 - 1/6 the price of new solvent.			
28. Be sure plant is not occasionally under negative pressure. Negative pressure can starve gas burners resulting in a fuel rich flame with excess CO. Negative pressure also results in increased air infusion through walls and windows, with resulting cold drafts and worker complaints.			
29. Be sure all stages in a process are really necessary. In some applications, washer stages may be eliminated or partially shut down, as may dry off ovens.			
30. If batch ovens are used, maximize loading and optimize working hours for highest energy efficiency. Similarly, minimize warm up time as much as possible.			
31. Because solvents are increasingly scarce and expensive, consider filtering, distilling, or otherwise recycling solvent.			
32. It may be possible to improve paint oven heat transfer by increasing circulating air velocities or volume and by utilizing heating system radiant energy. Improved heat transfer may permit increased travel speeds with resulting increases in production with little or no increase in fuel requirements.			
33. Sequentially shut down ovens at end of shift or production run.			
34. Attempt to schedule all paint line operations for one shift if feasible.			
35. Be sure all gas immersion tubes used for liquid heating are clean (both interior and exterior) for best heat transfer.			
36. Be sure all air filters are kept clean.			
37. Change paint line conveyor speed and hook configuration as required with product changes to maximize productivity and minimize oven idle time.			
38. Reduce conveyor speed when parts are not flowing through wash or bake ovens.			

SECTION 6. EXAMPLE ENERGY ANALYSIS

NOTE: DATA AND CALCULATIONS ARE FOR A HYPOTHETICAL FOUNDRY "A".

GENERAL DESCRIPTION

The foundry produces jobbing type Gray and Ductile Iron castings, averaging 17 pounds each. Cope and drag green sand molding systems and a no-bake line operates one shift per day.

Facilities

Building Area	-	90,000 Square Feet
Manning Total	-	139
Average Shipments	-	1,530 tons/Year
Average Sales Volume	-	\$5.0 Million
Average Foundry Yield	-	39.3%

Melting Furnaces

Capacities: 2 Cupolas, 42" diameter water cooled w/apprx. 1%

O₂ enrichment melt at 4.5 tons/hr

1 Coreless Induction furnace, 340 KW
3,000 pound capacity (600# charge)

Melting: 8 hours per day - 5 days per week
48 weeks per year

Equipment

Molding comprises 4 squeezer machines, 3 cope and drag units and a no-bake mixer, 350 per minute capacity. Sand plant mixing capacity is 3,000 pound batch muller with 100 ton storage and distribution system. Core sand preparation is in 75 pound capacity batch mixers serving 5 Isocure machines. Two shell core machines are available. The cleaning department provides for cut-off by abrasive and gas torch methods. Heat treat furnaces operate on 21-hour and 18-hour cycles. Air compressors in three sizes operate up to 20 hours per day. No propane or fuel oil is used in the process except trucks.

TABLE 6-1
ELECTRICAL POWER USAGE*

BILLING PERIOD	ENERGY KWH	BILLING DEMAND	POWER FACTOR	ENERGY CHARGE	FUEL ADJUSTMENT* CHARGE	DEMAND CHARGE	GROSS BILL	NET BILL
JANUARY	74,560	N/A	N/A	N/A	N/A	N/A	N/A	3,833.00
FEBRUARY	78,720							3,835.00
MARCH	19,520							1,136.00
APRIL	62,080							3,025.00
MAY	58,880							2,892.00
JUNE	38,400							1,891.00
JULY	22,720							1,202.00
AUGUST	35,840							1,765.00
SEPTEMBER	23,680							1,219.00
OCTOBER	26,560							1,365.00
NOVEMBER	22,080							1,246.00
DECEMBER	49,920							2,590.00
TOTALS	512,960	↓	↓	↓	↓	↓	↓	25,999.00

* GENERAL PLANT ELECTRIC POWER USAGE.

$$\text{AVERAGE POWER COSTS} = \frac{25,999}{512,960} = \$0.051/\text{KWH}$$

TABLE 6-I
ELECTRICAL POWER USAGE*

BILLING PERIOD	ENERGY KWH	BILLING DEMAND	POWER FACTOR	ENERGY CHARGE	FUEL ADJUSTMENT CHARGE	DEMAND CHARGE	GROSS BILL	NET BILL
JANUARY	179,400	N/A	N/A	N/A	N/A	N/A	N/A	7,531.00
FEBRUARY	178,200							7,045.00
MARCH	90,600							4,135.00
APRIL	133,200							5,509.00
MAY	176,100							6,889.00
JUNE	173,700							6,893.00
JULY	119,100							5,125.00
AUGUST	167,400							6,658.00
SEPTEMBER	150,900							6,133.00
OCTOBER	153,300							6,432.00
NOVEMBER	148,200							6,446.00
DECEMBER	132,900							5,914.00
TOTALS	1,803,000	↓	↓	↓	↓	↓	↓	74,710.00

* MELT FURNACE ELECTRICAL POWER USAGE.

$$\text{AVERAGE POWER COST} = \frac{74,710}{1,803,000} = \$ 0.041/\text{KWH}$$

COST SUMMARY (PLANT & MELT FURNACE)

SERVICE	KWH	COST
FURNACE	1,803,000	74,710.00
GENERAL PLANT	512,960	25,999.00
TOTALS	2,315,960	100,709.00

TABLE 6-II
ANNUAL GAS CONSUMPTION

PERIOD	THERMS	BTU X 10 ⁶	COST
JANUARY	32,288	3,228.8	\$ 8,609.00
FEBRUARY	31,672	3,167.2	8,445.00
MARCH	12,389	1,238.9	3,304.00
APRIL	27,027	2,702.7	7,206.00
MAY	24,784	2,478.4	6,608.00
JUNE	25,081	2,508.1	7,175.00
JULY	17,232	1,723.2	5,106.00
AUGUST	22,930	2,293.0	6,793.00
SEPTEMBER	16,508	1,650.8	4,891.00
OCTOBER	21,890	2,189.0	6,805.00
NOVEMBER	18,617	1,861.7	6,359.00
DECEMBER	20,306	2,030.6	7,049.00
TOTALS	270,724	27,072.4	\$ 78,350.00

HEAT CONTENT OF GAS = 1,000 BTU/CU FT (FROM BILL)

100,000 BTU = 1 THERM

COST OF GAS = $\frac{78,350}{270,724}$ = \$ 0.289 PER THERM

TABLE 6-III
ANNUAL COKE CONSUMPTION

PERIOD	TONS	BTU X 10 ⁶ (@ 12,500 BTU/LB)	COST
JULY	13	325	\$ 2,264.00
AUGUST	61.1	1,527.5	10,801.00
SEPTEMBER	64.4	1,610	10,888.00
OCTOBER	134.1	3,352.5	23,772.00
NOVEMBER	95	2,375	17,001.00
DECEMBER	177.8	4,445	30,656.00
JANUARY	169.4	4,235	31,367.00
FEBRUARY	105.4	2,635	19,429.00
MARCH	56.1	1,402.5	10,801.00
APRIL	141	3,525	56,551.00
MAY	143.6	3,590	27,595.00
JUNE	122.74	3,068.5	23,762.00
TOTALS	1,283.64	32,091	\$ 264,887.00

$$\text{AVERAGE COST PER TON} = \frac{264,887}{1,283.64} = \$ 206.35$$

TABLE 6-IV

DESCRIPTION AND POWER USAGE OF ELECTRICAL EQUIPMENT

EQUIPMENT	TYPE	CAPACITY	OPERATION		H.P.	KWH	SERVICE
			HRS/DAY	DAYS/MO			
MOLDING #1 DEPARTMENT							
CONVEYOR	DELIVERY				5		
CONVEYOR	GOODMAN				10		
SHAKEOUT					10		
CASTING CONVEYOR					7.5		
INCLINED CONVEYOR					5		
INCLINED CONVEYOR					5		
HOPPER CONVEYOR					5		
DUST COLLECTOR					25		
SPILLAGE CONVEYOR					5		
SAND MILL					15		
SAND MILL					50		
BUCKET CONVEYOR					7.5		
MISCELLANEOUS					18		
SUBTOTAL					168		
MOLDING #2							
CRANES					50		
PRE MIX					8.5		
SHAKEOUT					20		
MISCELLANEOUS					5		
SUBTOTAL					83.5		

TABLE 6-IV (CONTINUED)

EQUIPMENT	TYPE	CAPACITY	OPERATION		H. P.	KWH	SERVICE
			HRS/DAY	DAYS/MO			
CORE ROOM							
MYERS HOIST	ROBBINS				10		
MIXERS					11		
DELIVERY CONVEYOR					9		
SAND MIXER					5		
HOIST	SHEPHERD NILES				5		
MISCELLANEOUS					11		
SUBTOTAL					51		
CLEANING DEPARTMENT							
GRINDERS					50		
TUMBLAST					25		
SWING GRINDER					50		
OVEN #1					10		
CUTOFF SAW					25		
DUST COLLECTOR					15		
CRANES					44		
CASTING BURNER					5		
CASTING FAN					10		
MISCELLANEOUS					15		
SUBTOTAL					249		

TABLE 6-IV (CONTINUED)

EQUIPMENT	TYPE	CAPACITY	OPERATION		H.P.	KW	SERVICE
			HRS/YR	DAYS/MO			
PATTERN SHOP							
TABLE SAW #1					7.5		
BAND SAW					5		
BAND SAW					5		
MISCELLANEOUS					6		
SUBTOTAL					23.5		
MELTING DEPARTMENT							
CUPOLA BLOWER					30		
SMOG BLOWER					50		
INDUCTION FURNACE		3,000#			6	340	
MISCELLANEOUS					7		
SUBTOTAL					93		
GENERAL							
COMP. #1					125		
COMP. #2, 3 AND 4					220		
MISCELLANEOUS					11		
SUBTOTAL					356		
GRAND TOTAL					1,024	340	

TABLE 6-V

DESCRIPTION AND FLOW RATES OF GAS-FIRLD EQUIPMENT

EQUIPMENT	TYPE	BURNERS		OPERATION		AVERAGE CFH	MAXIMUM CFH
		NO.	TYPE	HRS/DAY	DAYS/MO		
HEAT TREAT FURNACE #1	CAR		PREMIX	21	21	N/A	6,300
HEAT TREAT FURNACE #2	CAR		PREMIX	18	12	N/A	3,340
LADLE HEATERS (5)	-	5	-	3.5	21	N/A	1,000*
TAP HOLE TORCH		1	ATMOS.	3	21	N/A	200*
CUPOLA BED IGNITER			TORCH	2	21	N/A	200*
TOTALS							

*ESTIMATED GAS USAGE.

TABLE 6-VI

1989 ENERGY-EFFICIENCY RECORD

MONTH OR YEAR RECORDED	1989/90 Calendar Year	
UNITS OF PRODUCTION	1,530 Net good tons shipped	
FUEL COSTS		
Electricity	\$	100,709.00
Natural Gas		78,350.00
Propane		--
Oil		--
Coke		264,887.00
Other		--
TOTAL	\$	443,946.00
ENERGY USED		
KWH 2,315,960 x 3,412 Btu =	7,902	Btu x 10 ⁶
Mcf Gas 27,072 x 1/	27,072	Btu x 10 ⁶
Gal. Propane x 91,600 Btu =	None	
Gal. Oil x 140,000 Btu =	None	
Coke - lb. 2,567,280 x 12,500 Btu =	32,901	Btu x 10 ⁶
TOTAL BTU	67,065	Btu x 10 ⁶
ENERGY USED PER UNIT OF PRODUCTION		
(Million Btu) 57,065 =	43.83	Btu x 10 ⁶ /ton
(Units) 1,530 Tons		
COST PER MILLION BTU		
(Energy Cost) 443,946 =	6.62	Cost/Btu x 10 ⁶
(Million Btu) 67,065		
COST PER UNIT OF PRODUCTION		
(Total Cost) 443,946 =	290.16	Cost/Unit
(Units) 1,530 Tons		

1/ 1 Mcf = 1,000 cu.ft./hr - See Gas Bill for Btu content/cu.ft.

TABLE 6--VII

ENERGY-EFFICIENCY RECORD 2/ 3/

MONTH OR YEAR RECORDED				<u>1990 Projected (Electric only)</u>
UNITS OF PRODUCTION				<u>1,530</u>
				Net good tons shipped
FUEL COSTS				
' Electricity			\$	<u>123,195^{2/}</u>
' Natural Gas				<u>78,350.00</u>
' Propane				<u>--</u>
' Oil				<u>--</u>
' Coke				<u>264,887.00</u>
' Other				<u>--</u>
	TOTAL		\$	<u>466,342</u>
ENERGY USED				
' KWH <u>2,315,960</u>	x	3,412 Btu =		<u>7,902 Btu x 10⁶</u>
' Mcf Gas <u>27,072</u>	x	<u>1/</u>		<u>27,072 Btu x 10⁶</u>
' Gal. Propane	x	91,600 Btu =		<u>None</u>
' Gal. Oil	x	140,000 Btu =		<u>None</u>
' Coke - lb.	x	12,500 Btu =		<u>32,091 Btu x 10⁶</u>
				<u>=</u>
	TOTAL BTU			<u>67,065 Btu x 10⁶</u>
ENERGY USED PER UNIT OF PRODUCTION				
(Million Btu) <u>67,065</u>		=		<u>43.83 Btu x 10⁶</u>
(Units) <u>1,530 Tons</u>				
COST PER MILLION BTU				
(Energy Cost) <u>466,342</u>		=	\$	<u>6.95 Cost/Btu x 10⁶</u>
(Million Btu) <u>67,065</u>				
COST PER UNIT OF PRODUCTION				
(Total Cost) <u>466,342</u>		=	\$	<u>304.79 Cost/Unit</u>
(Units) <u>1,530 Tons</u>				

1/ 1 Mcf = 1,000 cu.ft./hr - See Gas Bill for Btu content/cu.ft.

2/ The electrical cost shown represents 1990 calendar year costs and are based on 1989 energy consumption with the new billing rates applied. The projected electrical cost is used as a base for calculating cost savings by implementation of demand control.

3/ All other energy costs are representative 1989 rates.

TABLE 6-VIII
ANNUAL PRODUCTION

FOUNDRY CODE A

CASTING METAL DI & GI

PERIOD	MELT TONS	SHIPPED TONS	HEAT TREAT TONS	SALES VALUE
JANUARY	459.1	216.6	N/A	
FEBRUARY	285.6	142.3		
MARCH	152.0	44.4		
APRIL	382.1	147.8		
MAY	389.2	163.1		
JUNE	332.6	152.1		
JULY	N/A	99.5		
AUGUST		154.1		
SEPTEMBER		77.8		
OCTOBER		141.7		
NOVEMBER		82.7		
DECEMBER		80.9		
TOTALS	3,890	1,530		\$5,000,000

AVERAGE MELT TONS/DAY = 30.0

REPORTED % SCRAP CASTINGS 14.17

REPORTED % MELT LOSS 10.8

AVERAGE FOUNDRY YIELD % 39.3

AVERAGE SALES VALUE/LB. \$ 1.63

*Melting on alternate days only

KILOWATT DEMAND LOAD PROFILE (JUNNERN)
INDUCTION FURNACE & GENERAL PLANT SERVICE

FOUNDRY A

Figure 6-1

TABLE 6-IX (CONTINUED)

HEAT TREATING UNIT NO. 2			
FURNACE MAKE <u>N/A</u>		BURNER MAKE <u>N/A</u>	
MODEL <u>N/A</u>		MODEL <u>N/A</u>	
SIZE <u>96" x 96" x 162"</u>		TYPE <u>N/A</u> SIZE <u>N/A</u> BTU/HR	
CAPACITY <u>N/A</u> LBS.		FUEL	
TYPE OF LINING <u>N/A</u>		RECUPERATOR MAKE <u>NONE</u>	
WALL THICKNESS <u>N/A</u> INCH		MODEL <u>--</u> TEMP <u>--</u> °F	
BLOWER MAKE <u>N/A</u>		TYPE <u>--</u> SIZE <u>--</u>	
MODEL <u>N/A</u>		CONTROLS MAKE <u>--</u>	
SIZE <u>--</u> CFM. PRESS <u>--</u> "WG		TYPE <u>--</u>	
VOLT <u>--</u> HP <u>--</u>			
TYPE OF HEAT TREAT CYCLE		ALLOY	
HEAT TREAT CYCLE - HEATUP <u>7.75</u> HRS		FUEL/AIR RATIO <u>N/A</u>	
- SOAK <u>6.75</u> HRS		HIGH <u>N/A</u> °F LOW <u>N/A</u> °F	
-COOL DOWN <u>18</u> HRS		SHELL MEAN TEMPERATURE <u>N/A</u> °F	
CYCLES PER WEEK <u>4</u>		FURNACE PRESSURE <u>N/A</u> "WC	
TEMPERATURE <u>1,650</u> °F		FLUE ANALYSIS (HIGH) <u>N/A</u> % CO	
AVERAGE LOAD <u>N/A</u> LBS		<u>N/A</u> % O ₂	
CASTING <u>N/A</u> LBS		<u>N/A</u> % CO ₂	
BASKETS <u>N/A</u> LBS		LOW <u>N/A</u> % CO	
STOOLS <u>N/A</u> LBS		<u>N/A</u> % O ₂	
LOAD DENSITY <u>N/A</u> LBS/WFT		<u>N/A</u> % CO ₂	
QUENCH <u>--</u> AIR, <u>--</u> H ₂ O <u>--</u> OIL		FUEL CONSUMPTION 3,840 CFH THERMS/CYCLE 387	
QUENCH TEMPERATURE <u>--</u> °F			

WALL AREA SQ. FT.WALL TEMPERATURE HOT FACE T₁ N/A °FWALL TEMPERATURE COLD FACE T₂ N/A °FAMBIENT TEMPERATURE °FENERGY COST/THERM \$ 0.3HEAT TREAT LOADS/DAY N/AHEAT TREAT LOADS/YEAR N/A

TABLE 6-X

OPERATIONAL DATA FACT SHEET

LADLE REHEAT DATA

LADLE CAP TONS	N/A	HEAT CYCLES/DAY	N/A
LADLE AREA INSIDE	N/A	SQ FT. LINING THICKNESS	N/A
COVERED	No	TYPE OF LINING	N/A
INSIDE TEMP	N/A	°F	OUTER SHELL TEMP
			N/A
AMBIENT TEMP			°F
GAS USAGE/HR	200	CU FT. CO ₂ READING	N/A
COMBUSTION AIR	N/A	CFM PRESSURE	N/A
			WG
PREHEAT CYCLE TIME		HRS FLUE TEMP	N/A
			°F
REFRACTORY K VALUE	N/A	RS VALUE	N/A
BLOWER HP	None	RECUPERATOR EFFCY	None
FUEL COST/THERM \$	0.3	ANNUAL USE	840
			BTU x 10 ⁶
NUMBER OF UNITS IN USE	Average of 5 ^{1/}		

^{1/} Used 3.5 hours per day - 240 days per year.

TABLE 6-XI

OPERATIONAL DATA FACT SHEET

CUPOLA DATA (TWO UNITS)

CUPOLA DIA SHELL	<u>42</u>	INS	REFRACTORY THICKNESS	<u>N/A</u>
LINING	<u>None</u>	INS	WATER COOLING GPM	<u>N/A</u>
HEIGHT OF TUYERES ABOVE HEARTH	<u>N/A</u>			INS
LAUNDER LENGTH	<u>N/A</u>	WIDTH	<u>N/A</u>	
METAL TO COKE RATIO	<u>5.3:1</u>	BED COKE	<u>5,600</u>	LBS
MELT RATE	<u>4.2</u>	TPH	COKE ADDITION/HR	<u>1,590</u> LBS
BLAST RATE	<u>N/A</u>	CFM PRESSURE	<u>N/A</u>	ONZ
NUMBER OF TUYERES	<u>6</u>	SPACING	<u>N/A</u>	
COOLING WATER USAGE	<u>204,000 GALLONS</u>	GPM	$T_1 - T_2$	<u>60</u> °F
FAN HP	<u>30</u>	MISC. HP	<u>50</u>	
HOT BLAST TEMP	<u>None</u>	°F	RECUPERATOR CAP	<u>None</u> BTU/HR
AFTER BURNER RATING BTU/HR	<u>None</u>			
OXYGEN ENRICHMENT PERCENT ADDITION	<u>One</u> %			
MELTING PERIOD; BLAST ON	<u>5.78^{1/}</u>	BLAST OFF	<u>Not Applicable</u>	
COKE BREEZE ADDITION, PERCENT OF COKE	<u>None</u> %			
ANTHRACITE ADDITION, PERCENT OF COKE	<u>None</u> %			

1/ Average figure.

ENERGY CONSERVATION POTENTIAL

METHODOLOGY

As discussed throughout this study, certain input data is a prerequisite in calculating potential energy savings from different foundry processes. The lack of information pertaining to combustion air analysis and gas flow rates to various equipment precludes calculation of actual energy savings as illustrated in SECTION II of this study.

Potential energy savings for upgrading gas-fired equipment will be figured on a percentage basis; percentages used are conservative as compared to documented savings, from similar changes, as recorded by the Foundry Industry.

Electrical energy savings are factual. Calculations are based on actual kilowatts consumed by melt furnaces. Load profiles were developed from utility company computerized data for 15- to 30-minute periods.

ELECTRICAL ENERGY COST SAVINGS

Electrical power cost savings can be realized by improved controls and changes in melting energy usage as calculated in the following work sheets.

Based on a sample billing period of one year, the cost reduction potential is:

1. Demand Control

	<u>Total</u>
Normal melting demand cost	\$11,885
Demand limited cost	<u>8,390</u>
Savings	\$ 3,495/yr

$$\text{Percent savings} = \frac{\text{reduction in cost}}{\text{normal demand cost of melting}} = 29.4\%$$

For graphic illustration of methodology used in calculating electrical savings see Section 3.

DEMAND CONTROLLING

The following approximate cost savings can be realized by the installation of demand limiting controls. Controlling the Peak Kilowatt demand to 350 kilowatts.

Potential Cost Savings = \$ 130 per month

Annual Cost Savings = \$ 1,670

For graphic illustration of methodology used for calculating cost saving see drawing below.

FIGURE 6-2. KILOWATT DEMAND LOAD PROFILE INDUSTRIAL BILLING RATE

TABLE 6-XII

DEMAND CONTROLLING

NORMAL MELTING COST			DEMAND CONTROLLING COST			
Month	Kilowatt Demand	Demand Charge	Kilowatt Demand	Demand Charge	Savings	%
Jan.	512	\$994.24	350	\$699.4	\$294	29.6
Feb.	513	996.06			296	29.7
March	499	970.58			271	27.9
April	505	981.50			282	28.7
May	511	992.42			293	29.5
June	518	1,005.16			306	30.4
July	508	986.96			288	29.2
Aug.	503	977.86			278	28.5
Sept.	500	990.60			291	29.4
Oct.	514	997.88			298	29.9
Nov.	513	996.06			297	29.8
Dec	513	996.06			297	29.8
		<u>\$11,885</u>		<u>\$8,390</u>	<u>3,495</u>	

Potential yearly saving (average) = 29.4%
Based on a maximum demand of 350 kw.

Upgrading Heat Treat Furnaces

Amount of total gas consumed	=	270,724 therms/yr
Total natural gas cost	=	\$ 78,350.00
Average cost per therm	=	\$ 0.289
Maximum gas usage per hour:		
Heat Treat Furnace #1	=	6,300 cu. ft.
Heat Treat Furnace #2	=	3,840 cu. ft.
Total	=	10,140 cu. ft.
Average heat-up time (Total)	=	13.25 hours
Average holding time (Total)	=	13.25 hours
Total cycles per year	=	150

Assume yearly gas consumption attributed to heat treat operations is 80% of total plant gas input of $(270,724 \times 0.8)$ 216,000 therms/yr.

Approximately 56% energy savings can be realized by:

- Installing ceramic fiber linings - 12-inch thick
- Upgrading burner system and controls
- Adding combustion air preheating

Energy saved = $216,000 \text{ therms} \times 0.56 = \underline{120,960 \text{ therms/yr}}$

Cost savings = $120,960 \text{ therms} \times 0.289 = \underline{\$ 34,957.00}$

Upgrading Ladle Heaters

Quantity of ladle heaters used at one time = 5
Hours of operation per year = 882 hrs/yr
Assumed average gas consumption = 1,000 cu.ft./hr

Total gas used per year:

(1,000 cu.ft./hr x 882 hrs) = 882,000 cu.ft./yr

OR 8,820 therms

Approximately 40% energy savings can be realized by:

- Upgrading lining
- Installing ladle covers
- Upgrading burner system

Energy saved = 8,820 therms x 0.4 = 3,528 therms

Cost savings = 3,528 therms x 0.289 = \$ 1,020.00

UPGRADING CUPOLA OPERATION

Amount of coke consumed	=	1,283.64 Tons
Total cost of coke	=	\$264,887.00
Average cost per ton	=	\$ 206.35
Cupola size diameter	=	42"
Cupola melt rate Tons/Hour	=	4.2
Total tons melted/Year	=	3,500 Tons
Metal to coke ratio (charged)	=	5.3 :1
Special conditions - O ₂ %		1.0

Energy (coke) savings can be realized by:

• Hot blast conditioning	22.8%
• Divided blast supply	26.2%
	<u>49.0%</u>

Energy savings (charged coke only) =

$$\frac{3,000 \text{ melt tons}}{(5.3:1) \text{ coke usage/ton}} \times 0.49 = 277 \text{ tons}$$

Cost savings = 277 tons x \$206.35 = \$57,160/year

CONVERT TO ELECTRIC MELTING

Replacement of cupola melting with electric furnace melting involves consideration of multiple variables which occur in foundry operation. An in-depth analysis is necessary to carry out a complete analysis and is not covered in this report.

ECONOMIC ANALYSIS

Payback period is calculated as follows:

$$\frac{\text{Total Capital Investment}}{\text{Gross Energy Cost Reductions/Year}} = \text{Years}$$

Payback years for individual projects are listed in PART G based on order of magnitude costs as follows:

• Demand Controller	\$ 4,000
• Upgrading Heat Treat Furnaces	80,000
• Upgrade Ladle Heaters	12,000
• Upgrading Cupola	<u>250,000</u>
TOTAL	\$346,000

The following conditions could lower the anticipated payback period considerably:

- Present day equipment costs used. However, the energy cost savings is based on 1989 calendar year average energy cost, except for electrical energy which is escalated to show approximate 1990 costs.
- No credit taken for government tax credit for installation of energy-savings devices.
- Calculation of return on investment utilizing life-cycle testing methods, which take into account depreciation, cost of money, and escalation of energy cost over the lifetime of the equipment, could possibly make the capital investment attractive.

SUMMARY OF ENERGY REDUCTION

SUMMARY TABULATION

ITEM	ENERGY SAVED BTU x 10 ⁶	COST SAVINGS \$	CAPITAL INVESTMENT	PAYBACK PERIOD
Power factor correction				
Demand controllers	NONE	\$3,495	\$ 4,000	1.14
Off-peak melting				
Load shifting				
Upgrading heat treat furnaces	12,096	34,957	80,000	2.3
Upgrading ladle heaters	352	1,020	12,000	11.8
Upgrading cupola furnaces	6,925	57,160	250,000	4.4
TOTAL	19,373	96,632	346,000	3.58

Total Btu reduction/ton of castings shipped

$$= \frac{19,373 \times 10^6}{1,530} = 12.66 \times 10^6 \text{ BTU}$$

PROJECTED ENERGY-EFFICIENCY RECORD

MONTH OR YEAR RECORDED	<u>1989/90 Calendar Year</u>	
UNITS OF PRODUCTION	<u>1,530</u>	
	<u>Net good tons shipped</u>	
FUEL COSTS		
Electricity	\$	<u>1,119,610^{2/}</u>
Natural Gas		<u>43,373</u>
Propane		<u>--</u>
Oil		<u>--</u>
Coke		<u>207,727</u>
Other		<u>--</u>
TOTAL	\$	<u>369,710</u>
ENERGY USED		
KWH <u>23,259.60</u> x 3,412 Btu =	<u>7,902</u>	<u>Btu x 10⁶</u>
Mcf Gas <u> </u> x <u>1/</u>	<u>14,624</u>	<u>Btu x 10⁶</u>
Gal. Propane <u> </u> x 91,600 Btu =	<u>--</u>	
Gal. Oil <u> </u> x 140,000 Btu =	<u>--</u>	
Coke - lb. <u>2,013,280</u> x 12,500 Btu =	<u>25,166</u>	<u>Btu x 10⁶</u>
TOTAL BTU	<u>47,692</u>	<u>Btu x 10⁶</u>
ENERGY USED PER UNIT OF PRODUCTION		
(Million Btu) <u>47,692</u>	=	<u>37.17 Btu x 10⁶</u>
(Units) <u>1,530 Tons</u>		
COST PER MILLION BTU		
(Energy Cost) <u>369,710</u>	=	<u>7.75 Cost/Btu x 10⁶</u>
(Million Btu) <u>47,682</u>		
COST PER UNIT OF PRODUCTION		
(Total Cost) <u>369,710</u>	=	<u>241.6 Cost/Unit</u>
(Units) <u>1,530 Tons</u>		

1/ 1 Mcf = 1,000 cu.ft./hr - See Gas Bill for Btu content/cu.ft.

2/ Electrical cost based on representative 1990 billing rates

ALTERNATE 1

END

DATE FILMED

12 / 31 / 90