

PROCESS PARAMETERS AND ENERGY USE OF GAS AND ELECTRIC OVENS IN INDUSTRIAL APPLICATIONS

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ABSTRACT

The study was conducted to evaluate the energy use of natural gas and electric ovens in the production of polymer bearings and components. Tests were conducted to evaluate and compare the performance of natural gas and electric ovens in the process of sintering billets which are made from a broad range of materials such as PTFE and other fluoropolymers, elastomers, thermosets, thermoplastics and composites. The purpose of this study was to compare the process parameters under similar conditions for industrial applications where electric ovens have predominant use. Tests were performed to obtain the process efficiency and examine cost savings potential in converting electric ovens to natural gas. Preliminary results show that, for the plant studied, cost savings of about \$10,000 per oven can be achieved, with a simple payback period of less than two years. The results also show that additional energy savings will be realized if the oven size and exhaust flow are carefully selected. The data obtained from these experiments were used to calculate process efficiency. Design features and environmental issues are discussed.

BACKGROUND

This paper will evaluate current practices of clients in the New England/New York which are covered by the Industrial Assessment Center (IAC) at the University of Massachusetts in their use of electric ovens and furnaces instead of natural gas fired ones in daily operations. The IAC at the University of Massachusetts (UMass) is funded by the United States Department of Energy (US DOE) Office of Industrial Technologies to provide energy, waste, and productivity assessments, at no charge, to small and mid size manufacturers. During its 15 year history, the UMass IAC staff has performed plant assessments at many plants where electric ovens are used, even when natural gas-fired ovens are readily available. In the last 12 months the UMass IAC have visited 25 plants and recommended oven retrofits to natural gas in 10 cases. The recommendations have resulted in an increase in energy consumption, due to the lower efficiency of gas fired ovens, but have a potential for significant cost savings due to the large

cost differential between natural gas and electricity. The average cost of energy in this part of the country is one of the highest in the nation. The marginal price of electricity for these plants ranged between \$0.06116/kWh and \$0.06718/kWh (\$17.92/MMBtu and \$22.37/MMBtu) for energy and \$2.645/kW and \$14.08/kW for demand. At the same time, the prices for gas were between \$3.02/MMBtu and \$5.64/MMBtu.

NATURAL GAS FIRED OVENS AS A RETROFIT

Many of the plants we visited make products that can tolerate a relatively large deviation from the oven's set point temperature (usually ± 5 °F). Such deviations can be maintained by simple gas fired equipment which does not require expensive measurement and control devices. Current natural gas technology easily allows for deviations of less than ± 0.5 °F.

One plant we visited had an oven that had been retrofitted about seven years earlier to use natural gas. The total cost of the conversion was \$17,500 and included \$7,500 for a retrofit kit and another \$10,000 for the labor to convert and tune the oven. Plant personnel had purchased a total of four retrofit kits at the time, with a plan to retrofit one oven and compare its energy use to that of its three other electric ovens. If the conversion proved successful and seemed economically beneficial, the remaining three ovens would then be converted to natural gas. In order to monitor gas use, a gas meter was installed. Measurements of the ovens' energy use were never taken, however, and three conversion kits remain on the shelf.

ANALYSIS OF A FIELD INSTALLATION

Data Collection

A typical electric oven that was monitored is a 90 kW, 600V, 3 phase unit. It is a walk-in oven with a 60 in. \times 60 in. \times 60 in. chamber. The oven is insulated with 6 in thick mineral fiberboard insulation. The oven footprint is 78 in. \times 87 in. and the height is 109 in. It has two fans; one recirculating fan with a 3 hp motor, and a 1 hp exhaust fan, which

should, by design, continuously exhaust 222 cfm of air from the oven.

Measurements were taken in two phases. In the first phase, which covered a period of less than two hours, measurements of the oven line amperage, line voltage and phase angle were taken using a Ranger IV¹ instrument. The sampling rate was four samples per second for all three phases. Using these inputs, instantaneous power, power factor and total power were also calculated and recorded.

At the same time, the data was collected with HOBO² amp clamps with a sampling interval of 15 seconds. That was the shortest interval that could be selected to allow for the data collection of one complete oven cycle, which usually lasts 5-6 days.

The results from the two instruments were then compared to determine the accuracy and degree of confidence with which HOBO data could be used. Although Ranger IV is a precise instrument with greater accuracy and the ability to record more data, it could not be placed in the oven's electrical panel because of its size and the number of connections that needed to be made. Since placing it beside the oven was unacceptable to plant personnel for safety reasons, we wanted to use HOBO as long as we could have confidence in its measurements. Since the data for energy use from the two devices were within 5% of each other, we felt that HOBO was acceptable and it was used for the study.

During the second phase, HOBO instruments were set up to measure line amperage coming into the oven. Oven temperature data were taken from the oven temperature charts. Data used to analyze energy use and potential savings were obtained over a period of six days. Power and temperature data are presented in Figure 1.

Oven power data are presented for each 15-minute interval, which is the interval used by the local utility to charge for demand. The highest demand recorded for one of these intervals in the oven cycle was 35.7 kW, and the average for the whole cycle was 22.5 kW.

¹ Ranger IV is made by Ranger, a Division of Westronics, Kingwood, TX 77339

² HOBO is made by Onset Computer Corporation, Bourne, MA 02532

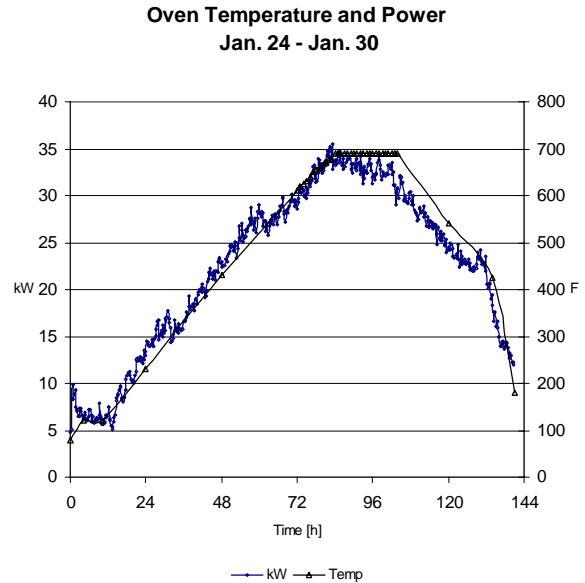


Figure 1. Graph of Electrical Oven Temperature and Power

Figure 1 also has the oven inside temperature, whose curve, as expected, closely follows the power curve. In this process of sintering, the billets were brought slowly to a temperature of 690 °F, kept there for about 13 hours and then slowly cooled back to the ambient temperature.

Energy Use and Cost Savings

Based on the oven energy consumption over one cycle, which was measured to be 3,177 kWh, and the total plant operating hours, it was determined that the oven's annual energy use would be 177,642 kWh, or approximately 606 MMBtu.

During the experiment, a natural gas-fired oven that has the same physical characteristics as the electric oven was filled with the same batch of material. Under the same conditions, the gas-fired oven, which has its own gas meter, consumed 12,516 cubic feet of natural gas. This corresponds to natural gas energy use of 12.516 MMBtu for one cycle, or 700 MMBtu annually. Like the electric oven, this oven has one 3 hp recirculating fan and one 1 hp exhaust fan. These fans together use 23,494 kWh or 80 MMBtu annually.

This plant has natural gas available at \$3.51/MMBtu. Its cost of electricity is \$2.83/kWh for demand and \$17.52/MMBtu (\$0.06116/kWh) for energy. Based on these prices it was determined that the annual cost to operate an oven is \$12,072 with electricity and \$3,992 with natural gas. The price for the natural gas fired oven includes \$2,457 for natural

gas and \$1,535 for demand and energy costs to operate the exhaust and recirculating fans. With an implementation cost of \$17,500, this gives a simple payback period of 2.2 years. The data on energy use and costs for each oven cycle over a period of one year are summarized in Table 1.

Table 1. Annual Energy Use, Operating Costs, Cost Savings and Payback Period for Electric and Natural Gas Fired Ovens

		MMBtu	kW	\$
Electric Oven	El. energy	606		10,860
	El. demand		35.7	1,212
	Total	606		12,072
Gas Oven	El. energy	80		1,434
	El. demand		3.0	101
	Gas energy	700		2,457
	Total	780		3,992
Annual Cost Savings				8,080
Simple Payback Period				2.2 years

Other Considerations

The plant has twelve ovens for billet manufacturing. The electric ovens range in size from 50 kW to 140 kW, and the gas-fired oven has a capacity of 350,000 Btu/h. The production process is organized such that no special attention is given to which oven will be used for a certain batch. Each oven is capable of performing the sintering process without difficulties.

Before billets are placed in the oven, they are evenly spaced on a metal rack to insure proper circulation of warm air around each billet and through its core. Depending on their size, four to seven billets form one batch. Billets are never stacked in the oven. During the cycle, an air-circulating fan maintains the uniformity of the temperature distribution inside the chamber.

Throughout the heating cycle, a small amount of air is extracted to remove fumes from the oven. This flow was measured to be 270 cfm on one of the two electric ovens for which data were taken for this study. Although the two electric ovens were the same size, were made by the same manufacturer, had the same design specifications and operated under identical conditions with the same settings at the control panel, one oven consumed about 20% less energy. No studies have been performed on the exhaust system to balance the air flow.

A graph comparing the energy consumption of the two ovens is presented in Figure 2. This graph

also has the ratio of energy use for two ovens that is a flat line, with a ratio of 0.8.

The only difference between the two ovens was their position in relation to the exhaust ducting. All the ovens in the plant exhaust into a common system with an additional exhaust fan for the whole system to augment individual fans. The actual flow from each oven was not controlled, and all the ovens had their exhaust dampers throttled to almost closed, with individual exhaust fans running during the process cycle.

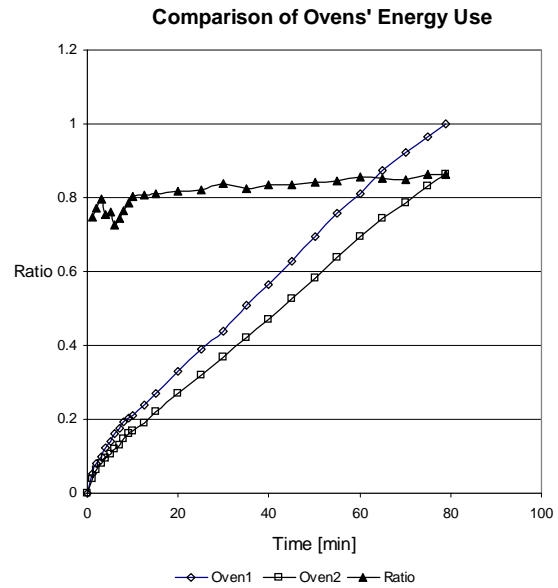


Figure 2. Comparison of Energy Use for Two Electrical Ovens

In order to understand oven energy use, a simple model was developed. The components that were modeled were heat losses through the oven envelope, heat loss due to infiltration and energy use of the exhaust and air recirculating fan. The results are presented in Table 2.

Table 2. Comparison of Energy Use for Two Electric Ovens during One Cycle

		Oven 1	Oven 2
Flow	cfm	270	215
Fans' Energy	MMBtu	1.436	1.436
	%	13.2	15.8
Exhaust Loss	MMBtu	8.219	6.484
	%	75.8	71.2
Envelope Loss	MMBtu	1.186	1.186
	%	11.0	13.0
Total Energy	MMBtu	10.841	9.106
	%	100.0	100.0

The results in Table 2 indicate that the highest contributor to energy loss is the exhaust.

A diagram of oven amperage, Figure 3, shows the same profile for current for the two ovens, but higher peaks in the oven with the higher air flow. This increase is associated with the increased exhaust flow rate. The two ovens have the same temperature profile for that period.

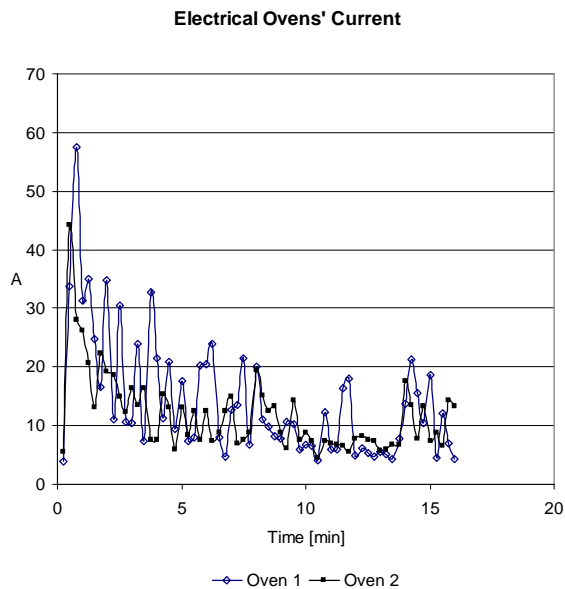


Figure 3. Current for Two Electrical Ovens

The oven that consumed less energy had a flow rate that was calculated to be about 215 cfm. This indicates that the quality of the sintering process is not compromised when the air exhaust rate is reduced by at least 20%. Clearly, energy savings would result if the plant took a controlled approach to its exhaust system and reduced the flow through each oven

Plant personnel indicated it is desirable to have some flow when the oven temperature is above 600 °F, when certain components in the billets are brought to the melting point, but that for most of the cycle the exhaust could be reduced to a minimum.

Based on that information, two options were studied. The first option was to simply reduce the exhaust flow through an oven from 270 cfm to 215 cfm. This would reduce energy use by 16% (Table 2).

The second option was to reduce the flow to 215 cfm when the oven temperature is above 600 °F, and to reduce it linearly, proportional to the oven temperature, when the temperature is below 600 °F, but never to go below 50 cfm. In this case, the energy loss through the exhaust would amount to 5.48 MMBtu, or 8.102 MMBtu for all three components of the cycle.

The potential energy and cost savings, together with the implementation costs, for these two options on an annual basis, are presented in Table 3. They are compared to a case where the oven has 270 cfm exhaust flow.

Table 3. Energy and Cost Savings, Implementation Costs and Payback Period for Two Proposed Exhaust Flow Options

		Option 1	Option 2
Energy Use	MMBtu	509	453
Energy Savings	MMBtu	97	153
	%	16	25
Cost Savings	\$	1,740	2,740
Impl. Cost	\$	1,200	2,650
Payback Period	years	0.7	1.0

CONCLUSIONS

It is common industry practice to purchase electric ovens because they are cheaper and easier to operate. Operating costs are often neglected, even in areas with high electricity costs, such as New England. But even when plant personnel are aware of energy economics, the demands of a busy industrial environment can prevent the best of plans from being implemented. Frequent personnel changes often leave little room for experiments and evaluation of new technologies. In the case presented here, plant personnel had a sound plan and expended considerable effort and resources to carry it out, but the results were never examined or acted on because of time and personnel constraints.

This is a good example of the role IAC can play in helping plant engineering to obtain the data needed to fully evaluate benefits and obtain permission to proceed with this work.