CEC Combustion Safety

11699 Brookpark Road
Cleveland, OH 44130 USA

P: 216-749-2992
F: 216-398-8403

www.combustionsafety.com

Strategies for Energy Reduction in Today's World
Low Cost/No Cost Basic Things that May Have been Overlooked in your Oven or Furnace Operations

INTRODUCTION

Technologies related to steel industry ovens and furnaces have come a long way since James and Daniel Heaton first established their Hopewell furnace in 1803 near Youngstown, Ohio. Today, we've got exotic heat recovery systems, fuel air ratio control systems run by computers, and refractory materials that once flew to outer space.

Most of the world operates something in between what the Heaton's started with and something space age. Regardless of what you own and operate, two things are clear: One is that in today's economy it will be a long time before you get lots of capital dollars for something new. The other is that you turn a space age unit into a clunker quick if you don't understand it or maintain it. This paper focuses on operational and maintenance related low cost/no cost strategies to reduce fuel costs and improve safety, reliability, and quality. It discusses the basics of many ovens and furnaces used throughout the steel industry and steel processing facilities.

The overall savings from implementing the items found here could be worth from 5% to 25% of your equipment's operating depending on the shape it's in today. Sure, everyone maintains their equipment. However, it's usually done by someone far removed from the optimum configuration for that equipment after years of it being cobbled together and made to "just run." One of the reasons is that there's little money to be made by anyone selling an owner or operator on the concept of optimizing an oven or furnace. Optimum efficiency means an investment in training and specific skill sets. It's something that requires constant attention to keep it sustainable and it requires considerable human capital to be successful.

Today business conditions are making for a loss of human capital. When this human capital leaves and there's no one around who remembers why or how something was configured, the end result is usually higher operating costs and reduced reliability. This paper seeks to help one rediscover the simple basic things that really make a difference when it comes reducing costs without impacting quality or functionality.

This paper starts with 4 basic furnace/oven systems that will be analyzed and addressed. These are the 1). The thermal envelope, 2) burner systems, 3) air moving systems, 4) controls.

This paper cannot address something useful for every furnace or oven built. This is a very broad topic developed over hundreds of years. It is hoped is that the reader can take away a few concepts that apply to their specific systems. Don't look for rocket scientist concepts in this paper. You will find here an overabundance of common sense things that you probably already knew but have not thought about in years. Your challenge is to take a few of these and actually apply them to your specific systems.

The Thermal Envelope

For purposes of this discussion, the envelope is defined as the thermal barriers of the oven or furnace including the doors and walls and their refractory and insulating systems. Although high skin temperatures and failed refractory and insulation could be important for safety and function, it's rare that saving energy by making these repairs is cost effective. It's been our experience that low cost/no cost thermal envelope success is about reducing unintentional air movement (infiltration) through ovens and furnaces.

Skin temperature and walls

Other than patching holes and sealing leaks (which is important) wholesale replacement of panels and re-insulating is usually not a cost effective option. The thermal envelope you own is a matter of the temperature requirements and the cost of fuels and materials when your system was designed. The insulation installed was simply a matter of what looked like the economical choice at the time. Even though it's very hard to cost justify improving the overall thermal performance of oven and furnace walls, you should definitely conduct a skin temperature survey to understand what you have and its current state. The bet time to think about doing something about this is if you are about to do a major overhaul or repair.

Skin temperature survey

Start with a mapping of your unit's skin temperatures. You can do this with an inexpensive non-contact infrared thermometer. You can make out a grid on your unit and mark it with chalk or make depictions on a drawing to gain an understanding of the overall skin temperature level and hot spots. It's not so much that there's a standard or a given temperature you're looking for. Instead you're looking more for anomalies or places where it's dramatically different.

Reasons for high skin temperatures

Original design was economical at the time.

The overall skin temperature level could be an indication of what the original design thermal envelope was and or how it is still holding up. It's very unlikely that there can ever be a cost effective project to replace panels just to save energy. For example, bringing a surface temperature down from 450F to 250F saves about 150 BTU's per square foot. If this heat is added with natural gas at an efficiency of 75% it means that you could save about 1,600,000 BTU's per square foot per year by changing out the panels or adding insulation, (8,000 hours per year of operation). If natural gas costs you $10 per million BTU's at your burner tip this means you could save about $16 per square foot for reducing the surface temperature. The costs for adding insulation or changing out panels is a very equipment specific issue. You'd have to be able to replace panels or upgrade insulation for less than $32 per square foot to get a 2 year simple payback in this case.

Oven or furnace still operating at a higher than design temperature
There are many cases where oven or furnace operating conditions have changed. We frequently find cases where operating temperatures are considerably higher than the original design. This means skin temperatures will be higher than expected. This could be a signal that insulation should be increased or changed if a major overhaul or repair is to happen.

Insulation or refractory broken down or damaged
Skin temperatures can also be impacted by insulation that has broken down in sandwiched panels. Fiberglass binders can start to break down at elevated temperatures over time. In some cases fiberglass or mineral wool can also settle or fall down inside panels over time. Refractory, including fiber modules, can become loose, can fall out, and can be damaged.

Infiltration and air movement
Ovens and furnaces are designed to transfer heat a number of ways. Not all of them depend on air movement. However, in every case there are pressure and draft issues (meaning air movement) whenever we heat something. The key to controlling infiltration and air movement is paying close attention to the condition of doors, seals and joints including car bottom closures. Paying attention to this unwanted air movement is the most lucrative thing you can do to save money on any oven or furnaces operation. One of the best ways to do this is to use smoke visualization and or infrared analysis.

Smoke visualization surveys
Smoke visualization can be done for less than $50 in materials. You can buy commercially available products that you light and put into a coffee can. You buy these for the number of minutes of smoke that you want. Before doing this, make sure that you're in an area where fire protection systems or smoke detectors won't go off. Also, make sure that the product you buy makes for a non-toxic friendly smoke.

If you have an oven or furnace down you can use smoke with a pressurization fan and review for leaks. If the unit is running you can put smoke at the doors and places like car bottom seals and very quickly understand where you need to take action.

Reasons for uncontrolled air movement

Doors are damaged or warped and don't seal well
Doors can be a victim of their moving mechanisms not functioning correctly, warping, and or misalignment. Door air leakage is most commonly attributed to seals that have gone bad. We have found that where possible fiber door seals work best. Seals don't last forever no matter what. If they're not being changed out it's because the cost of inaction is not being communicated well. In the case of a cumulative seal open area of about 6 square inches and a furnace negative pressure of even 1" water column the draw is about 200 cubic feet per minute. If a unit is operating at 900F this makes for a fuel use of about 226,000 BTU's per hour. This is worth about $18,000 per year in fuel savings for an 8,000 hour per year operation and $10 per million BTU's gas cost.

Car bottom furnaces can be especially hard to seal. The best closing systems use cylinders or clamps to slide into place and make a tight seal when the car bottom is in place. This might require some engineering work and fabricating but it’s a straightforward fix that can dramatically reduce infiltration. When you consider the sealing area of a car bottom furnace it’s not hard to cost justify better seals.

Burners and other penetrations are not sealed effectively.
Review openings around burners and other penetrations like thermocouples and joints in panels. If you find openings you might be able to make quick and inexpensive repairs by jamming fiber refractory materials into the openings.

Openings for product movement like conveyors are larger than they need to be.
Some ovens are designed for the product to move through on a conveyor. This might involve pieces being hung or being moved through on a conveyor. In many cases there’s no reason for these openings to be as large as they are. It may also be that these can be closed off with door mechanisms that can open and close.

Doors are open longer than they need to be.
In batch operations like forging furnaces you really have to ask yourself if doors are left open for longer than they have to be. In some cases this is a simple operational adjustment.

Tall ovens are making for a chimney effect (draft control issues)
In the case of tall ovens or furnaces there are sometimes substantial unintended chimney effects. This can make the air flow across the opening profile into the oven or furnace near the floor and out of the unit near the roof. This may be an opportunity to add air dams at the top and bottom minimize the air movement. Some units have draft controllers that throttle flues to make for precise draft levels (positive or negative pressures) inside furnaces. Make sure that yours work. These controls are in a severe duty and often not looked after as they should. If your draft controls are manual consider investing in making them automatic and continuous.

The Burner Systems

Remember, in its most basic form a burner mixes fuel and air. It may have been years since your burner and fuel train systems worked correctly or even as they were originally intended. There’s a lot of money to be saved by simply fixing things that are broken and have made for operating compromises over the years. A lot of these kinds of things don’t get repaired correctly because the area of combustion is seen as an art form by many. The following hopes to break down this art form and make it very simple to understand in a practical sense.

What follows are some easy to understand burner combustion efficiency checks along with things to review on your fuel train that could be making for fuel waste.

Evaluate the Burners Combustion Efficiency
The best was to assess a burner's combustion efficiency is of course to use a hand held combustion analyzer. However, this is not an option in many applications. Many ways have been developed to know what burners are doing to accommodate the diverse furnace designs that are out there. In some cases it's a matter of a flue gas analyzer somewhere in the system to get an idea of how many burners are even lit. If your burners fire into some type of closed chamber and or if you have some kind of indirect heating application with a flue then yes a simple hand held analyzer can tell the story. If however it's a re-circulated direct burner application you'll have to rely on other means.

Burners are usually adjusted for a specific air fuel ratio depending on what the service or duty is. In any cases, like for a common radiant tube burner you're looking for 2 to 6% excess Oxygen as measured by a flue gas analyzer at the discharge.

In cases where you can't use a flue gas analyzer setting the burner comes down to knowing the air and gas pressures being delivered at key defined points on the burner and trying to get a look at the flame if possible. It's best to observe flames from a safe point (tempered glass port) where firing is in the direction of the observer. If you see almost nothing but a red glow your near stoichiometric or a perfect 10 to 1 ratio of fuel and air. Most commercial burners are set with a slight amount of excess air to prevent going rich.

There are some obvious things to look for here like: sooting, carbon deposits and flames that are very bushy and yellow or orange. A flame that is very yellow and luminous on something that is not a low NOx burner, could be an obvious sign of a fuel rich condition. Flames that are very pale blue, noisy, and sharp edged are often too lean. In both cases you don't convert all of the CH_4 (natural gas) to its completely combusted form, (CO_2 Carbon Dioxide) and water. In the case of a flame being too lean you are submitted too much air which is quenching the flame and stopping the fuels chemical conversion. In this case mixing is also often very poor. When you don't convert the Methane completely and make CO (Carbon Monoxide) you leave about 27% of the incoming fuel value unused.

Setting burners to a correct air fuel ratio is not something to try if you have little or no experience. You can create very unsafe conditions by setting these wrong. Make sure that this is done by an experienced burner technician.

Investigate the Condition of Burner and Fuel Train Components

Burner Issues to Examine
Some burners need to make for proper mixing and ignition of fuel in severe environments. The air that enters them is partly to keep them cool as they seek to avoid having flames impinging on them. Carbon steel starts to change properties at about 850F. If something seemingly insignificant occurs like some dirt plugging a nozzle or hole, cooling air flow can be redirected and a part of the burner can be destroyed in minutes. Once this happens, burner nozzles and diffusers can start to be destroyed. This destruction can occur over a one-time event like a

damper or linkage going bad. It can also occur from the accumulation of deposits over time. Burner parts that overheat often warp, dissolve, and or twist. This keeps them from functioning as intended. You really can't see this unless you have a full view through a site port, which is rare. In most cases you'll have to pull a burner that does not appear to be performing properly to inspect it. That's just the beginning. You'll also have to learn why it overheated and what is causing it to no longer be functional.

Burners that are damaged or chronically being destroyed cost you money because they will not get your fuel completely burned in the most efficient manner. They also cannot control the shape of the flame as originally intended.

Fuel Train Issues to Examine

The fuel train is the series of pipe, fittings, valves and other components that controls the flow of gas and air to be delivered to the burner. The majority of these components are there for safe operation. Other components are there to maintain the proper firing rate and the desired fuel air ratio. The following describes issues that our firm has encountered in the course of inspecting and testing thousands of fuel train components over the past 10 years.

Gas valves (butterflies) worn out

Small butterfly valves, (typically 2" to 4"), are used in many applications for zone firing rate control valves. When these get old the bushings wear and get sloppy. You can find this easily by grabbing the linkage arm and seeing if you can move it a small amount while observing the shaft in the bushing. These things also leak gas at this bushing when they are worn. Besides the gas leakage loose bushings also make it hard to set these burners up efficiently and get repeatable results.

Leaking vent valves, (double block and bleed systems)

Many systems have double block and bleed fuel trains. These systems have two main automatic fuel shut off valves in series and a normally open vent valve in between them. This valve in between does the opposite of whatever the two main valves are doing. It is usually a valve that is not as high in quality as the main fuel train valves. When your system is operational this vent valve needs to seal tightly. We find about one in every 75 to 100 vent valves leak through in their closed position. The leakage might not be dramatic but it impacts the flame quality and also very directly wastes fuel. NFPA 86 (standard for ovens and furnaces) describes annual tightness testing requirements for all of these valves to make sure they hold. The annual test required is called a bubble test. A valve leaking 100 bubbles per minute costs you about $4,000 per year in fuel costs.

Regulator Stability

It's important that the gas regulator system pressure be stable. Gas pressure instability means flame instability and fuel air ratio issues. Gauge indications should be stable. The gas pressure should not be fluctuating or pulsing continuously. If it is the cause could be a defective regulator, a regulator venting issue, and or a regulator sizing issue.

Bent or leaking signal lines

Cross connected control systems rely on an air signal to bias the diaphragm of a regulator or control valve. This makes sure that gas flow is proportional to air flow and is your only hope for fuel air ratio stability. You need to verify that these air signal lines, usually ¼” tubes, are not leaking, bent or crimped.

Linkages

If your control system relies on linkages make sure they are firmly attached and not binding. In some cases, linkage bushings could be worn and make for conditions that are not repeatable. Linkages should be match marked once they are deemed to be in the proper condition. This is a simple matter of marking them so that if they ever do move the change will be immediately noticed and can be investigated.

Air Movement (Exhaust and ventilation air)

The national fire protection association (NFPA) classifies ovens and furnaces in 4 categories, A, B, C or D. Class A furnaces are those that liberate or could liberate flammable materials or volatiles in the course of processing something. Air movement and replacement is required as a safe operating condition for Class A units. NFPA 86 calls for ventilating such that 25% of LEL is never reached. Our firm sees many cases where this requirement is met in an overabundance of conservatism. Being conservative is a good idea. However, it’s just as important to review where you are today and how you got there. It’s also important to understand how conservative you are being and if changes can be made to reduce the ventilation requirements in a safe manner.

It starts with calculations and an assessment

NFPA 86 has calculations described along with an appendix with sample calculations for ventilation air flows. You’ll have to gather data about the amount of volatiles you are liberating. This will mean information about consumption of whatever it is (paints, glues, resins, binders, oils) and line speed.

There can be many things that may have changed from when your equipment was installed and where things are today. NFPA requires that a placard be provided from the manufacturer on your oven describing what it was built for and capable of doing. Something as simple as changing line speeds or changing the materials used or even the coating thickness could make for a big difference in the ventilation rate required. If you substitute materials that have less of an explosion hazard, you dramatically reduce the amount of ventilation air required. This can make for very easy savings since less air means less BTU’s. This consideration is rarely thought of as input to the purchasing manager’s decision when that person might be buying paints or glues or resins that are getting processed in an oven or furnace.

Identify your specific ventilation needs

Once you’ve got an understanding of what you need it’s time to review what you actually have. This will mean air flow measurement equipment like a hot wire anemometer and possibly some holes in ducts. You may also want to get a vane anemometer to measure air flow entering openings like product entrance and exit areas.

It's important to also understand that the air balance amongst various zones of an oven or furnace is important. You could have a long continuous oven with some zones that are Class A and others that are not. Balance means that air flows in and out of contiguous areas are maintained as per design requirements. Some zones may have a net air flow in while others need to have a net airflow out. This manifests itself at the ends where in some cases spill out hoods exist for contaminated ex-filtration to be removed. Make sure that the air velocity in or out of each end is in keeping with conditions required. For example, in some class A ovens (like for paint drying) the first zone may be where most volatiles are actually driven off. This means air has to leave and be replaced. You probably don't want flashed off volatiles migrating to other non-ventilated zones where they can accumulate and become an explosion hazard.

The Control System

The term, "controls" means many things to many people. Every oven or furnace has two control systems. One is the safety system or burner management system, BMS. The other is the fuel air ratio and firing rate controls system. We'll be discussing only the fuel air ratio and firing rate controls that allow us to maintain control of temperatures.

Measuring temperatures

Controlling temperatures all starts with measuring temperatures. There are lots of things that can go wrong with measuring temperatures. We're going to next examine important thermocouple issues that can lead to energy savings.

Verify that the right thermocouples are installed.

You'll need to start with a review of the type of thermocouples that are installed and what they actually measure. What they measure will also be a function of how they are installed and if they are still reading correctly. Thermocouple types are designated by the letters of the alphabet. They are rated to be more accurate for specific designated temperature ranges. Make sure that your oven is still operating with thermocouples that give it the best chance to provide accurate service.

Verify that your thermocouples are of the right length and in the right parts of the unit.

Thermocouples are available in almost any length. However, it they're too long and not in a sheath or supported they will sag and not measure where you thought they would measure. They can also be in some portion of an oven or furnace that is no longer seeing representative temperatures.

Verify that regular calibration is occurring.

Remember that if a thermocouple is dirty it cannot do its job. There can also be issues with the length of thermocouple wire and sheaths that can make calibration very important. This is a very basic issue. You'll need a port into the oven where you can insert a test thermocouple or you'll need to design an oven survey to find out if what you're reading and controlling to makes sense.

Have you surveyed the unit's temperature profiles?
Doing a survey means you send an instrumented data collecting device through the unit to measure what's going on. The device records temperatures during the entire oven or furnace cycle. You then down load the data and review what conditions were in the unit versus what you thought they were supposed to be or what the process actually requires. This can be an eye opening process.

In the case of high temperature processes where you can't run a data device through you would need to pull thermocouples for inspection and calibration to verify what is going on. Remember, even a very thin coating of almost anything will insulate a thermocouple and make it read lower than what's actually occurring in the unit.

There's lots of money to be saved by this one step. You could be running an oven or furnace at conditions that are not needed for the process to be successful.

The control system must be properly tuned
Temperature controls at their most basic level come in three forms. These are on/off, proportional control, and PID control.

Proportional control means the burner is at some variable rate of firing that is proportional to what the difference is between the set point and the actual temperature. This means if the set point is close to the actual temperature the burner fires just a little, there is no feedback in this kind of system. When set point is reached the burner shuts down.

Most ovens and furnaces you will encounter are using some type of PID control. In this kind of system there's actually feedback, so the burner system continuously adjusts. PID stands for proportional, integral, derivative. These terms are complex mathematical functions that describe calculations that a computer makes to change how hard the burner will fire in response to a needed amount of heat to get to a set point. Having feedback means that the system will try something, see what's happening, and make changes on the fly. PID control is a very common type of control used in many applications from household appliances to industrial equipment. Your car's cruise control uses a form of PID.

Tuning a PID control loop means trying to set the control parameters to get a nice smooth temperature curve without large peaks and valleys. Your recorder can tell you all you need to know about how well your system is tuned and or responding. A nice straight temperature line is ideal. When you continuously overshoot and undershoot in a significant way you tend to waste fuel and disrupt your process.

The burners must be properly sized
Burner turndown is a burner's ratio of high fire to low fire. In many cases furnaces or ovens run in some idle mode where it's important to be able to maintain some low firing rate without overshooting.

The burner size that you have installed today may have nothing to do with what you might really need. It may be making for control system or set up compromises that are very wasteful. For example, burners that are too large may have to be set up with lots of excess air so they can get to some low BTU output at low fire. This is a big fuel waster. Having a burner that is too large also means that overshooting is probably an issue. It might be possible to change burners' orifices and or reduce air flow to reduce the effective capacity of a burner that is too large. This is a lot less cost than replacing the burner.

Making these savings last and being safe
Implementing low cost/no cost fuel reduction strategies and equipment improvements really means nothing unless they're reasonably easy to implement and sustainable. The strategies identified in this paper can be amongst the most difficult kinds of improvements to implement and sustain. Adding a new improved burner or control can be a set it and forget it type of thing. The strategies presented in this paper could require you to uncover and investigate issues that have been years in the making. Many of these items will also require an investment in human capital meaning on going attention and monitoring. It may also require documentation of conditions and training of maintenance and operations personnel.

You will be discovering new issues that will need to become a part of an ongoing preventive maintenance program to save fuel. In some cases these strategies will make the operations safer and are things that should have already have been part of the culture, (like fuel train valve leakage testing required annually by NFPA 86).

This paper scratches the surface of the furnace and oven cost savings world. There are lots of tools and resources that are publically available for those that want to deep dive the subject. One of the best sources of information we have found is the Department of Energy's PHAST program. PHAST is an acronym for Process Heating Assessment Survey Tool. This is a software tool that one can apply to get an idea of more things you can do and what the actual savings might be. This software is somewhat complex and requires training. The good news is the training is available from DOE. Our firm has two certified users who have modeled a number of client systems with great success. The training took about a week. More information on DOE's tools and PHAST can be found at:
http://www1.eere.energy.gov/industry/bestpractices/software.html

Last but not least, please make sure you don't create safety issues in an effort to try and save energy. There are things you should know about that can make for a disaster if you're not aware of how they impact oven or furnace safety. Closing off exhaust air flows for example in a Class An oven could create an explosion hazard if you're not careful.

NFPA 86, (National Fire Protection Association's Standard for Ovens and Furnaces), is the foremost guide for oven and furnace safety. It's available at http://www.nfpa.org. If you own or operate ovens and furnaces it's a must. Stop what you're doing, get a copy, and read it cover to cover.

CEC Combustion Safety, LLC has been in business since 1984. With engineers and staff members that sit on Code committees such as *ASME CSD-1, NFPA 56, NFPA 85, NFPA 86*, and *NFPA 87*, our inside expertise is integrated within all of our practices and our global reach ensures that customers around the world are kept safe. CEC offers Testing and Inspections, Engineering & Upgrades/Retrofits, Gas Hazards Management, Training, and Field Services for all industrial facilities and different types of fuel fired equipment. By assisting organizations and their personnel with the safe maintenance and operation of their combustion equipment, CEC aims to save lives and prevent explosions while increasing efficiency and reliability of combustion equipment. Contact CEC at +1 216.749.2992 or visit www.combustionsafety.com for additional information.