Track: Industrial

Unit 11: Visit to Metal Processing Pant

What to Look For and What to Recommend To Improve Energy Efficiency

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Presentation Content and Flow

- Information on primary metal industry sectors (steel and Aluminum)
- Furnaces* and other heating equipment used in a plant
  - Description and function of the equipment
  - Where and how natural gas is used.
- What to look for to identify energy use and possible improvements
- What data can be collected during the plant visit and how to collect it
- Suggestions for low cost – no cost improvements
- Commonly used instruments for data collection for while visiting the equipment.
- Tools to use for detail analysis and reporting, if required

* The term "furnace" is used for description of furnace, oven, boiler, heater, etc. in this presentation

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Primary Metals Industry

- Primary metals industries include ferrous and non-ferrous metals.
- The metal industry facilities produce products for use by other industries or by the consumers.
- These facilities include
  - Metal melting furnaces
  - Casting facilities to produce semi-finished parts (slabs, billets, castings etc.)
  - Reheating and forming (rolling, forging etc.) of semi-finished shapes or parts
  - Heat treating of finished parts
  - Other heating processes

Almost all of these facilities use gas fired melters, furnaces, ovens etc.

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Major Metals Market Segments

- **Steel**
- **Aluminum**
- Metal Casting
  - Copper
  - Zinc
  - Lead
  - Magnesium

This presentation includes discussion on facilities for steel and aluminum industry in North America

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Steel Industry Facilities

- Two types of facilities are used for production of steel in USA
  - Integrated mills: Use blast furnace to produce pig iron, BOF to produce steel which is cast and rolled into products. .
  - Minimills: Use electric arc furnace (EAF) to produce steel from the steel scrap and other raw materials (i.e. direct reduced iron, hot metal etc.) which is cast and rolled to produce many products.

- There are nine to ten operating integrated mills located in Pennsylvania, Ohio, Michigan, Indiana and Alabama.
- There are more than 125 mini mills using EAFs. They are scattered all over the USA.

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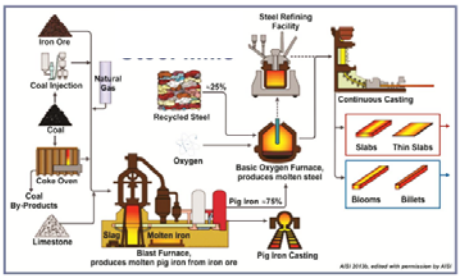
Integrated Steel Mill



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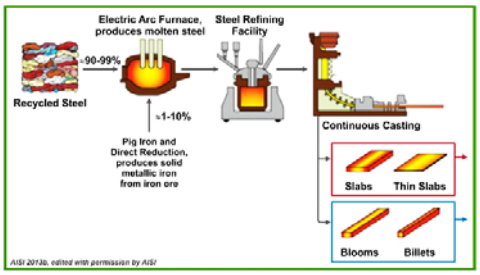
Mini Steel Mill



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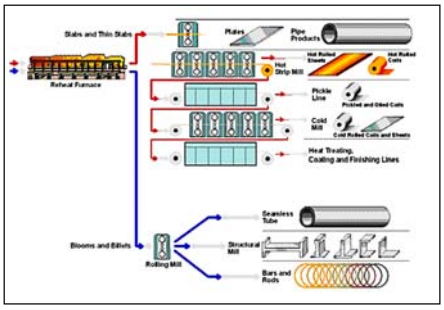
Steel Mill Primary Products



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Use of Natural Gas in Steel Making

Natural gas is used in the following processes/equipment in steel making.

Sintering and pelletizing process	Electric Arc Furnaces (EAF)
Blast furnace natural gas injection	Basic oxygen furnace (BOF)
Blast furnace air stoves to preheat blast air	Steel reheating furnaces – rolling
Tundish and molds heating	Annealing furnaces (Batch/continuous)
Ladle heating	Heat treating of semi-finished or finished steel
Coke ovens	Galvanizing/coating lines
Boilers	Other heating processes

Note: In most cases natural gas is used as supplemental or self standing fuel

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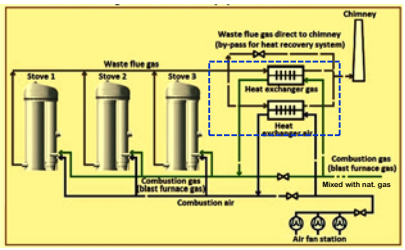
Blast Air Heating Stoves



- The stoves are used to preheat air used in a blast furnace
- They use Blast Furnace Gas (BFG), Coke oven Gas (COG) and natural gas as fuel.

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Coke Oven Battery Burners

- Coke oven batteries use by product gas (coke oven gas and blast furnace gas mixed with natural gas).
- COG produced from ovens is used as fuel in the steel mill equipment (blast furnace, boilers, and many furnaces).
- Use of coke oven installation is reducing-disappearing in USA due to environmental concerns and cost of operation.

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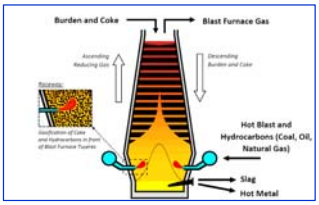
Natural Gas Injection - Blast Furnace



- Natural gas injection is not very common in USA.
- It is often used to reduce use of coke and/or increase productivity.
- Incentives to reduce CO2 emissions is a driver for use of natural gas.
- This presents a major opportunity to increase natural gas use in integrated mill.

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Steam Boilers

- Steam boilers and turbines are mostly used to generate electrical power in integrated steel mills.
- The boilers use by product gases (blast furnace gas – BFG and coke oven gas - COG) often mixed with natural gas as needed to maintain the steam production.
- Most boilers will have natural gas fired pilot burners.

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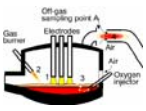
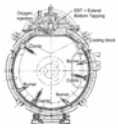
Electric Arc Furnace (EAF)





- EAFs use mostly steel scrap as charge material to produce molten steel.
- The molten steel from EAF is refined and cast as primary product.
- EAF uses electricity as major source of energy for melting the scrap with natural gas as supplemental fuel.
- Almost 2/3rd of total steel production in USA is by EAF process.

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Electric Arc Furnace (EAF)
Use of natural gas in oxy-fuel burners

Use of oxy-fuel burners

Courtesy: Homepage - MORE S.r.l. (more-oxy.com) ,

- EAFs use natural gas as a supplementary fuel in oxy-fuel burners to increase productivity of the furnace
- Natural gas supplies 5% to 10% of the total heat input to the EAF. This may amount to 15 to 25 MM Btu/hr.
- Oxygen is used in oxy-fuel burners for combustion of natural gas in EAF

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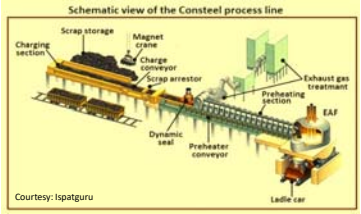
EAF Scrap Preheater



- Scrap preheating using EAF off gases
- This and other similar systems uses natural gas burners for supplemental fuel.

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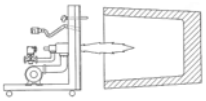
Ladle and Tundish Preheater – Dryer



- Ladle and tundish dryers and preheaters use natural gas burners
- A variety of burners (flat flame, high velocity, preheated air etc.) are used for preheaters.
- This is major natural gas user in a melt shop.
- Although often recommended, use of combustion air preheating is rarely used.

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Steel Processing - Natural gas Equipment

Reheat Furnaces (continuous or batch)

Annealing/Coating

Heat treating and auxiliary equipment

- Atmosphere furnace
- Direct fired furnace – oven
- Atmosphere generator

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Steel Reheating Furnaces

- Steel reheating furnaces are the single largest natural gas user equipment in most steel plants – integrated or minimill.
- They use combination of BFG-COG and natural gas in integrated plants while only natural gas in minimills.
- Reheat furnaces are used to heat the steel products (slabs, billets, ingots etc.) to about 2200^0F before hot rolling.
- Many different types of furnaces are used. They include walking hearth, walking beam, roller hearth, pusher type, rotary furnaces etc.
- All of these furnaces have multiple zones: preheating, heating and soak zones and they use gas fired burners.
- These furnaces use some type of flue gas heat recovery device, mainly recuperators or regenerative burners

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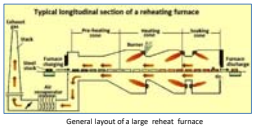
Steel Reheating Furnaces



General layout of a large reheat furnace

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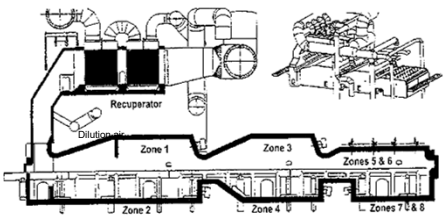
Typical Recuperator Installation
Steel Reheat Furnace



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Batch – Box Annealing Furnace

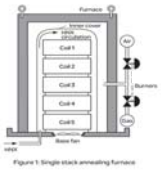

Figure 1: Single stack annealing furnace

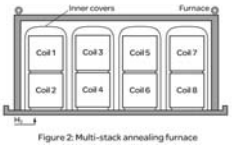

Figure 2: Multi-stack annealing furnace

- Batch or box annealing furnaces are used for strip coils and wire coils to anneal the steel.
- The coils are heated in non oxidizing atmosphere (exo thermic gas) and hydrogen in some cases.
- The modern furnaces use direct fired burners and use natural gas as fuel
- In some old plants the furnaces use radiant tubes and BFG or COG as fuel.

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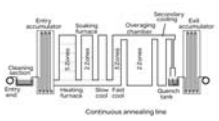
Continuous Annealing Line (CAL)



Continuous annealing line

- Continuous annealing lines (CAL) are used to anneal the metal strip from a coil.
- The CA line includes a metal cleaning section, a furnace, winding and unwinding equipment, accumulator etc.
- They are used for very high production rates (about 1 million tons per year) and require very large investments.
- CAL equipment is used by only a few integrated mills in USA.

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Metal Casting and Forging Facility

Equipment Using Natural Gas

Forging Plant

- Reheating forge furnace
  - Gas fired furnace
  - Induction furnace
- Heat treating (stress relieving) furnace
- Steam generator (boiler) for hammers – if used

Metal Casting

- Melting process
  - Cupola: air preheater, thermal oxidizer
  - Induction: scrap preheating
  - Electric arc furnace: gas burners, scrap preheater
- Ladle heating
- Sand and mold dryer
- Heat treating furnaces
- Misc. heating (i.e. troughs heating etc.)

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Heat Treating Facility Commercial and Captive

- Heat treating furnaces
  - Batch furnace:
    - Direct fired or radiant tube
    - Various configurations
  - Continuous furnace:
    - Direct fired or radiant tube
    - Roller hearth, belt type etc.
  - Induction heating facility
- Atmosphere generator: Exothermic, endothermic
  - Endothermic generators use natural gas as fuel and as a reactant to produce the atmosphere.
- Vacuum furnaces
- Immersion or other type of heaters for parts washers etc.

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Heat Treating
Fuel (Natural Gas) Fired Equipment


Integral Quench Furnace


In-ground pit furnace


Exothermic gas generator


Continuous Furnace


Car bottom furnace

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Aluminum Industry

- Two types of facilities used for production of aluminum
  - Primary aluminum plants. These plants produce aluminum metal from Bauxite and require electricity as main source of energy.
  - Secondary aluminum plants: These plants use aluminum scrap melting in gas fired furnaces to produce liquid aluminum and aluminum products.

- There are five primary aluminum plants (may be six) operating in USA.
- There are many (>100) secondary aluminum melting facilities in USA.
- Secondary melting facilities are scattered all over the US serving all major industries.

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Equipment in Secondary Aluminum Facilities

- Charge or scrap dryer – preheater.
- Thermal oxidizer (if used)
- Melting furnace
- Ladle or trough heating
- Homogenizing furnace
- Annealing furnaces – ovens
- Aging oven
- Coating line (for specialty plants).
- Other heating equipment

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Charge or Scrap Dryer - Preheater

Conveyor type scrap dryer and preheater

Traveling sow preheat furnace.

- The dryer - preheater uses gas burners.
- In some cases furnace exhaust gases are used to supply heat

Courtesy: Inductotherm corp.

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Crucible Furnaces

2000 # Electrical Crucible Furnace

1000 # Gas Crucible Furnace

- Crucible furnaces are used in batch operation
- Used for plants producing relatively small parts
- Heating, melting and alloying done in the same crucible.

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Barrel – Rotary Furnace

- Barrel or rotary furnace has been used by die-casting and other automotive parts industry for melting of scrap castings, extrusion scrap, UBC, and dross processing.
- The furnace is available in capacities ranging from 5 MT to 10 MT, and melt rates of 0.5 MT/hour to 1.5 MT/hour
- The furnace uses natural gas with a variety of burners and air-fuel ratio control
- It is fairly efficient with use of 1500 to 1800 Btu/lb. energy use. The melt loss is in the range of 1.5% to 3%.

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Reverbatory Furnaces

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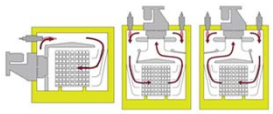
Aluminum Homogenizing Furnaces



- These are batch type furnaces used to homogenize the aluminum alloying elements within the parts
- They use large internal fans to recirculate furnace gases and provide uniform heating of the parts
- Direct fired natural gas burners are used to supply the heat. The combustion products are mixed with the recirculating gases.

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Aluminum Annealing furnaces

Coil annealing multi zone furnace.

- These are batch type furnaces used to anneal (soften) the metal.
- The furnace atmosphere is nitrogen and/or exothermic gas.
- Heat is supplied by radiant tubes which use natural gas burners. The combustion products are NOT mixed with the recirculating gases.
- They use large internal fans to recirculate furnace atmosphere and provide uniform heating of the parts

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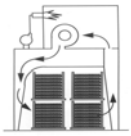
Aging Oven for Aluminum Parts



- These are batch type ovens used to heat the aluminum parts to accelerate aging process at relatively low temperature in the range of 400^0F to 800^0F.
- They use external fans to located in a "fire box" located, usually, on the roof of the oven.
- The fan recirculates furnace gases within the oven for uniform heating of the parts
- Direct fired natural gas burners are used to supply the heat. The combustion products are mixed with the recirculating gases.

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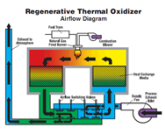
Coating Ovens and Thermal Oxidizers



- Continuous coil coating systems are used to coat paint or similar coatings on aluminum surfaces, usually unrolled from a coil.
- The systems are found in large aluminum finishing plants.
- The system includes coil handling system, a coating system, an oven with several zones and a thermal oxidizer.
- They use direct fired burners with gas recirculating system using fans

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What is it?
A furnace, An oven, a heater or....?

- In the following slides all gas fired equipment such as a melter, furnace, oven, heater, boiler etc. are represented by the word “Furnace”.
- They all have certain common sub-systems or components as represented in a generalized diagram.
- Try to use proper identification term (i.e. furnace, oven, melter, boiler etc.) while communicating with the plant personnel.

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Plant Visit and Actions

Information presented in the following slides is applicable to all industrial plants including steel and aluminum plants

- **What to look for to identify energy use/loss/waste and possible improvements**
- **What data can be collected during the plant visit and how to collect it**
- **Suggestions for low cost – no cost improvements**
- **Commonly used instruments for data collection for while visiting the equipment.**
- **Tools to use for detail analysis and reporting, if required**

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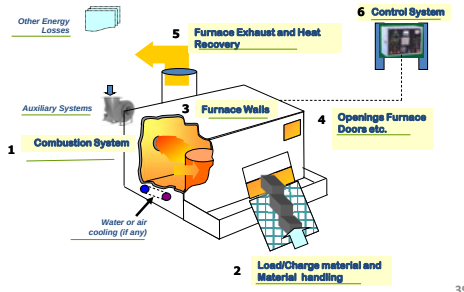
A Furnace - Areas to Look For



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Load – Charge Observations and Suggestions

- Moisture content of the load material
  - Keep it to minimum possible.
- Load temperature
  - Preheated load saves energy. Investigate possibilities of using waste heat to preheat the load
- Loading rate vs. rated capacity
  - Keep the furnace loading at or close the rated capacity as much as possible.
- Reduce the fixture-conveyor weight
  - Consider options and consider use of alternate material, design (cast vs. fabricated) etc.to reduce weight
- Fixture/conveyor temperature
  - Return the fixture/conveyor at the maximum practical temperature

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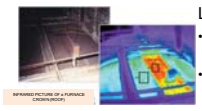
Furnace Walls and Piping



Look for

- Hot spots on the walls, around the burners and other locations.
- High wall temperature. Depending on the furnace temperature, it is considered too high if is higher than 100^{0}F to 250^{0}F.
- General condition of insulation inside the furnace. Cracked refractory, broken and loose wool indicate need for immediate repairs.
- Insulation condition for hot air piping, hot flue gas ducts, fan housing etc. They all need to be insulated with surface temperature within 200^{0}F to 300^{0}F.
- Broken insulation or lack of insulation on water cooled components located within the furnace

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Furnace Openings

Look For

- Furnace door: is it open too long and too far during charging or discharging of load ?
- Hot gas leaks or cold air entering the furnace around the doors indicating lack of proper seal between the furnace walls and the door.
- Furnace openings (such as observation ports, sampling ports etc.) in the walls - unused or not properly closed.
- Broken seals or lack of seals around the rollers or other parts as indicated by overheated areas.
- Open top (uncovered) hot metal transport ladles or crucible furnaces whether they contain liquid metal or not

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Water Cooled Parts

- Water cooled skid pipes and beams in steel reheating furnaces
- Water-cooled rolls in roller hearth furnaces
- Water-cooled panels in electric arc furnaces
- Water-cooled shell for vacuum furnaces

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Furnace Wall Heat Loss

Low cost or No Cost Suggestions

- Repair or replace damaged – broken insulation inside the furnace.
- Reduce radiation losses by eliminating, partially closing furnace openings.
- Use covers or other devices (e.g., radiation shields) to minimize radiation and convection losses from ladles, crucible furnaces etc. .
- Monitor furnace pressure (draft) and reduce stack opening as a first step where possible. Use draft control to eliminate or reduce furnace leakage (cold air into *or* hot gas out).
- Repair cracks, openings, seals around burner blocks, radiant tubes in the furnace walls, rolls etc.
- Maintain seals (usually water cooled) around walking beam mechanisms
- Reduce cooling losses by insulating water or air-cooled parts (rolls, skids, support beams etc.) in furnaces – particularly steel reheating furnaces.
- Consider use of optimum insulation (type and thickness) during relining of the furnace walls. Use fiber insulation where possible.

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Furnace Exhaust Area

- Check for
  - Use and location of exhaust gas temperature measuring device such as a thermocouple. Ask or check whether it is shielded or “exposed”.
  - Use of furnace pressure controller installed in the exhaust gas duct or stack
  - Presence of other devices such as oxygen probe or other type of probes.
  - Flue gas temperature control system that limits flue gas temperature entering a recuperator or other type of heat recovery system.
- Monitor or measure flue gas temperature from the furnace before gases are mixed with cold air or discharged.
- Monitor or measure flue gas oxygen and combustibles (CO, hydrocarbons etc.) content as they leave the furnace

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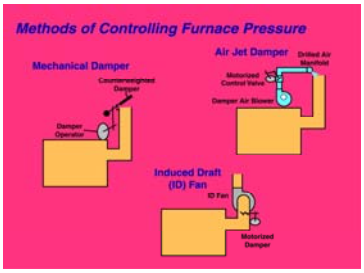
Reduce Heat Loss With Furnace Draft Control



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Heat Recovery Systems

- Look for a heat recovery system at the exhaust end of a furnace-oven-boiler.
  - Recuperator installed on the furnace to preheat combustion air.
  - Regenerator such as a heat wheel to preheat combustion air.
  - Heat exchanger or regenerators for preheating of oven exhaust gases using exhaust gas heat from a thermal oxidizer.
  - Boiler economizer to heat feed water.
  - Load or charge preheater – use of exhaust gas heat
  - Use of hot gases from one furnace to another furnace or oven operating at lower temperature (heat cascading).
  - Other type of heat recovery system (i.e. heat pipe, water heating, plant air heating etc.)

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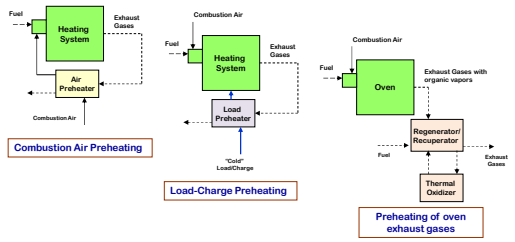
Commonly Used Methods



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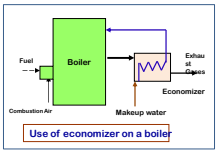
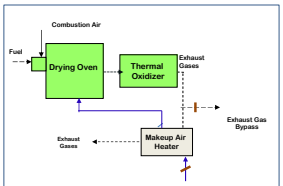
Commonly Used Methods



Use of economizer on a boiler



Makeup air heating for an oven

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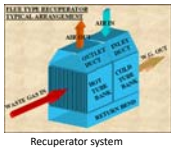
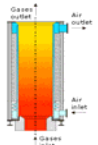
Recuperator and Other Heat Exchangers

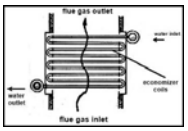


Recuperator system

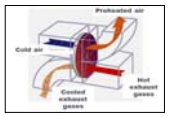
Heat exchanger - recuperator



Radiation recuperator



Boiler economizer



Heat Wheel type heat exchanger

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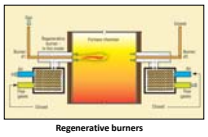
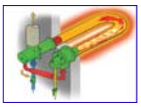
Heat Recovery – Burner Combination Systems



Regenerative burners

Self recuperative burner



Recuperative radiant tube burner

- Integrated burner – recuperator system
  - Regenerative burners: They use combination of two burners and regenerators that preheats combustion air.
  - Self recuperative burners: Combustion air heater is integrated within the burner itself.
  - Recuperative radiant tube burners: Combustion air is heated in a recuperator inserted within the exhaust end of a radiant tube.

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Components of a Combustion System

- **Burners – Heat sources**
  - Gas fired burners,
  - Radiant tubes,
  - IR burners (Radiant, Catalytic etc.)
- **Combustion air supply**
  - Air blower
  - Burner air supply control (valves, flow meters etc.)
  - Interlock equipment
  - Other components associated with process control
- **Natural gas (fuel) supply**
  - Pressure regulators
  - Safety system such as shutoff valves, vent valves etc.
  - Fuel flow control valves etc.
  - Other components related to process control
- **Process & safety specific components**
  - Flame supervision system
  - Flue gas recirculating system
  - Oxygen injectors
  - Other process specific components

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Type of Burners

- Metals industry heating equipment use nozzle mix burners with separate air and gas connections.
- High temperature furnaces such as steel reheat furnaces, aluminum melting furnaces use preheated air burners including regenerative burners.
- There are many different designs of burners such as high velocity burners, flat flame burners, low NOx burners, regenerative burners, self recuperative burners etc.
- Burner firing capacity varies from a few (~2) MM Btu/hr. to tens(~50) of MM Btu/hr. firing rate depending on the type and size of the furnace.

- It is difficult to identify the burner type from outside.
- Look inside the furnace to observe the flame shape to identify the burner type.

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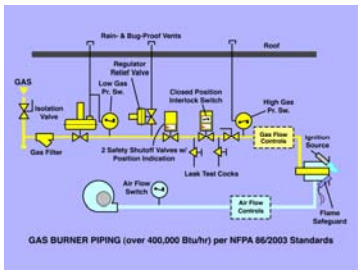
Burner Air and Gas Supply



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Burner Air-Fuel Ratio Control

- Constant air (or excess air) system:
  - Air flow is constant and only gas flow changes to meet the furnace – oven heat demand
- On or near "ratio" control. Air and gas flow change to maintain the set ratio of air and gas flow
  - Air-gas linkage type valve operators
  - Use of ratio regulator
  - Mass flow ratio control
  - Flue gas oxygen based control
- *These are described and discussed in presentation on burner control*

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Combustion System

Low cost – No Cost Recommendations

- Adjust burner air-fuel ratio control system to maintain near Stoichiometric combustion - usually less than 2% O_2 in combustion products or about 10% excess air for natural gas burners
- Avoid presence of excessive (usually >10 ppm) combustibles such CO, combustible hydrocarbons (HCs) s etc.).
- Avoid use of excess air burners where possible. Replace the burners and control system with ratio type system where possible
- Control make-up air to minimum required for the application where it is necessary for safety reasons.
- Preheat combustion air for high temperature processes
- Use O_2 enrichment where economical based on energy savings, productivity gains, etc.
- Control flame size, shape to ensure complete combustion within the furnace.

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Combustion System

Low cost – No Cost Recommendations

- Avoid air leaks in the furnace . This could use up lot of heat.
- Install an oxygen monitoring system in exhaust gas area and check it regularly.
- Use mass flow ratio control system, particularly when preheated combustion air is used.
- For large furnaces (>~50 MM Btu/hr. firing rate) consider using flue gas oxygen based control system.
- Calibrate the ratio control system at least two times a year – at change of season in cold weather parts of the country.
- Take combustion air from within the plant rather than using outside ambient air. However be aware of possibility of creating negative pressure in the plant!
- For all types of burners, particularly radiant tubes, tune the burners to avoid soot formation.
- Check for 'jumpered" switches or other mechanical parts. This is **ABSOLUTELY NO....**

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Commonly Used Controls

- Furnace zone temperature control:
  - Simple furnace zone temperature monitoring based
  - Product temperature based
  - Advanced computer model or simulation based of various types and
- High (over) temperature limit control
- Burner supervision (flame detection and failure) or burner combustion supervision control to detect flame or burner failure control.
- Furnace pressure control
- High – low gas pressure detection and related controls
- Low air pressure detection and related control
- Burner air-fuel ratio control
- Process and product specific controls
- Other controls related to material handling, recuperator excess temperature, oven atmosphere (LFL) control etc. ,

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Flue Gas Analysis and Temperature Measurement

Combustion analyzer and gas temperature measurement .

- Select a straight section of the duct/pipe or stack fro sampling location
- Avoid being close to bends or other restrictions.
- Measure flue gas temperature
- Take flue gas analysis: oxygen, CO, hydrocarbons etc.
- Measure emission of NOx and SOx
- Most instruments have printout of the results and data storage.
- Collect data under “steady state “ operation of the furnace

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Noncontact Temperature Measurement

- Noncontact or remote measurement of temperature
  - Wall surfaces
  - Furnace interior
  - Load temperature
  - Fixtures, baskets, tubes etc.
- These instruments require adjustment for emissivity of the “targeted” object.
- The instruments may offer several other features including downloadable data and images for further processing

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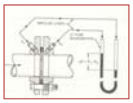
Flow Measurement



Measurement for

- Fuel (gas, oil, coal etc.) and combustion air
- Cooling water and air
- Steam or heating liquid
- Process atmosphere
- Process liquid being heated or treated
- ***In some cases flow measuring devices may be already installed and the readings may be available locally or in the control room***

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Furnace Draft – Pressure Measurement

Digital pressure measuring instrument

- A digital draft gage is used to measure static pressure or differential pressure for combustion system (air, gas etc. and their flows).
- Requires calibration using a more basic device such as an inclined tube manometer.
- Lot more convenient for use in the field.
- An inclined tube manometer cab be used inside the plant, close to a furnace or stack with some care.

Conventional draft gages

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Data Collection for Detail Energy Assessment

1. Furnace zone temperatures
2. Charge – load data (type, mass, inlet and outlet temperature)
3. Fixture data (type, mass, inlet and outlet temperature)
4. Process characteristics (vaporization, melting, reactions etc.)
5. Combustion air or O2 data (temperature, O2 content if enriched)
6. Ambient condition data (temperature) at air inlet
7. Air and gas flow rate readings if available
8. Air temperature at or near the burners
9. Flue gas analysis and data (temperature, O2, CO2 etc.)
10. Wall temperatures and dimensions
11. Openings (size, shape, wall thickness etc.) and location
12. Water cooling data – if any (flow, inlet and outlet temperature)
13. Furnace pressure at critical locations
14. Atmosphere information (type, flow. Inlet and outlet temperature)

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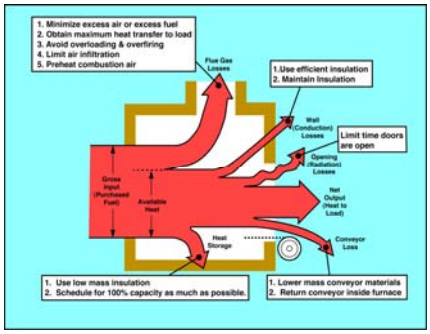
Heat Balance and Suggested Actions



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Tools for Further Analysis

- These tools can be used to conduct detail furnace analysis and generate furnace performance reports at a specific operating condition.
- These are free downloadable tools using the following links.
- Use of these tools requires some “study” or training.
- https://www.energy.gov/eere/amo/measur
- Process Heating Assessment and Survey Tool | Department of Energy
  - https://www.energy.gov/eere/amo/articles/process-heating-assessment-and-survey-tool

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Acknowledgement

Many slides used in this presentation are taken from several sources including presentations prepared by my friend Mr. Richard Bennett. Many thanks to Dick Bennett and others for their permission to allow use of the material included in this presentation.

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