Improving Thermal Efficiency for Process Heating Equipment

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What is Process Heating?

Supplying heat to materials in
• Furnaces
• Ovens
• Heaters
• Thermal oxidizers
• Dryers
• Kilns
• Boilers
• Other heating equipment
Energy Consumption and Saving Potential

Typical Energy Consumption Rates

- Process Heating/Steam Systems: 60 – 80%
- Electric Motor Systems: 8 - 15%
- Pumping Systems: 7 - 15%
- Compressed Air Systems: 2 - 7%
- Other*: < 2%

Potential Energy Saving Opportunities

- 10% to 30%
- 5% to 10%
- 10% to 20%
- 10% to 20%
- 5% to 10%

Process Heating Systems

Process heating systems use a variety of energy sources and methods of heating.

The three most commonly used systems in industry are:

- Fuel-fired heating systems that use fuel combustion to supply heat
- Electrically-heated systems (electrotechnologies) that use a variety of methods to generate and supply heat
- Steam-heated systems that use high-pressure steam to supply heat to the product or an intermediate medium, such as air, water, or other fluids
Fuel-Fired Process Heating

- In fuel-based process heating, heat is generated by the combustion of solid, liquid, or gaseous fuels, and transferred either directly or indirectly to the material.
- The combustion gases can either be in contact with the material (direct heating) or be confined and thus be separated from the material (indirect heating).
- Examples of fuel-based process heating equipment include furnaces, ovens, heaters, kilns, and melters.
- Approximately 65% of the process heating energy used in U.S. industry is based on fuel-fired systems.

Continuous Direct-Fired Furnace

The burners are fired directly in the furnace and, in most cases, the combustion products are in direct contact with the material being heated; for liquid and gas heating systems, the combustion products are in contact with the pipe or tube carrying the material.
Batch Direct-Fired Furnace

The burners are fired directly or indirectly in the furnace and, in most higher temperature (>1000°F) processes, the combustion products are not in direct contact with the material being heated. For lower temperature (<800°F) the combustion products are in contact with the product.

Indirect Heating Systems

Indirect heating using radiant tubes for a continuous heat-treating furnace

Indirect heating using radiant tubes for a batch type heat-treating furnace (Courtesy: Surface Combustion)

Radiant tubes in an indirectly heated continuous furnace

A batch type retort furnace for indirect heating of a load
Process Heating Systems – Steel Industry

Process Flow Diagram for Steel Making
Electric Arc Furnace – Mini-Mills
Process Flow Diagram – Rolling and Finishing

Process Heating System Components

- Heat Generation
  - Energy Source (fuel, electricity, etc.)
- Heat Transfer
  - Sensors/Process Controls
  - Advanced Materials
- Heat Containment
  - Crosscutting Enabling Technology
  - Design Tools/Systems Integration
- Heat Recovery
- Exhaust
  - Emission Controls of Exhaust Gases
  - Additional energy loss: Direct water injection, Indirect water cooling, Indirect air/gas cooling, Other types of losses

Material Handling

Process atmosphere

- Makeup air or process atmosphere
Steps to Improve Thermal Efficiency

- Analyze energy distribution:
  - How much energy is used and where is it going?
- Identify areas of loss or nonproductive use of energy
  - Where are the areas of heat loss?
- Estimate energy loss
  - How much energy is used or wasted as a loss?
- Identify possible energy-saving measures
  - What practical energy-saving measures can be applied to reduce or eliminate loss?
- Estimate possible energy savings
  - How much energy can be saved with application of the selected energy-saving measures?
- Analyze effects of possible energy-saving measures.
  - Are they practical? Will they have any detrimental effect on processes or other areas of operations (safety, quality)? Will they be cost-effective?
- Select appropriate energy measures and plan for application
## Data Collection Forms

### Data Collection Forms for Process Heating Energy Assessment

<table>
<thead>
<tr>
<th>No.</th>
<th>Area of energy use or loss</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Furnace information</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Load - charge material</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Furnace trays, conveyor, slag etc.</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Furnace atmosphere, make up air etc.</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Water air cooling - internal parts</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Wall losses</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Opening losses</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Exhaust gases</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Heat storage - rectangular or cylindrical furnace</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>Auxiliary power use</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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### Data Collection Form – Example

**Survey Date:**

**Plant Name:**

**Type of Furnace:**

**Type of Operations:**

**Component Name:**

**Description**

- Current condition
- Modified condition

**Type of Material (Solid/Liquid/Gas):**

- Type of Material (Solid/Liquid/Gas)

**Name of Material:**

- Name of Material

**Weight of the Load - Rate (lb/hr):**

- Weight of the Load - Rate (lb/cycle)

**Initial Temperature (Degree F):**

- Initial Temperature (Degree F)

**Final Temperature (Degree F):**

- Final Temperature (Degree F) (for Solid Charge)

**Select Name of the Liquid (SEE NOTE):**

- Select Name of the Liquid

**% Liquid in the Load as Charged (for Solid Charge):**

- % Liquid in the Load as Charged

**% Charge (weight) reacted or Feed gas reacted (for Solid Charge):**

- % Charge (weight) reacted or Feed gas reacted

**Type of reaction (Exothermic/Endothermic):**

- Type of reaction (Exothermic/Endothermic)

**Heat of reaction (Btu/lb):**

- Heat of reaction (Btu/lb)

**% Weight of material melted (for Solid Charge):**

- % Weight of material melted

**Specific Heat of vapor (Btu/(lb. deg F)):**

- Specific Heat of vapor (Btu/(lb. deg F) (for Gas Charge)

**Additional heat required (Btu/hr):**

- Additional heat required (Btu/Cycle)

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For continuous and batch operations, fill out the appropriate sections in the form.

Additional Information:

- FOR CONTINUOUS OPERATION
- FOR BATCH OPERATION
Measurement Instruments
(Pressure & Flow)

Measurement Instruments
(Temperature & Flue Gas)
Data Analysis
Process Heating Assessment and Survey Tool (PHAST)

PHAST can be used to:

• Estimate annual energy use and energy cost for furnaces and boilers in a plant
• Perform detailed heat balance and energy use analysis that identifies areas of energy use and energy loss for a furnace or a boiler
• Perform “what-if” analysis for possible energy reduction and efficiency improvements through changes in operation, maintenance, and retrofits of components/systems
• Obtain information on energy-saving methods and identify additional resources

Process Heating Assessment and Survey Tool (PHAST 3.0)
PHAST 3.0 – Access and Requirements

**PHAST version 3.0**
- The tool can be downloaded from the ORNL web site.
- [http://web.ornl.gov/filedownload?ftp=e;dir=uP23XIBaDwua](http://web.ornl.gov/filedownload?ftp=e;dir=uP23XIBaDwua)
- Select “Process Heating” and “Process Heating Assessment and Survey Tool (PHAST)” to download PHAST 3.0

**System Requirement:**
- Microsoft Office 2000 or higher with MS Access 2000 or higher.
- Certain functions (particularly import and export) do not work with MS Access 2010.
- Acrobat PDF Reader
Heat Supply, Demand and Losses
Fuel-Fired Heating System

Typical Heat Balance
for a Walking Beam Furnace EAF

Energy use:
Theoretical: 0.68 MM Btu/ton (2000 US lbs.)
Typical: Approximately 1.0 to 1.6 MM Btu/ton
Heat Supply, Demand and Losses
Before and After Energy Savings analysis

Process Heating System Revisited
Energy Saving Measures (slide 1)

1. Load - charge material
   1. Hot charging of load - charge material (external heat source)
   2. Reduce final load temperature
   3. Reduce moisture content of load
   4. Reduce load reactions (example - oxidation etc.)
   5. Avoid partial loading

2. Material handling
   1. Reduce weight of fixtures, trays, baskets etc.
   2. Return hot fixture, conveyor etc.

3. Heating (combustion) system
   1. Control of air-fuel ratio for burners
   2. Replace constant air burners by ratio burners
   3. Use of preheated combustion air: all or partial
   4. Use of outdoor air during winter in closed buildings
   5. Use of gas turbine exhaust gases for combustion air
   6. Use of alternate fuel
   7. Use of direct gas (fuel) firing to replace/supplement electric heating
   8. Use of oxygen (O2) enriched air or oxy-fuel burners for combustion

Energy Saving Measures (slide 2)

4. Flue - exhaust gases loss reduction and heat recovery
   1. Reduction of excess air or O2 in flue (exhaust) gases
   2. Combustion air preheating using flue gases
   3. Preheating of load or charge material using flue gases
   4. Use of make up air preheating - waste heat recovery
   5. Heat cascading in lower temperature processes
   6. Use heat from clean exhaust gases to heat water - use of direct contact heater
   7. Use of flue gases for HVAC or other (i.e. building) air heating
   8. Use of flue gases for fuel moisture removal (i.e. coal or bio-fuels)
   9. Use of hot flue gases for steam generation
   10. Use of waste heat (or steam) for absorption cooling
   11. Electric power generation using waste heat (i.e. ORC use)
   12. Use of regenerator system as replace or substitute recuperators

5. Wall losses
   1. Reduce wall losses - use of lighter & better insulation for the walls
   2. Reduce wind velocity (protection) for outside walls
   3. Furnace operation (shut-down and start up) schedule to reduce wall heat storage
   4. Furnace redesign to reduce hot wall surface areas
Energy Saving Measures (slide 3)

6. Openings Furnace Doors etc.
   1. Eliminate or reduce direct radiation losses from furnace openings
   2. Minimize opening or door opening times: reduce radiation loss + leakage loss
   3. Reduce heat loss due to exfiltration of gases from a furnace (Positive pressure)
   4. Reduce energy loss due to air infiltration (negative pressure)
   5. Control furnace - oven draft profile - pressure control and optimize flue size to control O2 in flue gases at turndown conditions

7. Water or air cooling (if any)
   1. Insulate internally water cooled or air cooled parts
   2. Replace water cooling by air cooling where possible
   3. Use hot water or air for absorption cooling or steam generation

Energy Saving Measures (slide 4)

8. Control System
   1. Control of air-fuel ratio (mass flow control) for burners
   2. LEL or LFL control for ovens
   3. Humidity control for a dryer
   4. Control furnace/oven pressure
   5. Model based control to assign zone set points at different operating conditions

9. Auxiliary Systems
   1. Use of variable speed drives for motors
   2. Use of fan and blower laws for energy savings
   3. Use of outdoor air in colder weather for indoor installations

10. Other measures to reduce losses
    1. Energy intensity improvement through reduction of product loss (scale, dross etc.)
    2. Upgrade to a more efficient equipment, (replacement case)
    3. Energy intensity improvements through productivity improvement
    4. Sankey diagram preparation for a heat balance
    5. CO2 reduction with alternate energy use
### Range of Energy Use and Savings Potential

<table>
<thead>
<tr>
<th>Area of energy use or loss</th>
<th>Range of energy use as % of the input</th>
<th>Range of energy savings use as % of energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load/charge material</td>
<td>15 to 75</td>
<td>0 to 25</td>
</tr>
<tr>
<td>Material handling</td>
<td>0 to 20</td>
<td>0 to 50</td>
</tr>
<tr>
<td>Heat supply/heat generation (combustion system, electric, and other)</td>
<td>N/A</td>
<td>0 to 50</td>
</tr>
<tr>
<td>Furnace exhaust and heat recovery</td>
<td>10 to 60</td>
<td>0 to 50</td>
</tr>
<tr>
<td>Furnace-oven walls</td>
<td>2 to 15</td>
<td>0 to 25</td>
</tr>
<tr>
<td>Furnace openings and doors</td>
<td>0 to 20</td>
<td>0 to 100</td>
</tr>
<tr>
<td>Water or air cooling (furnace internals – if any)</td>
<td>0 to 15</td>
<td>0 to 50</td>
</tr>
<tr>
<td>Control system</td>
<td>N/A</td>
<td>0 to 10</td>
</tr>
<tr>
<td>Auxiliary systems</td>
<td>2 to 10</td>
<td>0 to 25</td>
</tr>
<tr>
<td>Other losses (i.e. atmosphere, makeup air, ex-filtration of gases etc.)</td>
<td>0 to 50</td>
<td>0 to 50</td>
</tr>
</tbody>
</table>

Note: The exact values depend on a number of factors and they can be obtained only by conducting a good heat balance. The US DOE tool – PHAST can be used effectively to prepare a heat balance and estimate range of values.

### General Material Flow and Furnaces Used at Charter Steel’s Saukville, WI Plant

- Melting furnaces
- Refining
- Ladle – tundish heating
- Continuous casting
- Finishing (coating etc.)
- Annealing - Heat treating
- Cold rolling
- Reheating and hot rolling

In processing, they receive coils (mainly from Saukville Rolling), then they clean, anneal, and ship. They may also draw before or after annealing.
Plant Layout – Satellite View

Reheating Furnace

Size – 118 MMBtu/hr
Fuel – Natural Gas
Continuous Annealing Furnace

Furnace C2
Size – 17.6 MMBtu/hr
Fuel – Natural Gas
North Annealing Furnace
Furnace 5
Fuel – Natural Gas
Size – 10.2 MMBtu/hr

North Annealing Furnace
Furnace 2
Fuel – Natural Gas
Size – 10.4 MMBtu/hr
South Annealing Furnace
Furnace 41
Fuel – Natural Gas
Size – 10.2 MMBtu/hr

Demonstration
PHAST 3.0

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SAVE THE DATE
Process Heating In-Plant Training (INPLT) Event

CHARTER STEEL
Host Site at 1658 Cold Springs Road, Saukville, WI

January 19 to 22, 2015
(Process Heating Energy Saving Assessment Jan. 19 to 21 and In-Plant Training on Jan. 22)

CONTACTS
Charter Steel Division Internal Energy Manager: Tari Emerson, (262)268-2305, emersont@chartersteel.com
DOE Technical Account Manager: Sachin Nimbalkar, (865.946.1548), nimbalkarsu@ornl.gov

Questions and Answers
## Furnace Information

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Furnace Type</th>
<th>Location</th>
<th>Equipment #</th>
<th>Capacity (MMBtu/hr)</th>
<th>Operating Hours per Year</th>
<th>Production Capacity (Tons/year)</th>
<th>Ports Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reheat Furnace (Billet)</td>
<td></td>
<td>C2</td>
<td>17.54</td>
<td>8424</td>
<td>28,000</td>
<td>not flue</td>
</tr>
<tr>
<td>2</td>
<td>Continuous Annealing Furnace</td>
<td>Process, P3</td>
<td>5</td>
<td>10.20</td>
<td>8420.85</td>
<td>10,207</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>North Annealing Box furnace (2, 4, 5, or 6)</td>
<td>Process, P2</td>
<td>41</td>
<td>10.20</td>
<td>8420.85</td>
<td>10,207</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>South Annealing Furnace (41, 42)</td>
<td>Process, P1</td>
<td>2</td>
<td>10.40</td>
<td>8420.85</td>
<td>8,667</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>North Anneal (Salem) 2</td>
<td>Process, P2</td>
<td>2</td>
<td>10.40</td>
<td>8420.85</td>
<td>8,667</td>
<td></td>
</tr>
</tbody>
</table>

### Furnace Information

**North Anneal Furnace 2:**
Rough dimensions: 19’ x 18’ x 20’
10.4 MMBtu/hr

**North Anneal Furnace 5:**
Rough dimensions: 19’ x 18’ x 22’
10.2 MMBtu/hr

**South Anneal Furnace 42:**
Rough dimensions: 17’ x 15’ x 15’
10.2?? MMBtu/hr

**Continuous Anneal 2:**
Rough dimensions: 286’ L x 14’ 4’’ W x 16’ 3’’ H
18.51 MMBtu/hr