Overview of Waste Heat Recovery for Power and Heat

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Waste Heat Recovery for Power and Heat Workshop
Chicago, IL
September 29, 2010
A Brief and Broad Overview

• Later presentations will provide more detail.
• Weblinks in this PPT provide more information.

• Outline of this presentation
  • Where Do You Look for Opportunities?
  • What Can You Do With the Heat?
  • How Do You Do It?
    • Basic Concepts of Waste Heat Recovery and WHTP
  • What Equipment Is Used?
    • System Components
    • High Temperature CHP
    • Low to Medium Temperature CHP
Where Do You Look?
Examples of Waste Heat Sources

Waste heat opportunities at a wide range of projects

- Many industrial, but also commercial and institutional sites
- From low to high temperatures (~200°F to 3000°F)

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<tr>
<th>Condensate</th>
<th>Distillation</th>
<th>Fluid Heating</th>
<th>Gas Turbine Exh</th>
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<td>Drying, Baking &amp; Curing</td>
<td>Cement</td>
<td>Heat Treating</td>
<td>Fume Incinerators</td>
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<td>Cooling Water</td>
<td>Steam Boiler Exh</td>
<td>Coke Ovens &amp; Calcining</td>
<td>Metals Manufacturing, Furnaces</td>
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Temperature Range:
- 200°F
- 1000°F
- 2000°F
- 3000°F
High Temperature Opportunities
About 1000°F and Greater

Examples:
• Metals Manufacturing and Reheating (Steel, Al, Ni, Cu, Zn, Si…)
• Glass
• Coke Ovens and Calcining
• Fume Incinerators

Plus high ends of
• Turbine & engine exhausts, heat treating furnaces, drying & baking ovens, cement kilns
Low & Medium Temperature Opportunities

Up to About 1000°F

Examples:

• Turbine, Engine and Boiler Exhausts
• Distillation Columns
• Drying, Baking and Curing Processes
• Cooling Water from Industrial Processes

Plus low ends of

• Heat treating furnaces and cement kilns
What Do You Do With It?
Examples of End Uses

- Steam Generation and Process Heating for Industrial Processes
  - e.g. Steam use at paper mill or refinery
- Plant or Building Heating
- Electricity Generation
- Hot Water Heating
  - Commercial, Industrial & Institutional
- Cooling and Chilling
  - Commercial, Industrial & Institutional
How Do You Do It?

Concepts: Passive vs. Active Systems

• Passive Systems
  • Do not require significant mechanical or electrical input for their operation
  • Transfer heat from a higher temperature source to a lower temperature stream.
  • Example: Heat exchanger to transfer heat from exhaust air to preheat supply air

• Active Systems
  • Require the input of mechanical or electrical energy
  • “Upgrade” the waste heat to a higher temperature or to electricity
  • Examples: Industrial heat pumps, Rankine cycles
In evaluating a project, consider in order

1. Energy efficiency
   e.g. Insulation, reducing leaks, high efficiency burners, etc.

2. Passive heat recovery strategies
   i. Recycling energy back into the same industrial process.
      e.g. using a kiln’s exhaust to preheat its load
   ii. Recovering energy for other on-site uses
      e.g. using a furnace’s exhaust as a heat source for a nearby dryer.

3. Heat recovery by active systems
   e.g. CHP, heat pumps, and absorption technologies.

Consider most cost effective and simplest first.
Basic Concepts

What to Look For in Screening & Analysis

- Factors affecting cost effectiveness and feasibility include
  - Temperature (i.e. Quality)
  - Flow rate of heat source
  - Matching heat source and end uses
    - Heat source is available at times when it can be used
    - Quantity of heat source and uses are similar
  - Proximity of heat source and end uses
    - e.g. Exhaust duct is located near supply duct
  - Opportunity to “cascade” recovered heat in multiple uses
  - Exhaust composition
    - Clean or particulates, corrosive, abrasive, slagging, sticky, or oily
The Importance of Temperature

- Temperature largely determines the most appropriate technology and end use.
  - For example, in CHP systems
    - Steam cycle is conventional high temperatures
    - But other technologies must be used at lower temps

- Temperature ranges often classified as
  - High - 1100°F and greater
  - Medium – 400°F to 1100°F
  - Low – 80°F to 400°F

(Others sometimes define ranges differently.)

The Importance of Exhaust Characteristics

- Many waste heat sources pose challenges:
  - Particulate-laden
  - Corrosive
  - Abrasive
  - Slagging
  - Sticky
  - Oily

- Some of these challenges can be overcome
  ....strategies→

The Importance of Exhaust Characteristics

• Difficult exhausts do pose financial and technical issues.
• But consider possible strategies:
  • Filtration Systems
  • Material Selection
e.g. corrosion resistant “duplex steels” or TFE coatings
  • Heat Exchanger Design
e.g. provide access for to heat transfer surfaces for cleaning
e.g. ensure passages are large enough
  • Surface Cleaning with Soot Blowers, Acoustic Horns & Pulse Detonation
  • Mechanical Surface Cleaners
  • Automatic Wash Cycles
e.g. heat recovery from sticky exhaust of Tree Top apple dryer
• Example: Port Arthur Steam Energy’s CHP system at calcining plant uses acoustic horns to handle particulate-laden exhaust

PASE:  www.integralpower.com/portarthursteam.html
TFE and other coatings: http://www.haward.com/xylanandtfe/
Waste Heat Recovery System Components

For low to high temperature heat sources

• Heat Exchangers
• Power Generation Equipment
  • For example: ORC turbine, Steam turbine
• Auxiliary Equipment
  • For example, pumps and fans
  • Equipment for handling difficult waste heat sources

For low temperature heat sources

• Heat Pumps & Absorption Units
Most Systems Have Heat Exchangers

Heat Exchanger Terminology

- Two general ways of classifying heat exchangers
  1. By physical configuration and fluid flows
  2. By typical use or function

- Intermixing these classifications is common, sometimes causing confusion.
Classification of Heat Exchangers

One way of classifying heat exchangers is

- By physical configuration
  - Shell-and-Tube
  - Concentric Tube
  - Plate-and-Frame
  - Finned-Tube

- … and by fluid streams between which heat is transferred
  - Gas-to-Gas
  - Gas-to-Liquid
  - Liquid-to-Liquid
Example of Physical Configuration
Terminology

Shell-and-tube air-to-water heat exchanger

“Shell-and-Tube”
- Bundle of tubes within a cylindrical shell

“Air-to-Water”
- Air is on one side
- Water is on the other side

Other terminology may indicate what is on which side. For example,
- “Fire Tube Boiler” – Water on shell side, gases on tube side
- “Water Tube Boiler” – Water in tubes

http://www.mckenziecorp.com/boiler_tip_8.htm
Heat Exchanger Terminology

• A second way of classifying heat exchangers is by **typical use**.
• These types can have various physical configurations.
• Examples:
  • **“Recuperators”**
    Typical Use: Recover heat from flue gases to heat air
  • **“Economizers”**
    Typical Use: Recover heat from flue gases to heat boiler make-up water
  • **“Regenerators”**
    Typical Use: Recover heat from exhaust to preheat air using thermal mass
  • **“Heat Recovery Steam Generators” (HRSG)**
    Typical Use: Recover heat for steam generation
  • **“Waste Heat Boilers”**
    Typical Use: Recover heat for hot water or steam generation.
“Recuperators” are typically used to recover or “recuperate” heat from flue gas to heat air.

- **Example: “Metalic Radiation Recuperators”:**
  - Concentric-Tube is common physical configuration
  - Used for high temperatures (>1800°F)

- **Others recuperators include:**
  - “Convective Recuperator”
    - Physical configuration is often shell-and-tube
  - “Radiation-Convective Recuperator”
Example of Classification by Use Regenerators

“Regenerators” are heat exchangers that use thermal mass (e.g. bricks or ceramic) in an alternating cycle to recover heat from exhaust to preheat supply air

- First, thermal mass is heated by the hot gas.
- Then, air to be preheated passes over the mass to extract heat

- Example: “Rotary Regenerator”
  - Mass is wheel that turns through adjacent exhaust and supply ducts

http://www.process-heating.com/Articles/Industry_News/BNP_GUID_9-5-2006_A_1000000000000000000255829
http://www.recair.nl/paginas/30-recuperator-or-regenerator.html
Active Heat Recovery

Waste heat can be “upgraded” by active systems

- Absorption Chillers and Heat Pumps
- Mechanical Heat Pumps
- Combined Heat and Power Systems

…More ➔
Absorption Chillers & Heat Pumps

- **Technology:**
  - Absorption chiller uses heat to produce chilled water.
  - Absorption heat pump uses heat source to “upgrade” a lower temperature stream to an intermediate temperature.

- Heat source can be low pressure steam, hot gas or hot liquid stream.

- Most cost effective applications:
  - Heat source of about 200°F to 400°F,
  - Need for simultaneous heating and cooling.

**Weblinks**
- [http://www1.eere.energy.gov/industry/bestpractices/pdfs/steam14_chillers.pdf](http://www1.eere.energy.gov/industry/bestpractices/pdfs/steam14_chillers.pdf)
- [http://www.leonardo-energy.org/webfm_send/180](http://www.leonardo-energy.org/webfm_send/180)
- [http://www.northeastchp.org/nac/businesses/thermal.htm#absorb](http://www.northeastchp.org/nac/businesses/thermal.htm#absorb)
Heat Recovery for Power Generation at Temperatures of ~1000°F and Above

- Steam Rankine cycle is conventional for high temps
  - Waste heat boiler recovers heat to generate steam
  - Steam is expanded in a steam turbine to generate electricity
  - Low pressure steam can be used in other processes or condensed.
Other CHP Technologies for High Temperatures

• Other less conventional technologies exist.

• Reasons for being less common include:
  • Under development, cost concerns, lack of track record for the application

• Examples:
  • Stirling engine
    • Old technology that is reemerging
    • Long used in solar applications
    • Newer Applications: Micro-CHP (e.g. WhisperGen)
  • “Heat Recovery Gas Turbine” (Brayton Cycle)
    • Just like a conventional gas turbine, except uses waste heat rather than combustion.
    • Heat exchanger replaces combustion chamber

WhisperGen - http://www.whispergen.com/
Other CHP Technologies for High Temperatures

• Examples (cont.)

• Thermoelectric Generator – Under development
  • Direct conversion of temperature differences to electric voltage. Creates a voltage when there is a different temperature on each side.
  • Similar to thermocouple and photovoltaics.
  • Can be used to recover disparate source by running wires instead of pipes or ducts
  • Takes up very little space
  • Major R&D is for vehicle heat recovery

http://en.wikipedia.org/wiki/Thermoelectric_generator
http://www.electrochem.org/dl/interface/fal/fal08/fal08_p54-56.pdf
Power Generation at Low to Medium Temperatures

- Commercialized technologies for power generation at low to medium temperatures:
  - Organic Rankine Cycle
  - Kalina Cycle

...More ➔
Organic Rankine Cycle

• Similar to steam cycle, except working fluid is a refrigerant instead of water.

• Temperatures vary depending on design:
  • Heat sources may range between 300°F and about 750°F
  • Some can use lower temp heat sources, if cooling water temperature is lower.

• ORCs have a 40 year track record.
  • Geothermal applications
  • Bottoming cycle for steam power plants

• ORC heat recovery – track record since 1999
  • Cement kilns
  • Compressor stations

• New application: District Heating
  • Hot oil – heat source for ORC
  • Return water from heating loop – cooling water of ORC

  See: http://www.cookcountylep.org/Feasibility_Biomass_7_14_09.pdf
Kalina Cycle

• Temperature range of about 200°F to 1,600°F
  • Fills temperature gap between maximum for ORC and cost effective temperature of steam cycle.

• More efficient than either steam cycle or ORC.


• An example project:
  • Sumitomo Steel in Kashima, Japan,
  • Generates 3.1 MW using 208°F hot water as its heat source
  • Operating since 1999 with 98% availability
Up and Coming for Low to Medium Temperatures

- Others technologies are under development.

- Examples:
  - **Variable Phase Turbine**
  - **Piezoelectric Generator**
    [http://www.cleanpowerresources.com/content.php?sub_section=thermoenergyconversion&name=the_thermocoustic_alternator](http://www.cleanpowerresources.com/content.php?sub_section=thermoenergyconversion&name=the_thermocoustic_alternator)
Wrap Up

• Where Do You Look for Opportunities?
  • Industrial, commercial, and institutional
  • Low to high temperature sources
  • Consider dirty and clean heat sources

• What Can You Do With the Heat?
  • Steam and process heating, space heating, electricity, hot water, cooling & chilling

• How Do You Do It?
  • Energy Efficiency
  • Passive heat recovery
  • Active heat recovery
    • Absorption chillers and heat pumps
    • Combined heat recovery
Waste Heat Recovery: Technologies and Opportunities in U.S. Industry

http://www.gulfcoastcleanenergy.org/Portals/24/Reports_studies/WHR_DOE%20ITP.pdf
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