Overview of Waste Heat Recovery Technologies for Power and Heat

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A Brief and Broad Overview Of Waste Heat Recovery Technologies

• 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 (~90°C to 1600°C)
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?

Basic Concepts: Passive vs. Active Systems

- Heat naturally flows from high to low temperature.

- Passive Systems
  - Do not require significant mechanical or electrical input for their operation
  - Transfer heat from a higher temp source to a lower temperature sink.
  - 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 and combined heat and power systems.
Basic Concepts
Analysis Strategy

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.

Why this order? 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
  • Availability over the course of the day and year
  • Exhaust composition
    • Clean or particulate laden, corrosive, abrasive, slagging, sticky, or oily
  • 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 through more than one end use
The Importance of Temperature

• Cost effectiveness generally improves with temperature

• Temperature largely determines the most appropriate technology and end use.
  • For example, in CHP systems
    • Steam cycle is conventional at 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
- Don’t rule these out out of hand.

...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 to heat transfer surfaces for cleaning
e.g. ensure passages are large enough to minimize blockages
  - Surface Cleaning with Soot Blowers, Acoustic Horns & Pulse Detonation
  - Mechanical Surface Cleaners
  - Automatic Wash Cycles
e.g. Used in heat recovery from sticky exhaust of apple dryers
- 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](http://www.integralpower.com/portarthursteam.html)
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, also
Most Systems Have Heat Exchangers

Heat Exchanger Terminology

• There are 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.

… More →
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”
- 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 fluid is on which side. For e.g.,
- “Fire Tube Boiler” – Water on shell side, gases on tube side
- “Water Tube Boiler” – Water on tube side, gases on shell side

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 preheat combustion air

  • “**Economizers**”
    Typical Use: Recover heat from flue gases to heat boiler feedwater

  • “**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 Typical 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 its 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_100000000000000255829
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 →
Mechanical Heat Pumps

• Technology:
  – Conventional refrigeration cycle, but with “high” temperature refrigerants
  – Heats supply air or water to a temperature greater than the temperature of the waste heat source (i.e. achieves a “temperature lift”)
  – Can achieve very high COPs when the temperature lift is small.

• Applications:
  – Heat recovery from waste heat streams up to about 200°F
    • Drying, washing, evaporating, distilling and cooling.
  – Hot water and steam generation for space and process heating
  – Refrigeration and cooling

• Most cost effective applications:
  – Serving simultaneous heating and cooling needs
  – Recovery from moist exhausts to recover both latent and sensible heat
    • “Sensible heat” – heat associated with temperature
    • “Latent heat” – heat associated with humidity

Photos from Nyle Corporation:  www.nyle.com
Absorption Chillers & Heat Pumps

• Technology:
  – Absorption chiller uses heat to produce chilled water.
  – Absorption heat pump uses a heat source to “upgrade” a second 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 200ºF to 400ºF,
  – Need for simultaneous heating and cooling.

Weblinks
http://www1.eere.energy.gov/industry/bestpractices/pdfs/steam14_chillers.pdf
http://www.leonardo-energy.org/webfm_send/180
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 application: 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 physics 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
  - With some designs, source temperature can be as low as ~150°F to 200°F, if low temperature cooling is available.
- ORCs have a 40 year track record.
  - Geothermal applications
  - Bottoming cycle for steam power plants
- Track record back to 1999 for industrial heat recovery
  - Cement kilns
  - Compressor stations
Organic Rankine Cycle For District Heating

• District heating is a new application of ORCs

• Example: Grand Marais Biomass District Heat & CHP
  • ORC heat source is 630°F oil heated in low pressure thermal oil heater.
  • Cooling water for ORC is 160°F return water from district heating loop
  • 175°F hot water leaving ORC’s condenser is recovered for district heating

• Advantages over district heating with steam turbine include:
  • Thermal oil heater operates at 150 psig.
    • Does not require boiler operator, reducing labor costs
  • ORCs are packaged units or skid-mounted for easy installation.

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
    http://www.energent.net/technology/variable-phase-cycle.html
  - Piezoelectric Generator
    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 both 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
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