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An Overview of Industrial Waste Heat Recovery Technologies for Moderate Temperatures Less Than 1000ºF

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Disclaimer

While the information included in this guide may be used to begin a preliminary analysis, a professional engineer and other professionals with experience in waste heat recovery should be consulted for the design of a particular project.

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Introduction

Many industrial processes require large quantities of thermal energy, much of which is eventually exhausted to the environment, either to the atmosphere or water. Recovering this waste heat represents the largest opportunity for reducing industrial energy consumption in the U.S. Since the majority of waste heat sources have temperatures less than 1000ºF, it is especially important that we implement technologies suitable for these temperatures. The old rule of thumb that industrial heat recovery is cost effective only for temperatures of at least 1000ºF is not true today with increasing energy prices, technological development by equipment manufacturers and decreasing equipment costs. This factsheet provides a general overview of technologies for recovering heat from moderate temperature sources less than 1000ºF.

Heat recovery options can be broadly classified into three strategies:

- Recycling energy back into the process
- Recovering energy for other on-site uses
- Using it to generate electricity in combined heat and power systems

Heat recovery technologies may be also be classified as either passive or active. Passive heat recovery makes use of heat exchangers of various types to transfer heat from a higher temperature source to a lower temperature stream. Passive heat recovery technologies do not require significant mechanical or electrical input for their operation, except for auxiliary equipment such as pumps or fans. Active heat recovery technologies on the other hand require the input of energy to "upgrade" the waste heat to a higher temperature or to electricity. These technologies include industrial heat pumps and combined heat and power systems.

The use of waste heat is largely determined by its temperature, with different types of equipment appropriate over different temperature regimes. Other considerations are the flow rate, its availability over the course of the day and year, and the fouling characteristics of the exhaust. Technologies and strategies to manage corrosive, abrasive, and/or fouling exhausts include material selection, heat exchanger design, automatic washers, soot blowers, acoustic horns, pulse detonation, mechanical surface cleaners, and filtration systems.

About Clean Heat and Power

This factsheet is one in a series on Clean Heat and Power. Clean Heat and Power refers to clean, efficient local energy generation, including but not limited to combined heat and power, recycled energy, bioenergy, and other generation sources that lead to a demonstrable reduction in global greenhouse gas emissions. For more information refer to:

- The Northwest CHP Technical Assistance Partnerships, http://northwestchptap.org/
- The U.S. Clean Heat and Power Association, http://www.uschpa.org

Keypoints

- Waste heat recovery strategies at moderate temperatures less than 1000ºF are more cost effective today with increasing energy prices, technological development by equipment manufacturers and decreasing equipment costs.
- In a heat recovery analysis, first consider ways to reduce the quantity of waste heat by improving the energy efficiency. Next consider passive strategies, followed by active strategies.
- The most appropriate technology depends largely on temperature. Technologies by temperature range are:
    - Energy efficiency measures: All temperatures
    - Passive heat recovery: Temperatures greater than about 200ºF
    - Industrial closed-cycle mechanical heat pumps: Temperatures less than about 200ºF
    - Absorption chillers and heat pumps: Temperatures between about 200ºF and 400ºF
    - Organic Rankine Cycle CHP: Typically 300ºF to 750ºF
    - Kalina Cycle CHP: 250ºF to 1000ºF
- Other considerations are the flow rate, its availability over the course of the day and year, and the fouling characteristics of the exhaust.
- Industrial heat pumps are particularly suited for moist exhaust streams because they can recover both the heat associated with the waste stream’s temperature (“sensible heat”) and the heat associated with its humidity (“latent heat”).

Passive Heat Recovery Strategies (For temperatures greater than 200ºF)

An investigation of heat recovery opportunities should first consider ways to reduce the quantity of waste heat that is produced by improving the efficiency of the process. Next consider passive strategies, which often have lower installation costs and generally are simpler to implement and maintain than active heat recovery strategies. Importantly, passive heat recovery strategies often can be used in conjunction with active strategies. For example, if a heat exchanger precedes a heat pump in recovering heat from an exhaust stream, the heat pump can be smaller, and so will consume less energy and require a lower first cost to achieve the same temperature rise. Another example is heat recovery downstream of a CHP turbine.

Consider passive heat recovery strategies for waste heat temperatures greater than about 200ºF. Examples of passive heat recovery are:

- Preheating boiler make-up water using a feedwater economizer
- Preheating the supply air into a process such as a food dryer by passing its supply air and exhaust through an air-to-air heat exchanger
- Preheating combustion air
- Using the flue gases from a furnace or dryer to preheat the load entering it
- Using waste heat from a process to meet other in-plant needs such as space heating, water heating, recharging the media in desiccant dehumidification, or providing heat to other lower temperature processes

Industrial Closed-Cycle Mechanical Heat Pumps (For temperatures less than 200ºF)

Industrial closed-cycle mechanical heat pumps mechanically compress a refrigerant to heat the supply air or water of a process to a temperature greater than the temperature of the waste heat source (i.e., achieve a temperature lift.) Industrial heat pumps may be used to recover heat from waste streams in a variety of processes such as drying, washing, evaporating, distilling and cooling. Industrial heat pumps can also be used to produce steam and to provide process water heating and cooling. Closed-cycle mechanical heat pumps are suitable for heat recovery from waste heat streams up to about 200ºF, depending on the working fluid of the heat pump[1]. They are particularly suited for moist exhaust streams because they can recover both the heat associated with the waste stream's temperature ("sensible heat") and the heat associated with its humidity ("latent heat"). Closed-cycle mechanical heat pumps can achieve a very high coefficient of performance (COP) when the temperature lift is small. In general, heat pumps are most cost effective where they serve simultaneous heating and cooling requirements.

[1] The minimum temperature of the heat source also varies depending on the heat pump's working fluid and can be less than ambient. For example, a heat pump used to serve simultaneous heating and cooling requirements transfers heat from a source at a temperature less than ambient and uses it to meet process or space heating requirements.

Absorption Technology
(For temperatures between 200ºF and 400ºF)

Absorption technology uses thermal energy rather than mechanical shaft energy for its operation. Absorption units are referred to as absorption chillers when used to provide air conditioning or refrigeration using waste heat as an energy source. The same technology is referred to as Type-I absorption heat pumps when used for heating. Absorption chillers/heaters are designed to switch between heating and cooling modes.

Absorption chillers and Type I heat pumps are most economical when using a waste heat source ranging from approximately about 200ºF to 400ºF, especially if there is a need for simultaneous heating and cooling. The waste heat source can be low pressure steam or a hot gaseous or liquid stream. The operating temperatures of absorption units vary depending on the working fluid. Lithium bromide-based chillers can cool down to about 40ºF, while ammonia-based chillers can cool down to about 10ºF. Type I heat pumps can have output temperatures up to about 200ºF and achieve a maximum temperature lift up to about 120ºF.

Another less common type of absorption technology is the Type-II absorption heat pump, also known as a heat transformer. Heat transformers take waste heat at an intermediate temperature that is too low to be useable and upgrade a portion of it to a higher useable temperature. A portion of the heat must also be rejected to a lower temperature heat sink. Up to about half the heat of the waste heat source can be upgraded. Heat transformers can have output temperatures up to about 300ºF. Lithium bromide based units can achieve temperature lifts of 45ºF to 90ºF from waste heat sources at temperatures of 175ºF to 200ºF.

Absorption technology is experiencing resurgence with the growing interest in waste heat recovery. U.S. manufacturers have introduced expanded lines of absorption chillers and chiller/heaters ranging from 3 tons to more than 1,500 tons.

Moderate Temperature Combined Heat and Power
(For temperatures between 200ºF and 1000ºF)

Technologies for generating electricity from moderate temperature heat sources include Organic Rankine Cycle (ORC) systems and Kalina cycle systems. With all combined heat and power (CHP) technologies, the capacity and cost effectiveness of the system will generally increase with source temperature. CHP systems for moderate temperatures have greater installation costs than reciprocating engines of the same size, but the greater installed cost may be offset by lower maintenance costs and the zero fuel costs of waste heat recovery.

ORC systems can be compared to conventional steam turbine systems, with the primary difference being that its working fluid is a refrigerant instead of water. The operating temperatures of ORCs vary depending on the manufacturers' design but typically range between 300ºF and about 750ºF. At least three manufacturers – Infinity, Pratt & Whitney (owned by UTC), and ElectraTherm – build ORC systems that can operate with waste heat temperatures less than 200°F. Typically, installed costs will range from $2,000 to $4,000 per kilowatt and can be as low as about $1,300 per kilowatt for the “HVAC-derivative” units now appearing on the market. ORCs have been used in geothermal applications and as the bottoming cycle for steam power plants for over 40 years. Industrial waste heat recovery systems using ORC turbines at cement kilns and compressor stations have been operating since 1999.

The Kalina cycle technology, distributed by Raser Technologies in the U.S., is practical over a wider temperature range – 250ºF to 1000ºF – compared to the ORC and is 20% to 40% more efficient than either an ORC or a steam turbine for temperature sources less than 1000ºF. Installed costs typically range from $2,000 to $3,000 per kilowatt. Like the ORC, the Kalina cycle has been used at geothermal plants and as the bottoming cycle of gas turbine and steam power plants. Kalina cycles using industrial waste heat as an energy source have been operating trouble-free since 1999 at a steel plant, and since 2005 at a hydrocarbon plant.

Manufacturers

Manufacturers of technologies discussed are listed below. Some manufacturers may have been inadvertently omitted and investigation of possible others is encouraged. Inclusion of a manufacturer on this list does not constitute or imply its endorsement, recommendation, or favoring by the CHP Application Center or its cooperating agencies.

Closed-Cycle Mechanical Heat Pumps and Absorption Technology

U.S. manufacturers of industrial closed-cycle mechanical heat pumps include Nyle Corporation and Colmac Coil Manufacturing. International manufacturers include Sanyo (Japanese) and Friotherm (Sweden).

U.S. manufacturers of industrial absorption technology include Broad Air Conditioning, Carrier Corporation, Cention Corporation, Energen, Energy Concepts, McQuay International, Robur, Trane, Thermax, Inc., Yazaki Energy Systems, Inc., and York International. International manufacturers and suppliers include Institute for Energy Technology (Norway) and Rinheat-Ahlstrom (Finland).

Organic Rankine Cycle Turbine Systems

Manufacturers of ORC systems available in the U.S. include Infinity Turbine, Ormat, Pratt & Whitney (owned by UTC), ElectraTherm, Cryostar, and Barber-Nichols. ORCs manufactured by Italy’s Turboden are now available in the U.S. through GPM, Inc. Other European manufacturers include Tri-O-Gen, Adoratec, Freepower and GMK.

Kalina Cycle Turbine Systems

The Kalina cycle technology is distributed by Raser Technologies in the U.S.

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