Industrial Heat-Recovery Strategies

Summary

Industrial processes use large quantities of fuel and electricity that ultimately produce heat, much of which is wasted either to the atmosphere or to water. Many types of equipment have been developed to re-use some of this waste heat. This may save up to approximately 20 percent of a facility’s annual fuel bill and, in some instances, reduce pollution emissions and plant maintenance. However, in other applications it may increase pollutants (e.g., preheating combustion air increases combustion temperatures which can increase NOx) and maintenance.

Waste heat’s usefulness is determined by its temperature; the higher the temperature the higher the quality or value. Most waste-heat-recovery devices transfer heat from a high-temperature effluent stream to a lower-temperature input stream. They can either increase the temperature of the input stream, or change the input stream from a liquid to a vapor, as in a boiler. All these devices can be broadly categorized as heat exchangers. Waste heat can also be utilized by passing hot gases or steam through a turbine, to generate electricity or to drive pumps, fans or other mechanical equipment.

Heat recovery equipment must take into account temperature and pressure ranges, corrosiveness of the effluent and input streams, presence of materials that could foul the heat exchange surfaces, and thermal cycling. Extreme values of any of these may dictate the use of special materials and design, resulting in high implementation costs. In
addition, the waste-heat source and the site for use of the recovered heat should be reasonably close.

### How This Technology Saves Energy

In a process that requires heat as an input, using waste heat can displace fuel or electricity that would otherwise have to be purchased. Of course, the waste heat must be enough hotter than the input requirements (taking into account losses in heat exchangers and in transit) that the fuel savings make up for capital and operational costs of the heat-recovery equipment.

Figure 1 is a simplified schematic of the material and energy flows for a single process. In actual industrial facilities several processes would probably exist and the potential for energy or material flows may exist between processes. In addition, heat recovery from any process output might be usable by any input.

Note that Figure 1 only indicates possible energy flows. Not all processes have economically recoverable heat. Even effluent streams with high value energy may not be useful due to contaminants. On the other hand, depending on circumstances, waste-heat recovery from one process may eliminate the need for any fuel in another process.

### Types of Energy-Efficiency Measures

There are many types of waste-heat recovery devices, designed to address common combinations of waste-stream temperatures, media and environments. The names applied to specific types of devices in this document are generally

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1 Bold-Italic words are defined in the section titled Definitions of Key Terms
consistent with field practice, but some variations do exist among industries.

This section addresses broad categories of heat exchangers: heat recuperators; regenerative heat exchangers; heat pipe heat exchangers; waste heat boilers; and gas and vapor expanders. Several specific types of devices are described within each of the recuperator and regenerator categories.

**Heat Recuperators**

*Recuperative heat exchangers* usually recover heat from the exhaust gases of a furnace, oven, incinerator or other source of medium- or high-temperature gases and transfer it to incoming combustion air. Recuperators may be classified by the relative directions of gas flow: In parallel-flow heat exchangers, both gases flow in the same general direction; in counterflow exchangers they flow in opposite directions; in cross-flow exchangers they flow at right angles to each other. Counterflow heat exchangers have the greatest effectiveness, parallel flow arrangements the lowest. Figure 2 shows conceptual diagrams of each arrangement.

Descriptions of the most common types of recuperators follow.

- **Metallic Radiation Recuperators** consist of two concentric lengths of metal tubing. The inner tube carries hot exhaust gases which radiate heat to the inner wall of the recuperator. The external annulus carries a cooler gas to be heated—usually air for combustion in a boiler or furnace. Metallic radiation recuperators have the advantage of being simply constructed and of relatively low cost. They are installed close to the point of use for the recovered heat, and they extend the life of the stack. They do, however, tend to be large. Figure 3 illustrates the construction of a metallic radiation recuperator.

Parallel flow is generally favored for radiation recuperators as the exhaust gases give up their heat faster to the low-temperature gas, extending the life of the inner shell. Some designs have two sections, the bottom one using parallel flow for quicker cooling and the upper using counterflow for greater effectiveness.

The inner shell is often of high-temperature materials while the outer
shell is usually a different, less expensive material. To account for differential expansion caused by large temperature differentials, the radiant recuperator is often suspended from a free-standing support frame, with an expansion joint between the furnace and recuperator.

- **Convective Recuperator**: Hot gases circulate through several small diameter pipes contained within a larger shell. The cooler gases pass over the pipes, absorbing much of their heat. Such units are more compact than radiation recuperators; Figure 4 illustrates construction and flow. (Note that all three types of flow configurations (parallel-, cross- and counterflow) are present in this single design).

Convective recuperators are more expensive than radiation recuperators, but are more compact and have higher effectiveness. One disadvantage is that extreme temperatures may occur in the recuperator if the lower-temperature combustion air flow is reduced due to reduced burner load. If this is a possibility, an ambient air by-pass should be provided to “waste” a portion of the heated combustion air and ensure adequate cooling of exhaust gases. Large temperature fluctuations can cause recuperator components to expand and contract, possibly leading to cracks or separations. It is vital to protect against damage, as efficiency losses may increase fuel costs by 10 to 15 percent, and rebuild costs may be as high as 90 percent of initial costs.

Ceramic tube recuperators have been developed that allow operating temperatures to 1500°F on a practical basis. They are constructed of short silicon carbide tubes with flexible seals; however, leakage of up to a few percent between fluid streams is not uncommon.
• **Vertical Tube-Within-Tube Convective Recuperator:** An alternative arrangement of the convective recuperator, in which the cold combustion air is heated in a bank of parallel vertical tubes which extend into the flue gas stream, is shown schematically in Figure 5. The advantage is the ease of replacing individual tubes, which can be done during full operation. This minimizes cost, inconvenience, and possible equipment damage due to shutdowns forced by recuperator failure. Cost is not high, but neither is effectiveness.

![Figure 5: Vertical tube-within-tube recuperator cross section (Source: Dean)*](image1)

• **Radiation/Convective Hybrid Recuperator:** For maximum effectiveness of heat transfer, combinations of radiation and convective designs are used, with the high-temperature radiation recuperator always first. These are more expensive than simple metallic radiation recuperators, but are also less bulky. A schematic diagram is provided in Figure 6.

![Figure 6: Radiation/Convective hybrid recuperator cross section (Source: Dean)*](image2)

**Regenerative Heat Exchangers**

Scavenge waste heat from gas-to-gas, gas-to-liquid or liquid-to-liquid. Heat sources can be combustion exhaust, gas turbines, reciprocating engines, chemical reactors and steam condensate.

• **Melting Furnace Regenerator:** For glass- and open-hearth steel-melting furnaces, *regenerative heat exchangers* consist of two refractory-lined chambers, often constructed of brickwork (referred to as checkerwork). While one chamber is heated by exhaust gases, combustion air is absorbing heat as it passes through the other, previously heated, chamber. A valve
directs the exhaust and combustion gases; switching the flows should be controlled for optimum effectiveness. This type of regenerator is good for high-temperature applications but is expensive to construct and takes up a large amount of space.

- **Heat Wheel:** Heat wheels, also known as rotary regenerators, are used in low- to medium-temperature waste-heat recovery. Figure 7 illustrates the application of a heat wheel. It is a porous disk fabricated from a high-heat capacity material. It continuously rotates through two adjacent ducts that carry gas streams of different temperatures. The axis of the disk is parallel to the streamflows at the partition between the ducts. As the disk slowly rotates, sensible, and possibly latent, heat is transferred to half the disk by the hot gas and from the other half of the disk to the cool gas.

The overall efficiency of sensible heat transfer for heat wheels can be as high as 85 percent. They can be as small as five feet in diameter and have been built as large as 70, with air capacities up to 40,000 ft³/min. Using multiple units in parallel may help prevent a mismatch between capacity requirements and the limited number of sizes available in packaged units. Large units are custom designed.

Heat wheels are available in four types. The first, called a packed wheel, has a metal frame packed with a core of knitted mesh stainless steel or aluminum wire. The others are called laminar wheels. One is of corrugated metal with many parallel flow passages. Another is constructed from a ceramic honeycomb matrix and is used for higher temperature applications up to about 1600°F. In the fourth variety flow passages are coated with a hygroscopic (i.e., desiccant) material so moisture may be recovered.

Heat wheels have high effectiveness and, depending on the application, may be able to recover moisture and latent heat as well as sensible heat. They are
available off-the-shelf and installation options are flexible enough that custom designs can usually be avoided. Disadvantages include the potential for cross-contamination between stream flows, the existence of moving parts and need to maintain seals between the wheel and its housing.

- **Passive Regenerator:** Composed of two sets of alternating channels, separated by thin metal walls, through which hot and cool gases travel; heat is transferred across the separating boundaries. Disadvantages include large size and relatively high cost. These units are best suited to low- and medium-temperature applications; their greatest advantage is that they are very good at preventing cross-contamination between gases. Figure 8 illustrates a typical unit.

- **Finned-Tube Regenerator:** Also known as economizers, these are gas-to-liquid heat exchangers. Cool liquid (often water) circulates through tubes with fins attached to them; the tubes are within a larger shell through which hot exhaust gases flow; the fins effectively increase heat transfer. Such units are somewhat costly but are widely used for their high effectiveness in low- or medium-temperature applications. A potential disadvantage is that they may not be usable for dirty stack gases unless a means of cleaning the fins is provided. Figure 9 shows a typical application.

- **Shell-and-Tube Regenerators:** These are similar in construction to convective recuperators, but are liquid-to-liquid heat exchangers. Baffles are normally installed parallel to the axis of the shell, causing shell-side flow along the length of the shell. With proper design, shell-and-tube units with very high effectiveness can be built. Although baffles increase both the cost and the pressure drop through the exchanger, they increase the effectiveness of heat exchange.
Advantages include wide availability of many designs and configurations, their high effectiveness in a compact package, and the existence of “off-the-shelf” units. The most important disadvantage is that repairs and maintenance can be difficult and costly.

**Heat Pipe Heat Exchanger**

Has high efficiency and compact size. Heat exchange is performed by a bundle of pipes extending through the exhaust and inlet ducts; each is a sealed element inside which is an annular wick and an appropriate fluid. (See Figure 10.)

Heat absorbed from hot exhaust gases evaporates the fluid, causing the vapor to collect in the center core. The latent heat of vaporization is carried in the vapor to the cold end of the heat pipe where the vapor condenses, giving up its latent heat. The condensed liquid is then carried by capillary (and/or gravity) action back to the hot end where it is recycled. Advantages of heat pipes are high effectiveness and compact size. They are also free from cross-contamination. The greatest disadvantage is high cost.

**Waste-Heat Boilers**

These are ordinarily water tube boilers in which hot exhaust gases pass over a number of parallel tubes containing water. The water is vaporized and collected in a steam drum for distribution to a steam load. Capacities range from less than a thousand to almost a million cubic feet per minute of exhaust gas.

Figure 11 depicts an arrangement in which exhaust gases pass over the wa-
ter tubes twice; finned tubes allow a more compact configuration. The dia-
gram shows a mud drum, a set of water tubes and a steam drum. The pressure
and rate of steam production depend on the temperature and flow rate of the
hot gases and the efficiency of the boiler. If the waste heat in the exhaust
gases is insufficient to generate the re-
quired process steam, it is sometimes possible to add auxiliary burners which
burn fuel in the waste-heat boiler or to add an afterburner. Waste-heat boilers
have the advantage of being less ex-
\pensive than installing a new combu-
sion boiler because they need no burn-
ers; their disadvantage is that they are
large and, in retrofits, it may be difficult
to find space for them.

**Gas and Vapor Expanders**

Industrial steam and gas turbines are in
an advanced state of development and readily available. Gas turbines for low-
pressure waste gases are available;
e.g., top gases of a blast furnace could produce as much as 20 MW of power,
representing 20 - 30 percent recovery of the available energy.

Of greater applicability are steam turbines
for mechanical work or driving electrical
generators. *Back-pressure turbines* are
available with allowable exit pressure op-
eration above 400 psig; *condensing tur-
bines* operate below atmospheric exit
pressures. Steam to drive the turbines
can be generated in waste-heat boilers,
but direct use of such steam in plant
processes would be more efficient.

Using turbines for waste-heat recovery
can produce mechanical or electrical en-
ergy for direct use, reducing peak loads
and saving electrical energy. However,
this comes at the cost of a high degree of
complexity and maintenance require-
ments.

**Applicability**

Heat exchangers exist for nearly every possible combination of heat source
and use. Table 1, on the next page, in-
dicates how common types are gener-
ally applied.

If multiple uses are available, the high-
est temperature uses should generally be addressed first, and other uses in
order of decreasing temperature re-
quirements. Without a heat pump, re-
covered heat can only be applied to
lower-temperature processes.

**Field Observations to
Assess Feasibility**

This section discusses field observa-
tions that can help determine the feas-
ibility of waste-heat recovery.

**Related to Applicability**

Field observations can indicate poten-
tial applications for waste-heat recover-
ery; the following list details some of the characteristics to consider. But be
aware that in-depth review needs to be
made by a qualified engineer before
likely candidates are identified.
<table>
<thead>
<tr>
<th><strong>Heat Recovery Device</strong></th>
<th><strong>Temp. Range</strong></th>
<th><strong>Typical Sources</strong></th>
<th><strong>Typical Uses</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Recuperator</td>
<td>H</td>
<td>Incinerator or boiler exhaust</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td>Convective Recuperator</td>
<td>M-H</td>
<td>Soaking or annealing ovens, melting furnaces, afterburners, gas incinerators, radiant-tube burners, reheat furnaces</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td>Furnace Regenerator</td>
<td>H</td>
<td>Glass- and steel-melting furnaces</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td>Metallic Heat Wheel</td>
<td>L-M</td>
<td>Curing and drying ovens, boiler exhaust</td>
<td>Combustion air preheat, space heat</td>
</tr>
<tr>
<td>Hygroscopic Heat Wheel</td>
<td>L</td>
<td>Curing and drying ovens</td>
<td>Combustion air preheat, space heat</td>
</tr>
<tr>
<td>Ceramic Heat Wheel</td>
<td>M-H</td>
<td>Large boiler or incinerator exhaust</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td>Passive Regenerator</td>
<td>L-H</td>
<td>Drying, curing &amp; baking ovens, exhaust from boilers, incinerators &amp; turbines</td>
<td>Combustion air preheat, space heat</td>
</tr>
<tr>
<td>Finned-Tube Regenerator</td>
<td>L-M</td>
<td>Boiler exhaust</td>
<td>Boiler make-up water preheat</td>
</tr>
<tr>
<td>Shell &amp; Tube Regenerator</td>
<td>L</td>
<td>Refrigeration condensates, waste steam, distillation condensates, coolants from engines, air compressors, bearings &amp; lubricants</td>
<td>Liquid feed flows requiring heating</td>
</tr>
<tr>
<td>Heat Pipes</td>
<td>L-M</td>
<td>Drying, curing &amp; baking ovens, waste steam, air dryers, kilns (secondary recovery), reverberatory furnaces (secondary recovery)</td>
<td>Combustion air preheat, boiler makeup water preheat, steam generation, domestic hot water, space heat</td>
</tr>
<tr>
<td>Waste Heat Boiler</td>
<td>M-H</td>
<td>Exhaust from gas turbines, reciprocating engines, incinerators, furnaces</td>
<td>Hot water or steam generation</td>
</tr>
<tr>
<td>Gas/Steam Turbines</td>
<td>M-H</td>
<td>High-pressure steam reduced for low-pressure application, waste steam</td>
<td>Generation of electrical or mechanical power</td>
</tr>
</tbody>
</table>

*Table 1. Matrix of waste-heat recovery devices and applications.*
• In evaluating a source, quantity, temperature, duration and moisture are of primary importance. The greater any of these is, the more heat will be available.

• In evaluating a possible use, desirable characteristics are reasonable proximity to the source and a need for heat when the source can provide it.

• Where significant volumes of steam are sent through pressure-reducing valves, it may be possible to replace the PRV with a steam turbine to extract work. To the extent possible, the turbine should match the steam requirements of the process. If the requirements vary, the turbine should be sized for the minimum steam load so that it can operate most of the time; excess process steam can be passed through a PRV in parallel with the turbine.

• The proximity of waste-heat uses influences total energy savings, due to heat loss in fluid transit from the source, and the energy required to move the fluid.

• Latent heat from the condensation of moisture in exhaust gas can be significant, but condensation is often undesirable due to the potential for corrosion downstream of the heat-recovery device.

Related to Energy Savings

This list identifies process input and output characteristics that can help give a relative sense of possible energy savings from waste-heat recovery.

• The greater the temperature, flow rate and moisture content, the greater the quantity of heat in the stream.

• The proximity of waste-heat uses influences total energy savings, due to heat loss in fluid transit from the source, and the energy required to move the fluid.

• Latent heat from the condensation of moisture in exhaust gas can be significant, but condensation is often undesirable due to the potential for corrosion downstream of the heat-recovery device.

Related to Implementation Cost

Flow streams that provide large energy savings generally also mean increased implementation cost—larger flows require larger heat exchangers and higher temperatures may require special materials. Usually energy savings will more than offset the additional cost. Other considerations related to implementation cost:

• Special materials to address corrosive effluent streams will increase cost without increasing energy savings.

• If the source and use are far apart, the cost of piping, ductwork, pumps and/or fans to deliver the recovered heat will increase costs.

• Heat exchangers conserve fuel and their original cost is relatively modest, but they may involve significant other expenditures. For example, combustion air preheat may require high-temperature burners, larger combustion air ducts with expan-
sion/contraction fittings, cold air lines for cooling the burners, and other items of expense. The implications of heat recovery on both sources and uses need to be considered carefully before a final decision.

**Estimation of Energy Savings**

Waste-heat recovery can save up to 20% of the energy costs in industrial facilities, as noted earlier. Most of the energy savings will affect fuel consumption, however, and electrical heating or ancillary equipment may also be affected. In the following equations, the subscript *rem* denotes quantities related to equipment removed or decommissioned as a result of a measure.

Electrical energy consumption will often be increased due to additional equipment or electrical loads, such as new pumps or increased fan or pump loads to overcome increased flow resistance; the subscript *add* will denote such increased loads.

**Standard Savings Calculation**

General equations for predicting heat exchanger performance are:

\[
\begin{align*}
kW_{\text{savings}} &= kW_{\text{rem}} - kW_{\text{add}} \\
kWh_{\text{savings}} &= \sum (kW_{\text{rem}} \times hours_{\text{rem}})_i - \sum (kW_{\text{add}} \times hours_{\text{add}})_i
\end{align*}
\]

\[
therm_{\text{savings}} = E \times C_{\text{min}} \times (T_{h,\text{in}} - T_{c,\text{in}}) \times (1 - losses) \times 10^{-5} \div \text{existing efficiency}
\]

where:

\[
\begin{align*}
E &= \text{heat exchanger effectiveness (dimensionless)} \\
C_h &= \frac{\left(T_{\text{h,in}} - T_{\text{h,out}}\right)}{\left(T_{\text{h,in}} - T_{\text{c,in}}\right)} \\
C_c &= \frac{\left(T_{\text{c,\text{out}}} - T_{\text{c,in}}\right)}{\left(T_{\text{h,in}} - T_{\text{c,in}}\right)} \\
C_{\text{min}} &= \text{lesser of } C_h \text{ and } C_c \text{ (BTU/°F)} \\
T_{\text{h,in}} &= \text{inlet temperature of hot fluid stream (°F)} \\
T_{\text{h,out}} &= \text{outlet temperature of hot fluid stream (°F)} \\
T_{\text{c,in}} &= \text{inlet temperature of cold fluid stream (°F)} \\
T_{\text{c,\text{out}}} &= \text{outlet temperature of cold fluid stream (°F)} \\
losses &= \text{efficiency loss transporting recovered heat to application (dimensionless)} \\
\text{existing efficiency} &= \text{the overall efficiency of the equipment that would supply the heat if the heat exchanger were not installed (dimensionless)}
\end{align*}
\]
The advantage of this approach is that only the hot and cold stream inlet temperatures, which are more likely to be available, are required. Values of $E$ can be obtained from charts available from manufacturers for specific heat exchangers.

For waste-heat boilers, electrical demand and energy savings equations are the same as for heat exchangers. Therm savings would be calculated as provided below. Note that these savings can only be realized when the waste-heat source coincides with a use for the steam that would otherwise be met by a fuel-fired steam generator.

$$\text{therm}_{\text{savings}} = 10^5 \frac{\text{WHRB}_{\text{efficiency}} \times \text{cfh}_E}{\text{existing}_{\text{efficiency}}}$$

where:

$\text{cfh}_E = \text{flow rate of exhaust gas, (ft}^3 \text{/hour at standard conditions)}$

$\text{WHRB}_{\text{efficiency}} = \text{efficiency of the waste-heat boiler (dimensionless)}$

$T_I = \text{exhaust gas temperature into waste heat boiler, (°F)}$

$T_O = \text{exhaust gas temperature leaving waste heat boiler, (°F)}$

$0.020 = \text{constant converting volume flow rate of exhaust gas (ft}^3 \text{/hr) and temperature difference (°F) to heat rate in BTU/hr. (BTU/ft}^3 \cdot \text{°F)}$

$$= \frac{\text{flue}_\text{gas density} \times \text{flue}_\text{gas specific heat}}{0.020 \times (T_I - T_O) \times 10^{-5}}$$

$$= 0.0783 \text{lbs/ft}^3 \times 0.26 \text{BTU/lb \cdot °F}$$

(both values approximate)

The flow rate of exhaust gas at standard conditions from a combustion source can be calculated as:

$$\text{cfh}_E = \text{Stoichiometric}_\text{Air} \times (1.0 + \text{EA}) \times \text{fuel}_\text{rate}$$

where:

$\text{EA} = \text{excess air for the combustion process (fraction)}$

$\text{fuel}_\text{rate} = \text{rate at which fuel is fed to the combustion process (ft}^3 \text{/hr)}$

$\text{Stoichiometric}_\text{Air} = \text{volume of air at standard conditions required to completely combust one unit of fuel with no oxygen left over (9.52 ft}^3 \text{ air/ ft}^3 \text{ gas)}$

As with waste-heat boilers, energy savings for gas or steam expanders require coincidence of waste heat and a use for the output of the expander. If electricity is generated, electrical demand will be reduced by the generated kW. Electrical energy consumption will be reduced by the amount of energy generated that is consumed on-site. If mechanical energy is generated, electrical savings will equal the kW and kWh that would have been consumed by any replaced electrical equipment, less electricity consumed by the expander’s ancillary equipment. There should be no increase in therm consumption if the heat to drive the expander is truly waste heat.
**Typical Service Life**

Heat exchangers should have service lives of 20 to 25 years. Special applications or harsh environments may shorten that life. Waste-heat recovery boilers and turbines have service lives of 30 years.

**Operation and Maintenance Requirements**

As with most industrial equipment, performance logs should be kept for heat-recovery devices to ensure long-term performance. At a minimum, inlet and outlet temperatures, flow rates and pressures of both fluid streams should be maintained. For waste-heat boilers, steam pressure, temperature, and flow rate should also be recorded, and for turbines, the output of the turbine.

The most important maintenance issues relate to safe and damage-free operation. Operating within design limits is essential. This includes ensuring condensation does not occur in the hot fluid downstream of the device unless it is so designed. Only those fluids for which the device is designed should be passed through it.

From a performance perspective, the most important maintenance issue is maintaining clean heat exchange surfaces. Slow degradation of performance may indicate buildup is occurring; this should be addressed. Benchmark performance should be established at installation or immediately after thorough cleaning of all heat exchange surfaces.

**Laws, Codes, and Regulations**

Wherever pressurized flows will exist, the appropriate section of the ASME Boiler and Pressure Vessel Code (1989) must be followed.

For combustion processes, an increase in combustion temperatures increases the formation of oxides of nitrogen (NOx), a regulated pollutant. The Clean Air Act of 1990 and applicable state or local air quality codes should be consulted.

If electricity is to be generated and sold to the utility, the facility will have to meet FERC’s requirements as a cogeneration “qualifying facility”. In addition, interconnection with the utility will require installation of electrical equipment and metering in accord with codes for such installations.

Many heat recovery applications are not packaged installations and must be designed by a qualified engineer.

**Definition of Key Terms**

- **Density**: The weight of a substance per unit volume.
- **Desiccant**: A material with hygroscopic properties.
- **Effectiveness**: Ratio of heat actually recovered to the maximum potential heat recoverable, taking into account the inlet temperatures of the two streams in a heat exchanger.
• Hygroscopic: A hygroscopic material is one that has a propensity to absorb water. Water will be absorbed until the material is saturated and can be subsequently released to a lower-humidity environment. Heat is released as water is absorbed and absorbed as it is given up.

• Latent Heat: The heat required to convert a liquid to a gas, or vapor in the evaporation process. Latent heat remains “bound” to the vapor until it is cooled sufficiently to convert back to a liquid (i.e., condense), when that heat is released. Note that the temperature of the material does not change during the change of state; latent energy is involved strictly with a change of state of the material.

• Mass Flow Rate: Mass flow rate is a measure of how much of a substance is flowing past a given point in a specified period of time. It is often expressed as pounds per second, pounds per minute or pounds per hour.

• Quality: The quality of the energy in the waste-heat stream is determined by its temperature: the higher the temperature, the higher the quality of the heat.

• Recuperative Heat Exchanger: Such heat exchangers, or recuperators, recover heat from waste flue gas to preheat combustion air.

• Regenerative Heat Exchanger: Such heat exchangers, or regenerators, are of many designs and may transfer heat from gases or liquids to gases or liquids. The term “regenerator” is not applied uniformly among industries; in practice, the specific type of regenerator (e.g., shell-and-tube, heat wheel, etc.) is referred to in the field.

• Sensible Heat: Heat absorbed or given up by a material that results in a change of temperature of that material, but not a change of state.

• Specific Heat: The specific heat of a substance is a measure of the amount of heat required to raise by one degree the temperature of a specified mass of the substance. For example, a specific heat of 1 BTU/pound·°F would require 1 BTU of heat to raise the temperature of 1 pound of the substance by 1°F.

• Value: The value of the energy in the waste-heat stream is determined by its temperature: the higher the temperature, the higher value of the heat.

References to More Information


**Further information may be obtained from:**

Heat Exchange Institute  
1300 Sumner Avenue  
Cleveland, OH 44115

Tubular Exchanger Mfrs. Assoc.  
25 North Broadway  
Tarrytown, NJ 10591

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**Major Manufacturers**

DesChamps Labs, Inc.  
P.O. Box 220  
Natural Bridge Stn., VA 24579  
Tel (540) 291-1111  
Fax (540) 291-3333

Coolenheat, Inc.  
P.O. Box 1368  
Linden, NJ 07036  
Tel (800) 221-0801  
Fax (908) 862-1506

ABCO Industries, Inc.  
2675 East Hwy. 80,  
Abilene, TX 79601  
Tel (915) 677-2011  
Fax (915) 677-1420

Each of these firms makes several different heat-recovery devices, and many other manufacturers exist. A good source for manufacturers and products grouped by type is *Heating Piping and Air Conditioning’s* annual “Info-dex” issue (Penton Publishing, Chicago, IL; (312) 861-0880).

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