

Heat recovery for Canadian food and beverage industries




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Heat recovery for Canadian food and beverage industries

Prepared by
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and the Marketing and Economics Branch

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PREFACE

This publication is aimed at those who are interested in energy conservation. It is intended to stimulate the food and beverage processor's interest in waste heat recovery technology. More specific information is available and advice should be sought from qualified engineering staff before making any alterations to your plant and production processes.

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SUMMARY

In food and beverage industries, energy is often discarded in the atmosphere or disposed of in waste streams. Now, in an age of high energy costs, one of the most effective ways to reduce energy consumption is to make use of waste heat. Waste heat is defined as the heat contained in a fluid rejected from a process at a temperature higher than ambient levels in the plant. The utilization of waste heat offers several advantages over other energy sources: it is present at the plant site, it is available during the plant's operating season, it may reduce environmental pollution problems, and it may eliminate the need for cooling towers.

The practicality of heat recovery depends on the plant having operations or streams at lower temperatures that can actually use the recovered heat, the amount of waste heat available, the ease of implementing and maintaining the heat recovery system, the schedule of availability of waste heat and the cost of installing the system required.

The direct recirculation of heat permits the recovery of almost 100% of the waste heat. Because this is not always feasible, the installation of heat recovery equipment, known as heat exchangers, is necessary. A heat exchanger is a system that separates the waste heat stream from the fluid to be heated but allows heat to flow across the system's separation boundaries (it transfers heat from one fluid to another without mixing the fluids). This is possible because a temperature difference exists between the two fluids.

To install heat recovery equipment in existing situations in which waste heat is expelled, a number of details must be carefully evaluated to decide on the technical and financial feasibility of any project.

First, the characteristics of waste heat streams and the potential operations which will receive the wasted heat must be determined:

- the average temperatures and their ranges;
- the flow volume of the fluids;
- the schedule and duration of flow;
- the proximity of the source and the heat receiver;
- the properties of the fluids (e.g., viscosity, nature of dirt and contaminants, requirements for cleanliness or purity, and likelihood of fouling).

Second, the necessary operating characteristics of the heat recovery system must be evaluated:

- the maximum and average operating heat exchange capacity;
- the minimum useful capacity;
- the pressures and their ranges;
- the need for backup or alternative systems if a disruption of either the source, the heat exchanger or the receiving operation occurs;
- the need for cleaning outflows or inflows of fluids;
- the ease, frequency and rapidity of startup, turndown and shutdown;
- the adequacy of control and monitoring systems;
- the side effects on other systems such as reduced requirements for existing heaters or boilers;
- the potential for thermal storage.

This evaluation will enable users to select appropriate equipment for the situation and calculate installation costs, systems connections, controls and monitors. Simple installations can be done with off-the-shelf equipment and in-house expertise or with the advice of equipment suppliers. In more complex situations, the specialized help of consulting engineers may be required.

When selecting heat recovery equipment it is useful to know the names, addresses and product lines of prospective equipment suppliers. Directories enable users to select equipment suppliers who have experience with equipment related to their industry.

Thermal storage systems can often make heat recovery feasible if the waste heat production occurs at a different time or rate than energy consumption of the recipient fluid. Energy is usually stored in the form of heated liquid, with water being the preferred storage medium due to its low cost and high specific heat.

Contamination of potable water and food products in food and beverage plants must be prevented. The adoption of safety control measures should therefore be an important consideration. Provision should be made to bypass the heat recovery system so that the process can continue its operation if there is a malfunction. With regard to the regulatory aspect of using heat exchangers in a food plant, the guideline states that a heat exchanger in contact with potable water or a food product should be made of a non-absorbent, corrosion-resistant material capable of withstanding repeated cleaning and disinfection but that will not contaminate the water or food, or transmit toxic substances, odor or taste.

The amount of waste heat available in a plant varies widely from sector to sector in the food industry owing to the different processes and energy requirements involved. There are also substantial differences in waste heat from plant to plant within each sector due to such factors as product concentration, continuous or batch operation, plant size and location. The actual amount of potentially useful waste heat can only be revealed by a comprehensive audit of the plant's energy consumption. There is no specific type of industry precluded from the potential benefits of heat recovery; each industry has the potential to benefit from this technology.

The technical review of equipment and options allows the food processor to evaluate whether heat recovery is technically feasible and which pieces of equipment will do the job required. The food processor must then decide whether the operation is also financially feasible and, if so, which piece of equipment is best suited to the plant's needs.

Financial feasibility means that the operation should save money and increase the firm's profits. The heat exchangers should save money for the firm given the present energy prices; financial returns will improve as energy prices increase. An investment that is technically feasible may or may not be financially viable. There are many factors that may make or break an investment in a heat exchanger. Some of these factors are the current and future energy prices, interest rates, tax effects, and capital cost of the equipment.

Financial analysis is done to evaluate all of these concerns. It brings together the technical evaluations and the decision criteria for financing operations. Economic analysis is generally done to solve the problems of evaluating current investment opportunities. The analysis should be performed in such a way as to enable decision makers to evaluate the effects of changing conditions on the decisions made. A sensitivity analysis is then done by varying the assumptions to determine their singular or combined effect on the conclusions. In this way, risk and uncertainty can be evaluated.

There are many opportunities for investing in heat recovery equipment that may require either small or large investments. In both cases, after a thorough technical and financial analysis, the investment may pay back well and provide an acceptable rate of return in line with the basic investment criteria of the firm. The case studies appearing in this report show the benefits encountered by Canadian food industries that invested in heat recovery equipment.

The potential for heat recovery has been evaluated in a report prepared for Energy, Mines and Resources Canada. This report indicates that 12.5% of the total energy consumed by food and beverage industries is practicably recoverable by using present heat recovery techniques. Given this large potential and possible benefits from recovering the waste heat in food and beverage industries, it is important to undertake assessments of the application of new heat recovery technology. Assessments must be both technical and economic, and permit comparisons with other investment opportunities.

INTRODUCTION

In food and beverage industries, energy is often discarded into the atmosphere or disposed of in waste streams. In the past, this dumping of excess energy via drains, sewers, vents and smokestacks was easy and economical. Now, in an age of high energy costs, food and beverage processors are searching for ways to save money through energy conservation. One of the most effective ways of reducing energy consumption is to use waste heat.

WHAT IS WASTE HEAT?

Waste heat is defined as the heat contained in a fluid rejected from a process at a temperature higher than the ambient levels of the plant. Fluids that exist at temperatures lower than ambient levels are also a form of waste energy that can be used for cooling.

There are numerous sources of waste heat in the food processing industry. Cooking, retorting, pasteurizing and ventilating processes as well as refrigeration systems generate a great deal of waste heat. In addition, hot water is often wasted because it is frequently flushed to the sewer after being used only once.

WHAT IS HEAT RECOVERY?

Heat recovery involves the transfer of waste heat to another medium (such as air or water) and/or process where it can be used later. The practicality of heat recovery depends on whether the plant has processing operations or streams at a lower temperature that can actually use the recovered heat. It also depends on the amount of heat available (temperature, flow rate, availability of the waste heat), the ease of implementing and maintaining the heat recovery system, and its cost and returns. General applications include heating or cooling of process fluids and other fluids: for example, heating boiler feedwater, preheating washwater, precooling or preheating product, and heating or cooling incoming ventilation air.

Utilization of waste heat offers advantages over other energy sources: it is present at the plant site, it is available during the plant operating season, it may reduce environmental pollution problems, and it may eliminate the need for cooling towers.

WHAT IS A HEAT EXCHANGER?

The most efficient way to recuperate heat is by removing contaminants from the fluids and then directly recirculating the waste heat stream. This method allows for almost 100% recovery of the waste heat. However, since direct recirculation is often impossible or infeasible, the installation of heat recovery equipment, or heat exchangers, is necessary.

A heat exchanger system separates the waste heat stream from the fluid to be heated. It allows heat to flow from one fluid to another across the separation boundaries without mixing the fluids. The heat transfer occurs because a temperature difference exists between the fluids.

The two streams should be separated for either of the following reasons:

- to prevent one stream from contaminating the other (extremely important in food processing, especially in terms of avoiding contamination of potable water or the food product);
- to palliate a pressure difference that may exist between the two streams.

It may be necessary, in some situations, to use a third fluid. For example, an intermediate stream could be used to transport the waste heat over long distances when the source and exchanger are far apart.

CHARACTERISTICS OF HEAT EXCHANGERS

There are many types and characteristics of heat exchangers. With respect to heat transfer fluids, heat exchangers can be classed into three groups: gas/gas, gas/liquid, and liquid/liquid.

The two fluids within the heat exchanger can flow in parallel (both fluids flowing in the same direction), countercurrent (both fluids moving in parallel but opposite directions) or crosscurrent directions (both fluids flowing at right angles to each other). The flow can also be single or multipass (i.e., the heat transfer fluids pass over the heat transfer surface one or more times).

FACTORS TO CONSIDER WHEN CHOOSING A HEAT EXCHANGER

To install heat recovery equipment in situations where waste heat is being expelled, a number of details must be carefully evaluated in order to decide on the technical and financial feasibility of any project.

First, the characteristics of the waste heat streams and the potential heat receiving operations must be determined:

- the average temperatures and their ranges;
- the flow volume of the fluids;
- the schedule and duration of flow;
- the proximity of the source and the heat receiver;
- the properties of the fluids (e.g., viscosity, type of dirt or contaminants, requirements for cleanliness or purity, and likelihood of fouling).

Second, the necessary operating characteristics of the systems and the heat exchangers must be evaluated:

- the maximum and average operating heat exchange capacity;
- the minimum useful capacity;
- the pressures and their ranges;
- the need for a backup or alternative system if a disruption of either the source, the heat exchanger or the receiving operation occurs;
- the need for cleaning inflows or outflows of fluids;
- the ease, frequency and rapidity of startup, turndown and shutdown;
- the adequacy of control and monitoring systems;
- the side effects on other systems (e.g., reduced requirements from existing heaters or boilers);
- the potential for thermal storage.

This preliminary analysis will enable the user to identify appropriate equipment for the situation and calculate installation costs, systems connections, controls and monitors. Simple installations can be done with off-the-shelf equipment, in-house expertise and the advice of equipment suppliers. In more complex situations, the specialized help of consulting engineers may be required.

When selecting heat recovery equipment, it is useful to know the names, addresses and product lines of prospective equipment suppliers. Directories enable users to select experienced equipment suppliers with equipment related to their industry. Two excellent directories are available:

- 1) *1983 Canadian Directory of Energy Conservation Products and Suppliers*, published by and available from:

Energy Conservation and Oil Substitution Branch
Energy, Mines and Resources Canada
580 Booth Street
Ottawa
K1A 0E4

or any of the department's Conservation and Renewable Energy Offices.

- 2) *Food in Canada: "1984 Buyer's Directory,"* Vol. 43, No. 10, October 1983

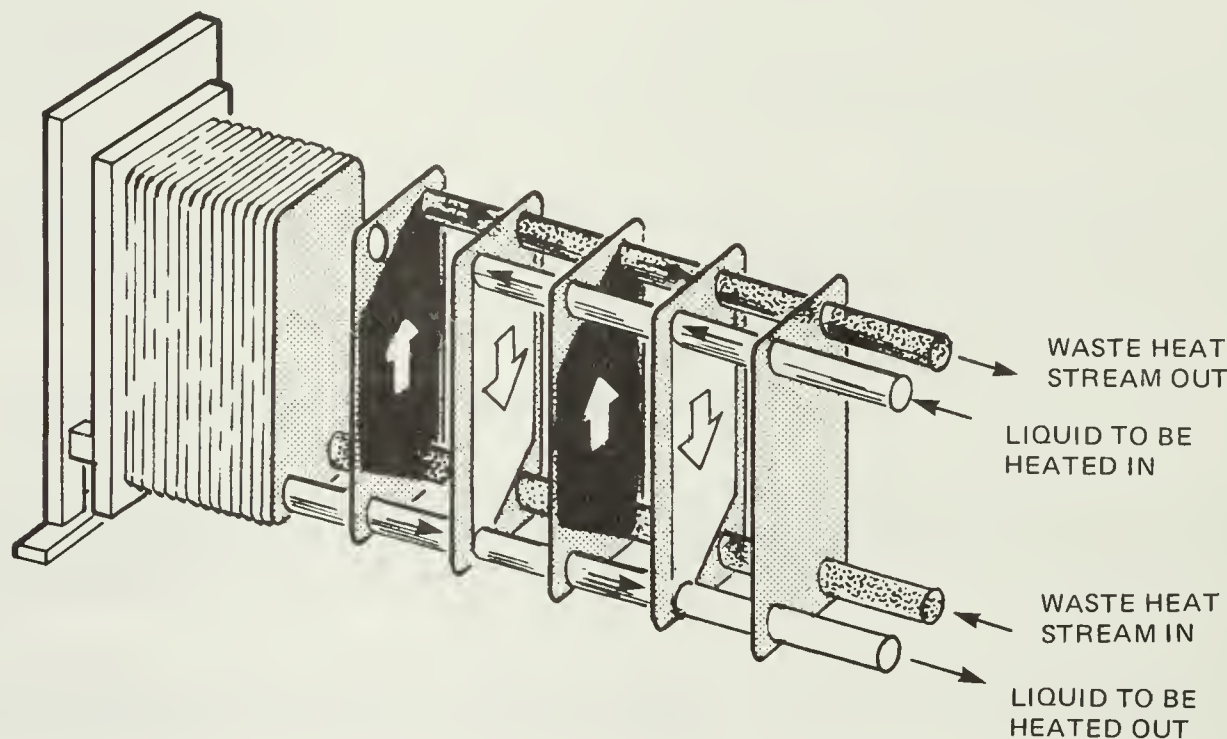
available from: Food in Canada
Maclean Hunter Ltd.
777 Bay Street
Toronto, Ontario
M5G 2C8

BASIC TYPES OF HEAT EXCHANGERS

This section outlines the basic types of heat exchangers most used for heat recovery in food and beverage industries.

Plate heat exchanger

This gas/gas or liquid/liquid heat exchanger is a system that consists of a metal frame in which a variable number of corrugated metal sheets are clamped together. Adjoining plates are spaced apart and sealed against leakage and intermixing by gasketing. The two fluids flow in alternate interplate channels, usually in a countercurrent direction. Plate corrugations produce turbulence and an increased surface area, thus providing high heat transfer and high effectiveness.



1. Plate heat exchanger

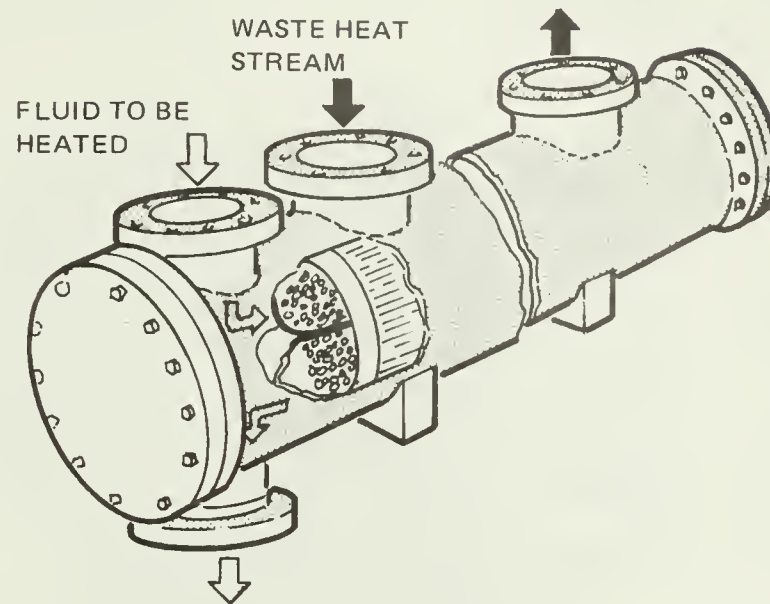
Plate heat exchangers are the simplest and easiest to clean, inspect and maintain as there is quick access to heat transfer surfaces for cleaning and inspection. They are also easy to clean in place (C.I.P). For these reasons plate heat exchangers are a suitable choice for an application that directly involves potable water or the food product. They are generally limited to liquids with less than 5% solid particle content and particle sizes below 1 mm in diameter.

A regenerative pasteurizer, used in the dairy and egg processing industries, for example, includes a heat recovery device consisting of a liquid/liquid plate heat exchanger. The hot product that comes out of the pasteurizer preheats the incoming cold product and is itself cooled.

Specific applications for a plate heat exchanger include preheating boiler feedwater with hot wastewater, preheating scalding inlet water with scalding overflow, or using wastewater from a blancher to heat potable water.

Shell and tube heat exchanger

This gas/liquid or liquid/liquid heat exchanger consists of a bundle of small, parallel tubes contained within a cylindrical shell.



2. Shell and tube heat exchanger

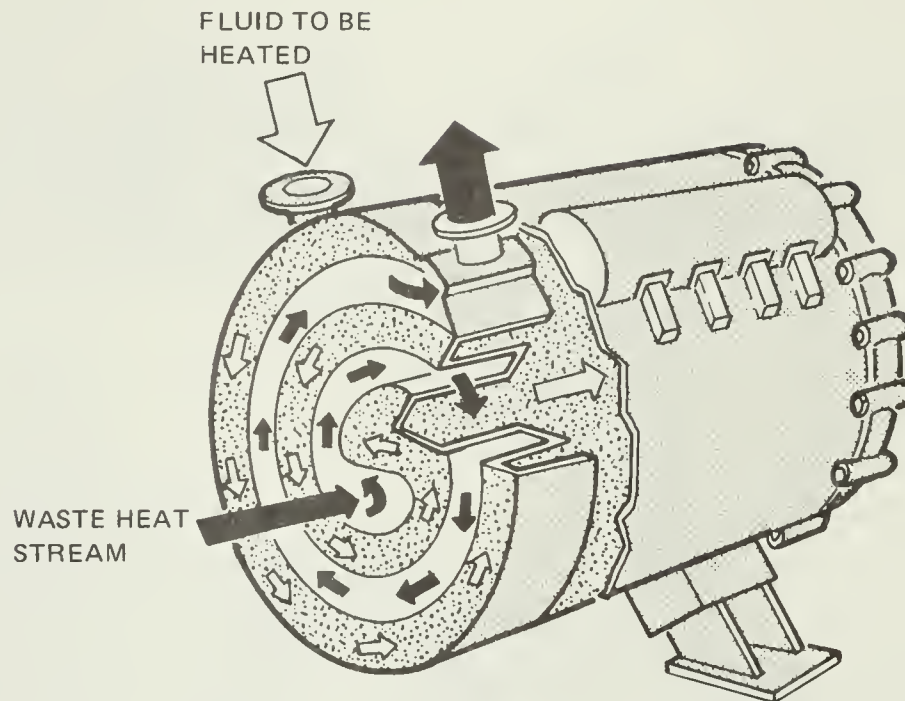
One fluid flows through the tubes and the other through the shell and over the tube bundle. When a vapor containing the waste heat is used to heat a liquid, the vapor flows through the shell, while the liquid to be heated flows in the tubes. A removable tube bundle makes the heat exchanger easier to clean, although the tubes themselves may still be difficult to clean. This type of heat exchanger is most often used for non-food processing steps as both the shell and the tubes can be difficult to inspect. These heat exchangers are restricted to solutions with a low solid particle content. Waste heat recovery applications include heating water with the heat released by the condensers in refrigeration systems, heating water by using the vapor discharged from inedible rendering cookers, or heating scalding inlet water with scalding overflow. Also, one of the most common is boiler blowdown heat recovery.

Finned tube heat exchanger

This gas/liquid heat exchanger consists of a bundle of tubes through which the liquid to be heated flows and over which flow exhaust gases containing waste heat. Fins attached to the tubes provide additional surface area for transferring waste heat. This heat exchanger is used for heating water for all kinds of uses, such as for boiler feedwater or as hot water for cleanup (see "Economizer").

Spiral heat exchanger

This heat exchanger consists of two relatively long plate metal strips that are concentrically rolled to form a pair of separate leakproof spiral channels.

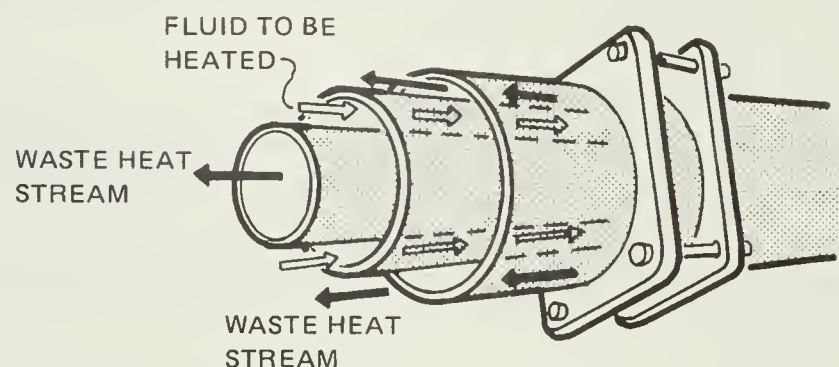


3. Spiral heat exchanger

Compared with shell and tube units, spiral heat exchangers offer greater compactness, negligible maintenance, easy accessibility for inspection and cleaning, and low fouling characteristics. This type of exchanger is frequently used for handling fouled cooling water and is effective for recovering the heat from atmospheric pressure steam. For example, a spiral heat exchanger could be used to condense atmospheric steam from open cookers to heat hot water for plant cleaning operations.

Tubular heat exchanger

This is a liquid/liquid or gas/liquid heat exchanger consisting of two or three concentric tubes. The heating or cooling fluid flows through the inner tube, and the product to be heated or cooled flows in the second tube. If three tubes are used, the heating or cooling fluid flows in the outer tube as well.

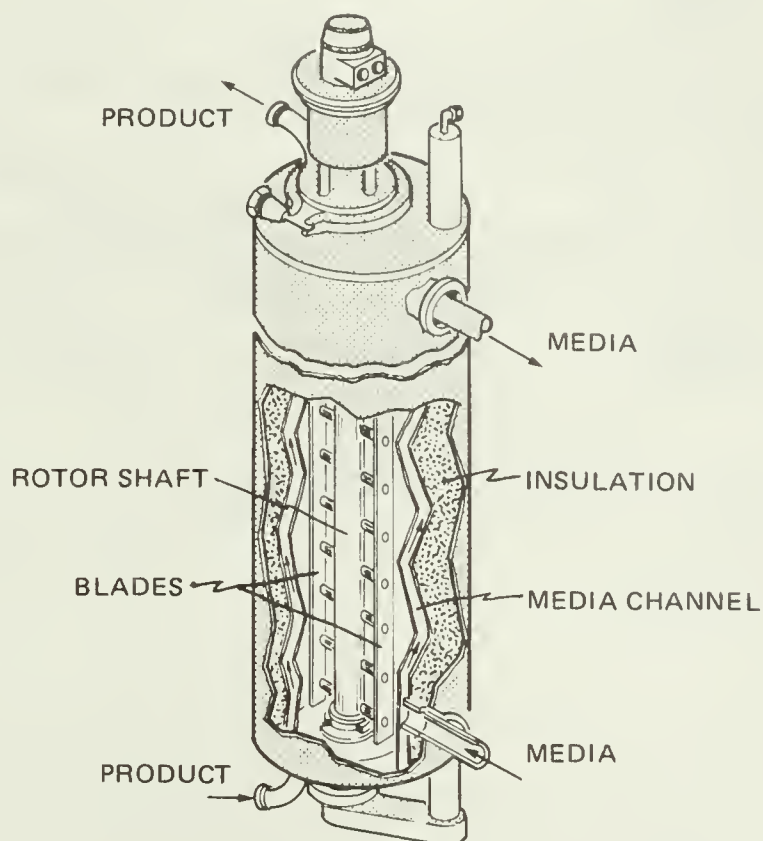


4. Tubular heat exchanger

This type of exchanger must be completely dismantled when an inspection for leakage or fouling is needed. Although these exchangers can be difficult to maintain, they are easily cleaned in place. Heat recovery applications include those that involve a viscous liquid or a liquid with particulate matter. When liquids are used, the permissible solid particle content may be as high as 40%.

Scraped-surface heat exchanger

The scraped-surface heat exchanger consists of a rotating bladed shaft positioned concentrically within a jacketed, insulated tube. The product flows in the inner tube, where it is continuously agitated and removed from the walls by the blades. Heating or cooling fluid flows in the annular space between the heat transfer cylinder and the outer insulated tube.

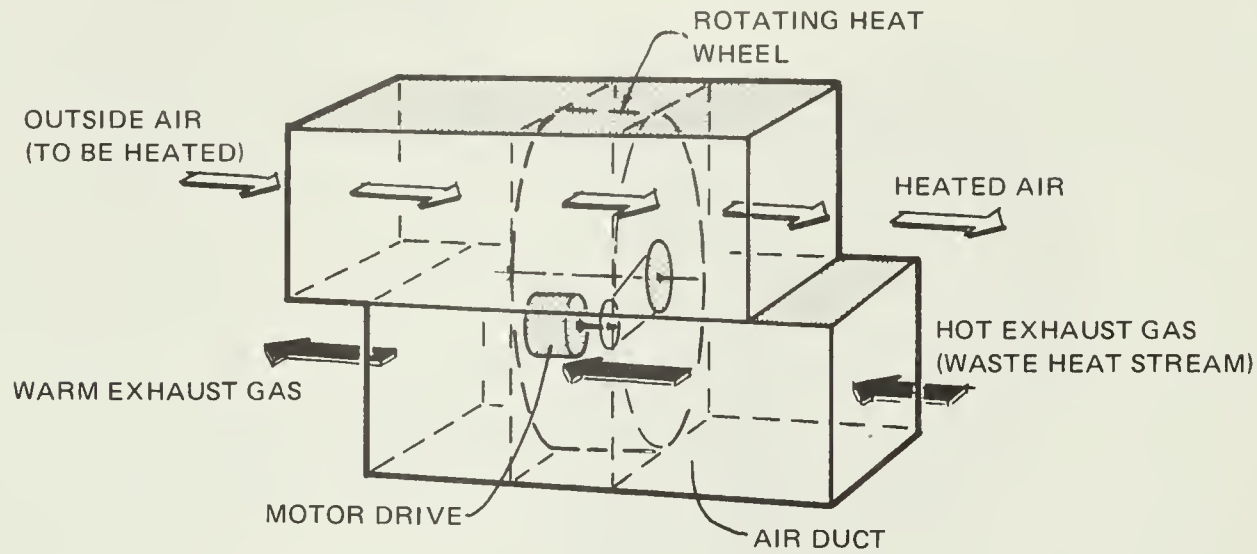


5. Scraped-surface heat exchanger

Scraped-surface heat exchangers are designed for heavy-fouling products and for crystallization processes and can handle a product containing as much as 75% solid particles. This type of exchanger can be positioned horizontally or vertically. Cleaning and inspection are accomplished by lowering or sliding the rotor and blade assembly.

Heat wheel or rotary regenerator

This gas/gas heat exchanger consists of a large porous disc made of high heat capacity material (e.g., stainless steel mesh, ceramic), which rotates between two side-by-side counterflow air ducts, one for cold air, the other for hot. As the wheel turns, it first absorbs heat from the warmer air stream and stores it temporarily. The wheel then comes into contact with the cooler air stream and transfers the heat to it.



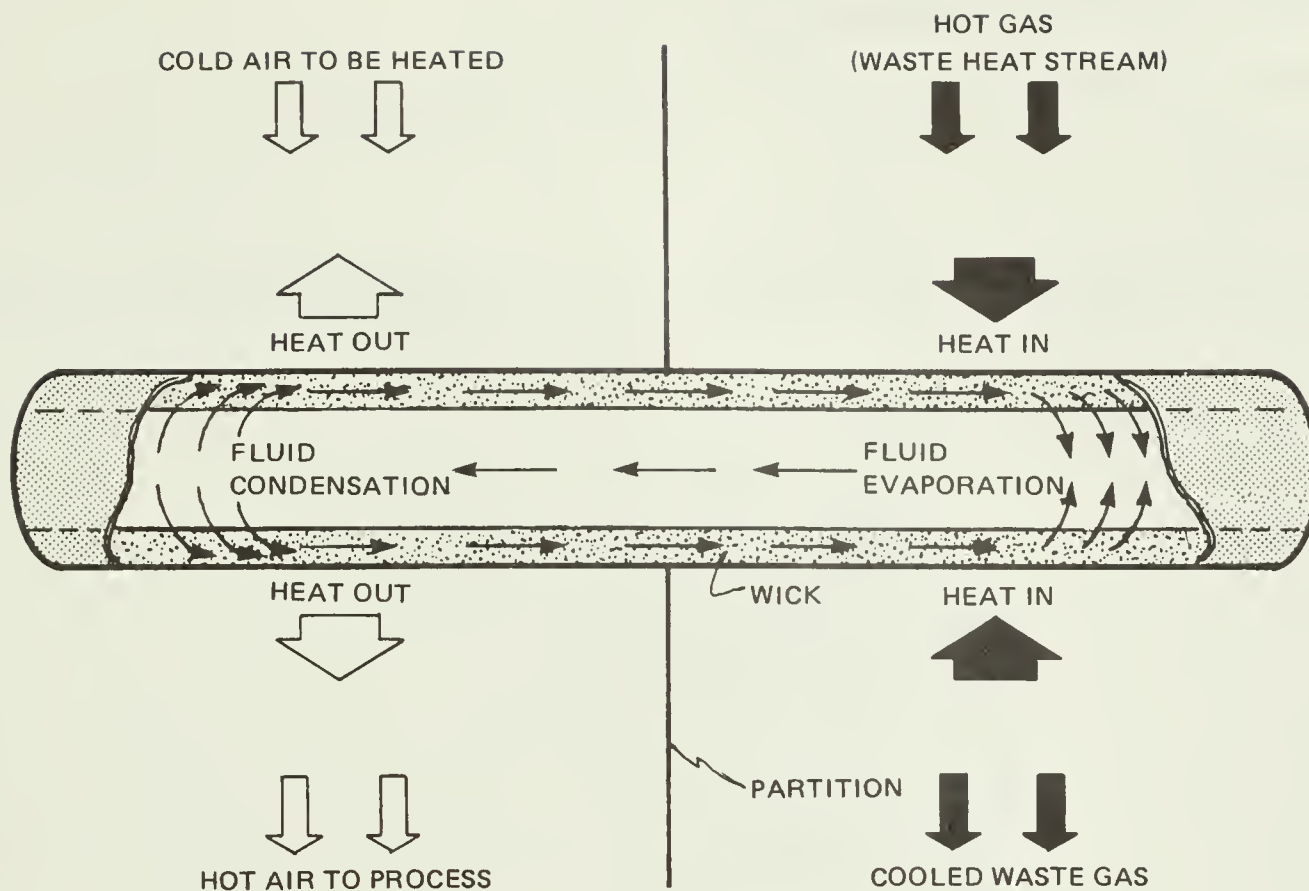
6. Heat wheel or rotary regenerator

Applications include preheating the incoming ventilation air and incoming air in dryers and ovens with exhaust air.

Heat pipe

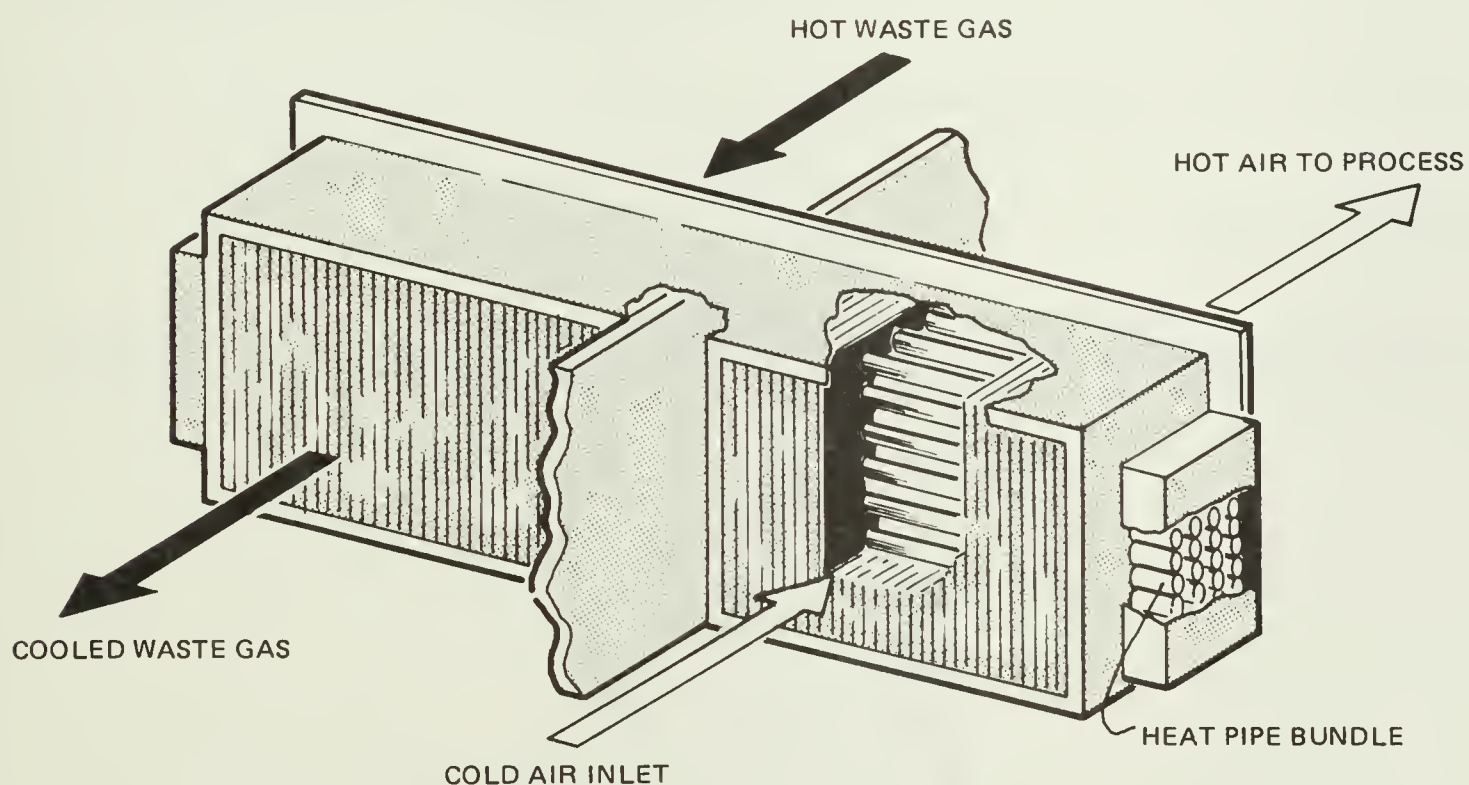
This gas/gas or gas/liquid heat exchanger consists of a sealed metal tube containing a heat transfer fluid and an annular capillary wick.

Heat absorbed from hot exhaust gases evaporates the fluid at one end of the pipe. The vapor moves to the cold end of the pipe, where it condenses and gives up its latent heat, thereby heating the cold fluid. The condensed fluid then returns by capillary action to the hot end of the pipe and is thus continuously recycled.



7. Heat pipe

Heat pipes are usually incorporated into bundles in which each pipe extends across two ducts, one containing warm fluid and the other cold. This heat exchanger does not allow cross-contamination. Applications include preheating air for dryers and ovens and preheating combustion air for boilers.



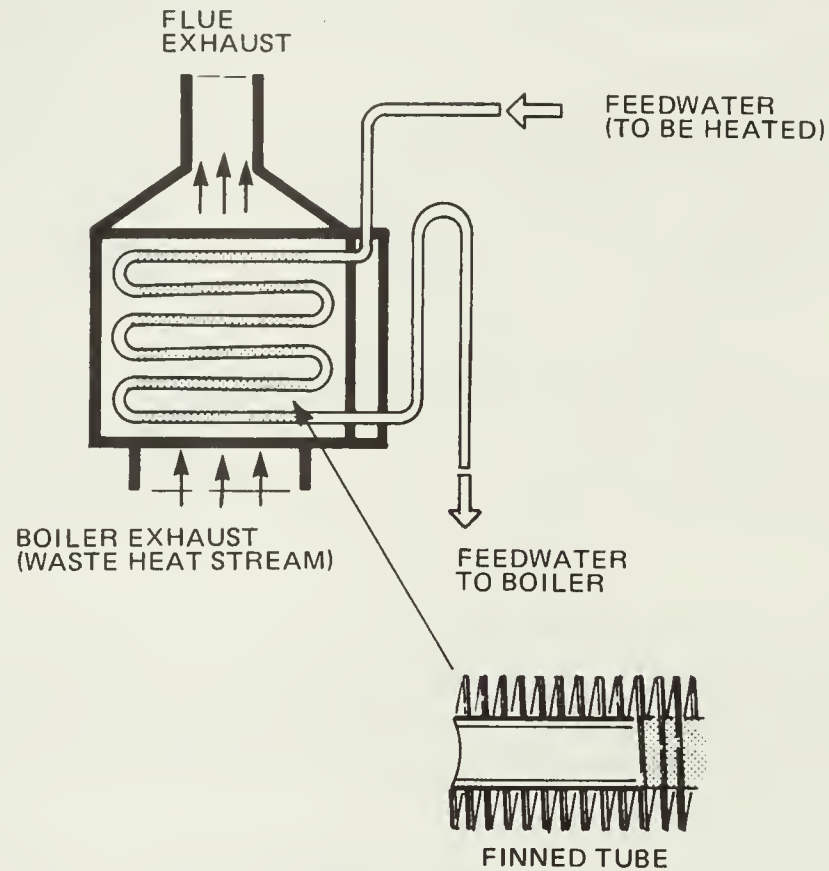
8. Heat pipe system

SPECIFIC TYPES OF HEAT EXCHANGERS

There are many variations of the basic heat exchangers described above, such as:

Economizer

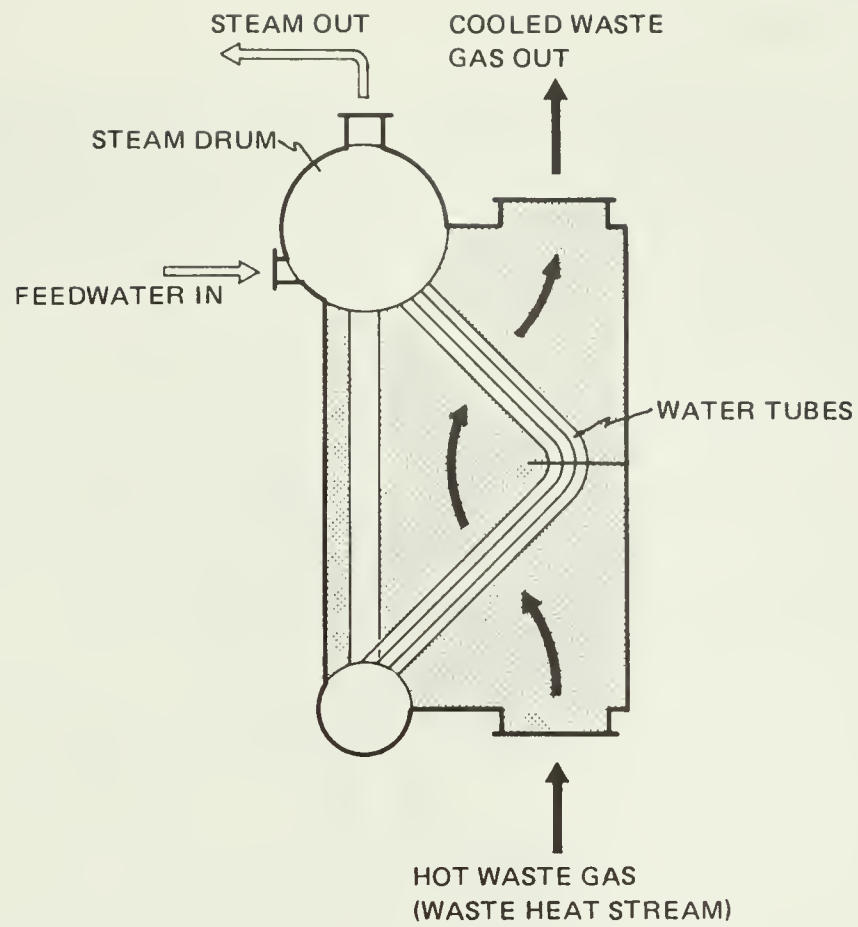
An air-to-water heat exchanger consisting of a bank of finned tubes installed in a flue and used to transfer heat from the hot flue gases to water pumped through the tubes. The heated water is used for boiler feedwater.



9. Finned tube economizer

Waste heat boiler

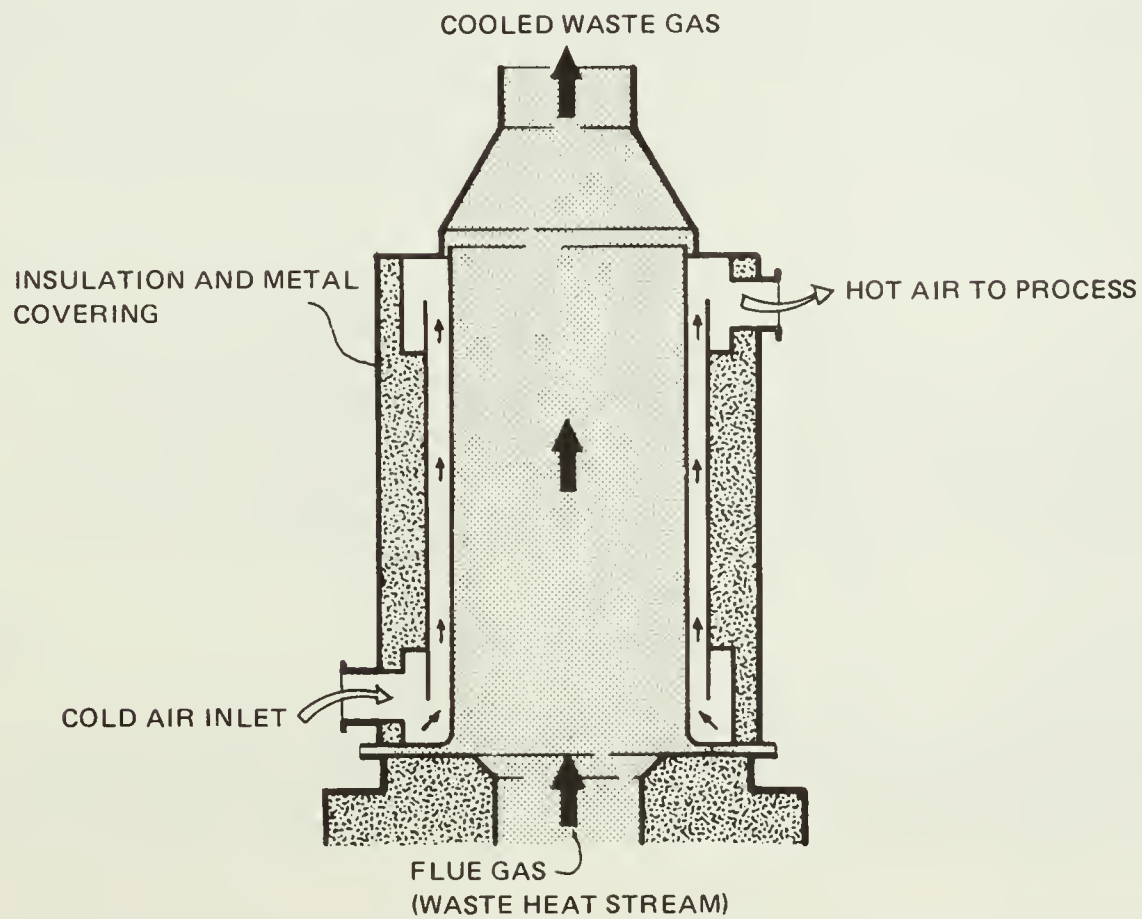
A heat exchanger in which hot exhaust gases pass over parallel tubes containing water; the water vaporizes and is collected in a steam drum from which it is drawn off for processing or heating. This device can be used to recover heat from hog singer flue gases.



10. Waste heat boiler

Combustion air preheater

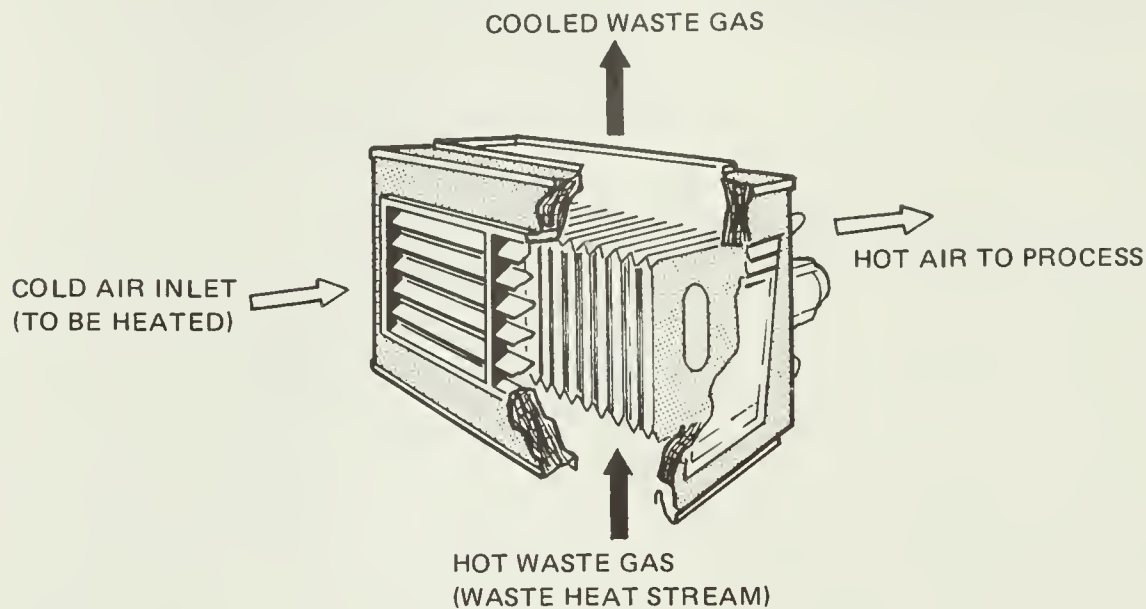
A gas-to-gas heat exchanger that recovers waste heat from the hot flue gases of a furnace to heat incoming air for combustion.



11. Combustion air preheater

Air-to-air plate exchanger

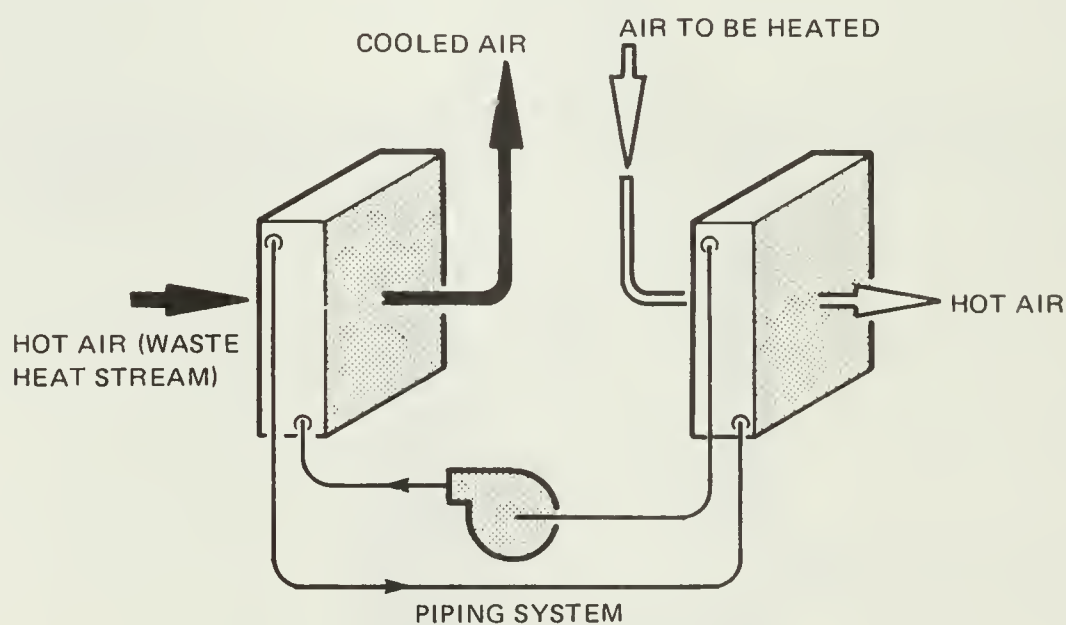
It consists of a series of alternate channels that allow the hot and cold gases to flow close to each other, separated only by a thin wall of conductive metal. Proper sealing and gasketing will prevent cross-contamination and the unit can be easily cleaned, maintained and inspected. Applications include heat recovery from baking, drying and curing ovens, and from heating and ventilation systems.



12. Air-to-air plate heat exchanger

Runaround system

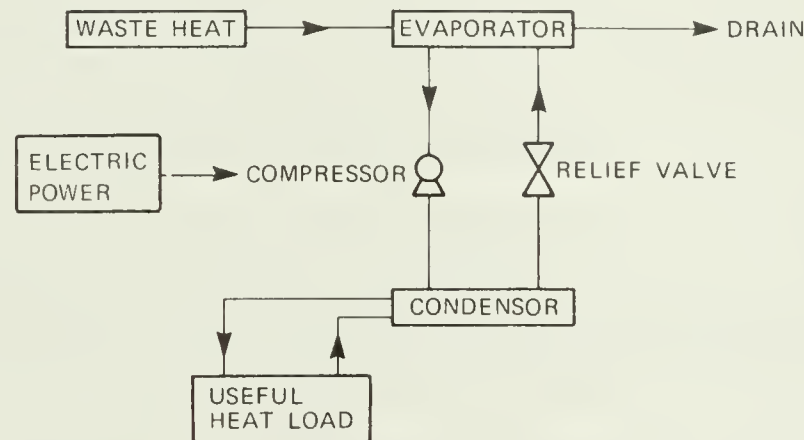
A gas-to-gas heat exchanger consisting of a closed insulated piping system through which a heat transfer fluid (often glycol) is pumped. This intermediate fluid picks up heat in coils or finned tubes installed in the hot exhaust air stream and rejects heat by way of coils into the cold incoming air stream. Leakage from one air stream to another is thus eliminated. This system can be used when the waste heat source and its application are far apart or when heat is to be collected from several sources. The runaround system could be used to recover heat from the exhaust air of a dryer to heat the intake air.



13. Runaround system

HEAT PUMP

Heat exchangers can be classified as passive devices, as they do not require an external energy source to accomplish heat transfer. Instead, they depend on a temperature gradient to cause the transfer from an area of high energy concentration (heat source) to an area of low energy concentration (cooler sink). However, there are potential situations in food and beverage industries where the temperature of the waste stream is lower than that of the heat-receiving operations. This is where an active device, a heat pump, could be used for the energy exchange. Heat pumps use an external energy source to increase the temperature of the recovered waste heat. This system works basically as a refrigeration cycle in reverse. The liquid in the evaporator absorbs heat from the waste heat source and vaporizes; the vapor is then compressed to a high pressure. From there it goes to the condenser, where this previously absorbed energy is given up to the fluid to be heated. Since new heat pumps are capable of reaching temperatures above the boiling point of water, many potential applications such as direct steam generation or heating cleanup water can be considered.



14. Heat pump

THERMAL ENERGY STORAGE

Storage systems can often make heat recovery feasible if the waste heat production occurs at a different time or rate than the energy consumption of the receiving operation. The storage of the recovered thermal energy will permit uncoupling of the production of waste heat from the ultimate user process. Thermal energy is usually stored in the form of heated liquid, water being the preferred storage medium in food processing because of its low cost and high specific heat. For example, the recovered energy from a refrigeration condenser could be stored as hot water in an insulated tank and be used for heated plant washwater later in the day.

FOULING

Fouling is the buildup of deposits, over time, on the heat exchanger surfaces due to exposure to the fluids. These deposits can consist of residues, chemical corrosion or mineral deposits. It is very important to consider this aspect in order to properly choose the right heat exchanger to handle the full load. Fouling can greatly reduce heat transfer capacity and increase pressure drop. Frequent cleaning and maintenance are therefore required, since fouling and the difficulty of cleaning increase over time. Filtration may be required to remove contaminants from the waste heat stream.

FREEZING

Freezing problems can occur during the winter when air-to-air heat exchangers are used to preheat outside air. If outside air is relatively cold and exhaust air is warm and humid, freezing of condensation on the warm side of the exchanger may occur and completely block the air passage. To solve this problem, defrost controls will be required, which will reduce overall effectiveness.

SAFETY AND CONTROL SYSTEMS

In food processing plants, contamination of potable water and food products must be prevented. There should be a provision to bypass the heat recovery system so that the process can continue its operation if there is a system malfunction. Controls for the heat recovery systems should be compatible with the instrumentation.

Heat exchangers are checked for leaks by a variety of tests in the factory. However, in some cases, a leak may eventually develop because of such things as gasket failure or stress fractures. For this reason, if potable water or a food product is involved, monitoring and control systems (such as pH monitoring or differential pressure sensing) should be installed for detection of leaks and prevention of cross-contamination. Indicators of a system malfunction should be tied into process control and alarm networks if available.

REGULATIONS, CODES AND STANDARDS

Local and national codes and standards for heat exchangers exist in every country. Most often, the mechanical design is more closely regulated by codes and standards than the thermal design. These codes and standards are established to regulate and specify the design, manufacture and operation of heat exchangers in order to protect the public interest (safety). However, they tend to be more concerned with large and complicated devices operating at elevated pressures rather than simpler devices most common to the food industry.

Concerning legal requirements for food safety, The Food and Drug Act, Part I, Section 4, states: "No person shall manufacture, prepare, preserve, package, or store for sale any food under unsanitary conditions."

With respect to the meat industry, the *Meat Hygiene Manual of Procedures* (see "Equipment" in Chapter 2.7) points out: "In the effective control of operation sanitation, nothing is more important than simply designed and easily cleaned equipment of non-corrosive and rust-resistant material."

Many heat recovery applications involve non-food processing steps. In these instances there is no real concern about contamination. However, a general guideline to follow is that if the heat exchanger is to be in contact with potable water or a food product, it should be made of a non-absorbent, corrosion-resistant material capable of withstanding repeated cleaning and disinfection but that will not contaminate the water or food or transmit toxic substances, odor or taste ("Code of Practice — General Principles of Food Hygiene," *Codex Alimentarius* Commission).

INDUSTRY SECTOR PROFILES OF WASTE HEAT AVAILABILITY

The amount of waste heat available in a plant varies widely from sector to sector in the food industry owing to the different processes and energy requirements involved.

There are also substantial differences in waste heat from plant to plant within each sector due to such factors as product concentration, continuous or batch operation, plant size and location. The actual amount of potentially useful waste heat can only be revealed by a comprehensive audit of the plant's energy consumption.

However, in each sector there are general opportunities and applications for waste heat recovery. These are briefly discussed below for various sectors of the food industry.

Red meat processing

Waste heat availability is highly dependent on the type of processing plant. In a slaughterhouse, the major energy use is for refrigeration of carcasses. If by-products are processed, by-product rendering is also a major energy user. In beef slaughtering, another major energy consumer is the cleanup operation, which uses large quantities of hot water. In hog slaughtering, the hair removal process (scalding, dehairing, singeing) uses a large amount of energy.

Recovery of waste heat from refrigeration systems and by-product dryers is practical, while that from rendering cookers is possible but more difficult because of the grease in the cooker's exhaust. Recovered energy could be employed for heating hot water used for cleanup, or for preheating boiler feedwater or intake air for dryers.

The hog singeing operation provides a relatively clean high temperature source of waste heat, as more than 90% of the input is vented into the atmosphere. This waste heat could provide a significant fraction of the

energy requirements of the scalding/dehairing process. Recovery of heat from hog scalders overflow water is also possible.

The production of processed meats involves many unit operations (cooking, smoking, cooling, etc.) and is usually more energy-intensive than slaughtering. Large energy uses are associated with refrigeration and smoking/curing of the product. Major sources of waste heat are condenser heat, wastewater, cooking and smoking vents. Again, recovery of heat from wastewater and from cooker exhaust may be difficult because of the grease in the exhaust.

Poultry processing

In poultry processing, large quantities of energy are required for scalding, cooling and freezing. The scalders and chillers have continuous overflow, and thus large amounts of energy are lost. However, recovery of heat (or cooling capacity) from scalders (or from chillers) is feasible, and the energy can be returned to the scalders (or chillers). Heat can also be recovered from refrigeration system condensers and used to preheat boiler makeup water or washwater.

Fruit and vegetable processing (freezing and canning)

Although the percentage of waste heat does not differ greatly between freezing and canning plants, the sources of the waste streams do. In freezing plants, the major source is the refrigeration system condensers. Heat is available from the hot refrigerant and should be easily recoverable. A second source is wastewater; however, waste heat from it is of low quality and solid particles in the wastewater might cause fouling problems in heat exchangers. Individual hot waste streams may offer some recovery potential if they are intercepted prior to mixing with the main waste flow.

In canning plants, the major waste heat sources are retort vents and wastewater. Heat from retort vents can be recovered, but no back pressure should be applied to these vents, since free flow of steam is essential during venting to ensure that adequate thermal processing of cans will be accomplished.

Waste heat can be used at numerous points in the plant. Water heating for can washing, blancher makeup water, plant cleanup and boiler feedwater are potential applications.

Dairy processing

Dairy processing plants usually use energy efficiently. Heat transmitted to milk products during pasteurization is normally rejected to incoming cold milk in the regenerator. A large percentage of waste energy is in the heat rejected by the refrigeration condensers. It can be used in generating hot water for use in cleanup, in preheating boiler feedwater, or in heating culture tanks for some unit operations. Wastewater and exhaust from spray dryers are other major sources of waste heat. Contaminants in the wastewater may restrict its use for heat recovery, but dryer exhaust can be recovered and used to preheat supply air for the dryer.

Biscuit manufacturers and bakeries

Flue gases from ovens, fryers, pan washers and boilers are major heat loss sources. Hot water can be produced from these sources for use in pan and plant cleanup. Recovery of low-grade heat from oven exhaust for lower temperature heat requirements (e.g., proofing, fermentation) is another possibility.

Egg processing

As in the dairy industry, heat received by egg products during pasteurization is transmitted to the cold incoming egg product inside a regenerator. Principal sources of waste heat depend very much on the type of product the plant is producing, but they are generally refrigeration systems, wastewater from egg washing, and exhaust air from drying operations.

Applications include preheating boiler feedwater, heating egg washwater and plant cleanup water, and preheating incoming dryer air.

FINANCIAL ANALYSIS OF INVESTMENT IN HEAT RECOVERY EQUIPMENT

The technical review of equipment and options allows the food processor to evaluate whether heat recovery is technically feasible and which pieces of equipment will do the job required. The food processor must then decide whether the operation is also financially feasible and, if so, which piece of equipment is best suited to the plant's needs.

Financial feasibility means that the operation should save money and increase the firm's profits. The heat exchangers should save money for the firm given the current energy prices; financial returns will improve as energy prices increase. An investment that is technically feasible may or may not be financially viable. There are many factors that can make or break an investment in a heat exchanger system. Some of these factors, which change from time to time, are: the present and future prices of energy, interest rates, capacity utilization and capital cost of the equipment, maintenance costs, risk and uncertainty of the technology, tax effects, incentive/assistance programs and side effects such as environmental pollution.

Financial analysis is done to evaluate all of these concerns. It brings together the technical evaluation and the decision criteria for financing operations. The analysis should be performed in such a way as to enable decision makers to evaluate the effects of changing conditions on the decisions made. Therefore, the analysis should have all items, costs, prices, discount rates, etc., clearly laid out so that it can be redone with minimal effort and that the sensitivity of the conclusions can be tested against changed conditions or assumptions.

A proper financial or economic analysis requires the use of dollar values for all costs and all benefits or savings of the investment opportunity over the effective useful life of the project. Since there is an opportunity cost to investing in equipment that will produce savings many years in the future, all dollar inflows or outflows must be discounted to present values to permit real comparisons of financial alternatives. The discount rate is the rate of return at which the money to be invested in the equipment could be put into some other investment. Among these alternatives are bank balances, stocks, bonds, other production equipment, marketing effort, etc. Discounting to present values brings all cash flows to one common comparison period — the present.

Inflation should either not be taken into account, or else all values should be inflated. It is preferable not to use inflated values, since the future rate of inflation is hard to predict. The effect of inflation after discounting to present values with real discount rates is nil except for items in which the inflation rate is different. If the real cost of energy or of any other item rises faster than other costs, then the difference in the rate of increase should be shown as an inflation or real growth rate.

If inflated values are used then the discount rate adopted must be the market rate that includes inflation. If uninflated values are used, the discount rate should then be the firm's market or opportunity rate less the present rate of inflation.

The steps of financial analysis

Follow these six steps when doing an economic or financial cost benefit analysis:

1. Evaluate the technology of the processes and the equipment and select alternative methods of accomplishing the savings;
2. Evaluate the constraints to implementing any of the possible objectives;
3. Identify and quantify the potential benefits or savings, such as:
 - fuel saved for the waste heat generating process
 - fuel saved for the waste heat receiving process
 - reduced costs of waste energy disposal
 - labor cost reductions
 - changes in productivity
 - changes in other processes
 - environmental and health improvements
 - scrap value of equipment
 - tax effects
 - incentive assistance benefits

4. Identify and quantify costs:

Capital expenditures

- land and buildings
- machinery and equipment
- design and engineering
- installation (including cost of site preparation)
- startup costs
- equipment replacement costs

Operating costs

- labor
- materials and supplies
- maintenance and repair
- energy costs associated with reclamation system

Tax effects and other costs such as incremental overhead or administrative costs.

5. Tabulate all of the benefits and costs for the period in which they occur, and calculate and tabulate the present value of each item;

6. Once all of these costs and benefits have been quantified, lay them out clearly so that anyone can follow the data and assumptions that are used in their derivation.

The alternatives can now be evaluated and compared with each other and with the basic investment criteria of the firm.

A thorough technology investment assessment should be accompanied by a tabulation of every cost, price, revenue, benefit, savings, etc., complete with the assumptions used in deriving them. This is followed by a sensitivity analysis, which is done by varying the assumptions to determine their singular or combined effect on the conclusions. In this way uncertainty can be evaluated.

An assessment of the investment criteria and the amount and timing of cash flows together with the sensitivity analysis of the assumptions allows the making of an informed decision about investments in new technology. If technology assessments are well done and presented with a good layout, comparisons with new opportunities are easily done. As decision makers become aware of the feasibility of new energy conservation technologies, they can readily compare them with other investment opportunities. As conditions change, the ranking of the priority of investments will change.

CASE STUDIES

The following case studies show benefits found by the food industry after heat recovery systems were installed. Case study no. 1 illustrates a detailed technical and financial analysis.

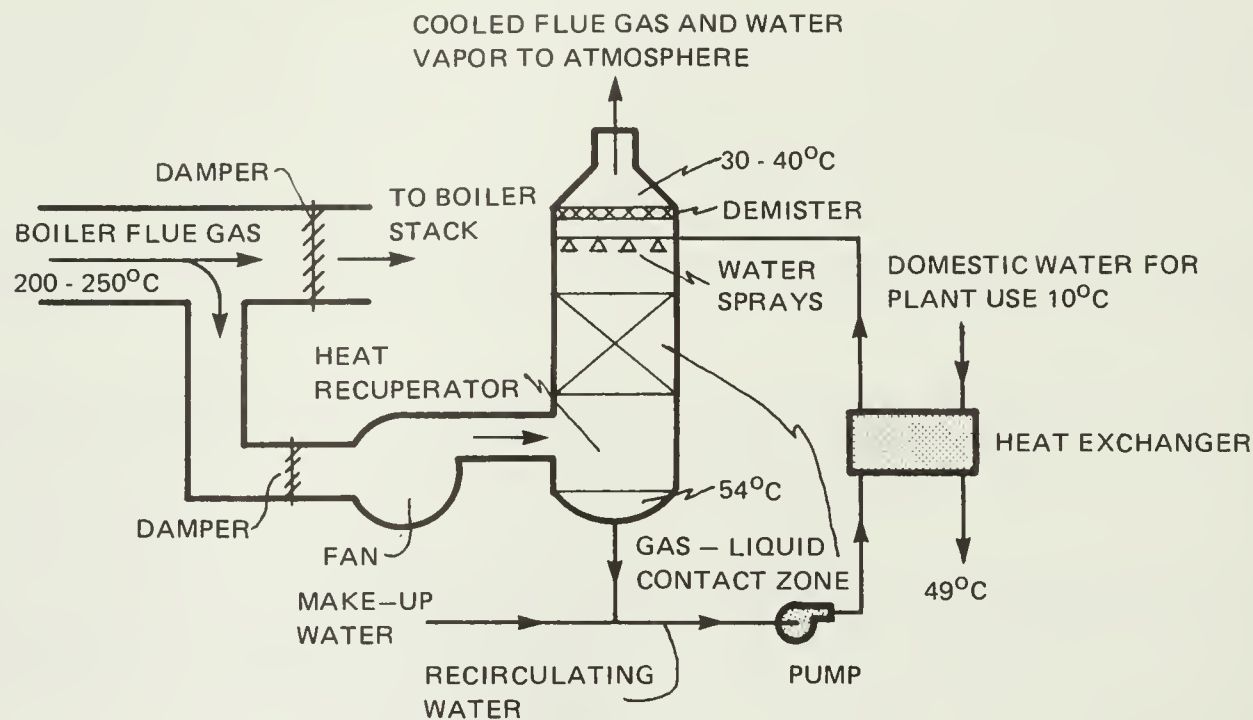
Case study no. 1 — rendering cookers

In the meat processing industry, rendering cookers provide a good opportunity for heat recovery because of the high temperatures and the large volume of steam involved. In this procedure, the vapor from the cooker was passed to a spray type condenser, which used plant effluent as the condensing medium. In the condensing process, all of the latent heat and a portion of the sensible heat in the vapor were transferred to the condensing medium. The resulting hot discharge was then passed to a hot well from where it was pumped through a heat exchanger to preheat the water.

A system similar to this one was installed in a Canadian meat processing plant. Unfortunately, the system failed owing to severe heat-exchanger fouling caused by the presence of grease and other waste materials in the plant effluent used in the spray condensers. This system was abandoned because frequent and expensive cleaning of the tubes was required. In addition, the system was not efficient in terms of heat recovery because the condensing of the vapor before it entered the heat exchanger resulted in high-grade heat sources being converted to much lower grade heat. The condenser discharge was rarely hotter than 60°C by the time it reached the heat exchanger. For efficient heat recovery, it would have been preferable to recover heat from the atmospheric pressure-saturated vapor (101.3 kPa) than that from the 60°C water.

A rendering plant has recently installed a system to preheat potable water using heat recovered from the vapor that is exhausted by four batch rendering cookers. Each 3630 kg capacity steam-jacketed cooker exhausts 2105 kg of vapor during each 2.4 hour batch-cooking process. The average demand for hot water at 93°C for production and sanitation during the production shift is 480 L/min.

The system recovers heat by passing vapor at atmospheric pressure through a steam-condensing heat exchanger. Vapor from each cooker passes through pipes to a header connected to a knockout tank capable of holding one full cooker charge. The spiral type heat exchanger selected provides a high degree of turbulence, ease of inspecting and cleaning, and permits subcooling of the vapor to 57°C, allowing recovery of some of the sensible heat. Excess vapor goes to two of the existing spray condensers.



15. Rendering cookers heat recovery system

In performing a rigorous analysis of the energy flows, a disequilibrium was detected between the rendering process, which supplies the waste heat, and the sanitation process, which uses the heat. Until 4:00 p.m., there was a greater demand for hot water in the plant than the rendering cookers could supply. After 4:00 p.m., there was an excess of waste heat. This situation required the continued operation of a water-heating system to make up the deficit and a bypass system to exhaust the excess heat when it could not be employed.

In this case, the labor related to the handling of the rendering vapor does not change. Previously, some labor was required for operating and cleaning the spray type vapor condensers before the water and the waste heat were passed directly to the general system. Roughly the same labor will be required for maintaining the operation and cleaning the steam-condensing heat exchanger.

Since the recovered heat is not put back into the rendering process, there is no fuel saving on the waste heat generating process. The recovered energy heats the water used in sanitation and other production processes. Therefore, the saving is the amount of energy that would have been required to heat the water that will now be heated by the energy recovered from the rendering cookers during that period. During rendering startup from 7:30 to 9:00 a.m., the average hot water demand exceeds the vapor exhaust rate. Therefore, the savings will simply be the total amount of recoverable heat. The rendering vapor rises steadily to attain 3520 kg/h during this period. A savings of 54 425 m³/year of natural gas was calculated, representing an annual energy savings of \$4245.

During the maximum rendering period from 9:00 a.m. to 4:00 p.m., the equivalent hot water demand exceeds the vapor exhaust rate. Therefore, the savings will simply be the total amount of recoverable heat. After calculation, a natural gas savings of 507 970 m³/year was attained, representing an annual savings of \$39 621/year.

During the sanitation shift from 4:00 to 8:00 p.m., the rendering vapor exhaust exceeds the equivalent hot water demand. Therefore, the savings are calculated based on the thermal energy required to raise the temperature of 91 L/min water from 13 to 93°C. There will not be sufficient demand for the sensible heat

recovered by subcooling. After calculation, a natural gas savings of 62 150 m³/year was attained, representing an annual savings of \$4847. The total of these natural gas savings is 624 545 m³/year, which will reduce expenses by \$49 053/year.

The simple payback period is a commonly used method of evaluating an investment opportunity. It is the period in which the cash benefits equal the cash costs and the original investment is repaid. This method serves as a simple measure for deciding whether to proceed with a more detailed analysis. However, the problem with using the simple payback period method is that it obscures much valuable information, such as fluctuations in cash flows due to operational and financial variations (i.e., tax benefits in early years of operation, equipment maintenance, repair or replacement, real price changes and non-recurring costs in later years, and the significance of interest rates in discounting future costs and benefits). In this case, with the capital cost \$124 290, the simple payback period for the spiral heat exchanger used is $\frac{\$124\,290}{\$49\,053/\text{year}} = 2.5$ years. A more thorough financial analysis of spiral heat exchangers follows.

Table 1 illustrates the methods of financial analysis. It is assumed that natural gas prices will increase at a rate 2% faster than all other cost factors and the general rate of inflation. This is the real rate of growth estimated by Energy, Mines and Resources Canada. The annual fuel savings are calculated by multiplying the current annual fuel savings by the value of the compounded rate of increase of prices. If there were other savings (e.g., labor and materials), these would have a constant value provided that they only increased at the rate of inflation. Those costs would then be added to get the annual savings for each year.

In case study no. 1, the discount factor used is 10% real rate of interest. This means that the company would expect a 10% rate of return on investment after deducting the rate of inflation. The discount factor is the calculation of that value at 10%. It means, for example, that \$0.75 invested today would be worth \$1.00 3 years from now, owing to the compound interest earned. This factor is multiplied by the total annual savings for each year, which in this case is only the value of natural gas saved, to give the present value of the savings for the year. This calculated value is then subtracted from the present value of the costs to give the net present value for each year. In this case the only cost is the initial capital cost. The net scrap value of the equipment is assumed to be nil. There are no anticipated capital or other costs during the life of the project.

The net present value of the project is \$207 201, using a real discount factor of 10%, a 10-year project life, and a rate of growth in natural gas prices of 2% greater than the rate of inflation.

To proceed with a project, the net present value must be positive. This indicates that the investment returns a profit according to the assumptions used to calculate the value of the project.

These calculated values allow calculation of the benefit/cost ratio. In Case study no. 1, the B/C ratio is

$$B/C = \frac{\$331\,991}{\$124\,290} = 2.66$$

The benefit/cost ratio must have a value greater than 1 for an investment to be financially viable.

TABLE 1 Financial analysis of spiral heat exchanger (Case study No.1)

Year	Cost	Rate of real price increase (2%)	Annual savings in current \$ (49 053)	Discount factor (10%)	Present value annual savings	Accumulated present value annual savings	Net present value savings-costs
0	\$124 290						
1		1.0200	50 034	0.90909	45 486	45 485	-78 804
2		1.0404	51 035	0.82645	42 177	87 663	-36 627
3		1.0612	52 055	0.75131	39 110	126 773	2 483
4		1.0824	53 096	0.88301	36 266	163 039	38 749
5		1.1041	54 158	0.62092	33 628	196 667	72 377
6		1.1262	55 242	0.56447	31 182	227 849	103 559
7		1.1487	56 346	0.55316	28 915	256 764	132 474
8		1.1717	57 473	0.46651	26 812	283 576	159 286
9		1.1951	58 623	0.42410	24 862	308 438	184 148
10		1.2190	59 795	0.38554	23 054	331 491	207 201

The payback period is the time in which the net present value of the benefits equals the net present value of the costs. Table 1 shows that this period lasts almost to the end of the third year (2.9 years).

Many firms set an investment criteria that all investments must pay back within a specified time period or exceed a specific internal rate of return. If projects do not meet these criteria, they are rejected.

Case study no. 2 — steam plant flue gases

Canada Packers has installed a new and very efficient heat exchanger in its Winnipeg plant.

A direct contact heat recuperator is used to reclaim heat from the steam plant flue gases. The flue gas flows upward through the recuperator into which cold water is sprayed. The water is recirculated with a very small amount of makeup water.

Under optimum conditions, water leaving the recuperator will have been heated to 54°C. Flue gases will cool from 215 to 30-40°C. Dampers are installed to divert flue gases to a main stack in the event of a system failure.

The recirculated water flows through a plate heat exchanger and back to the recuperator. The clean, cold process water is preheated to 50°C in the exchanger. Process water can be further heated with steam for use as plant hot water. Table 2 presents the financial analysis of this case study.

TABLE 2 Financial analysis (Case study no. 2)

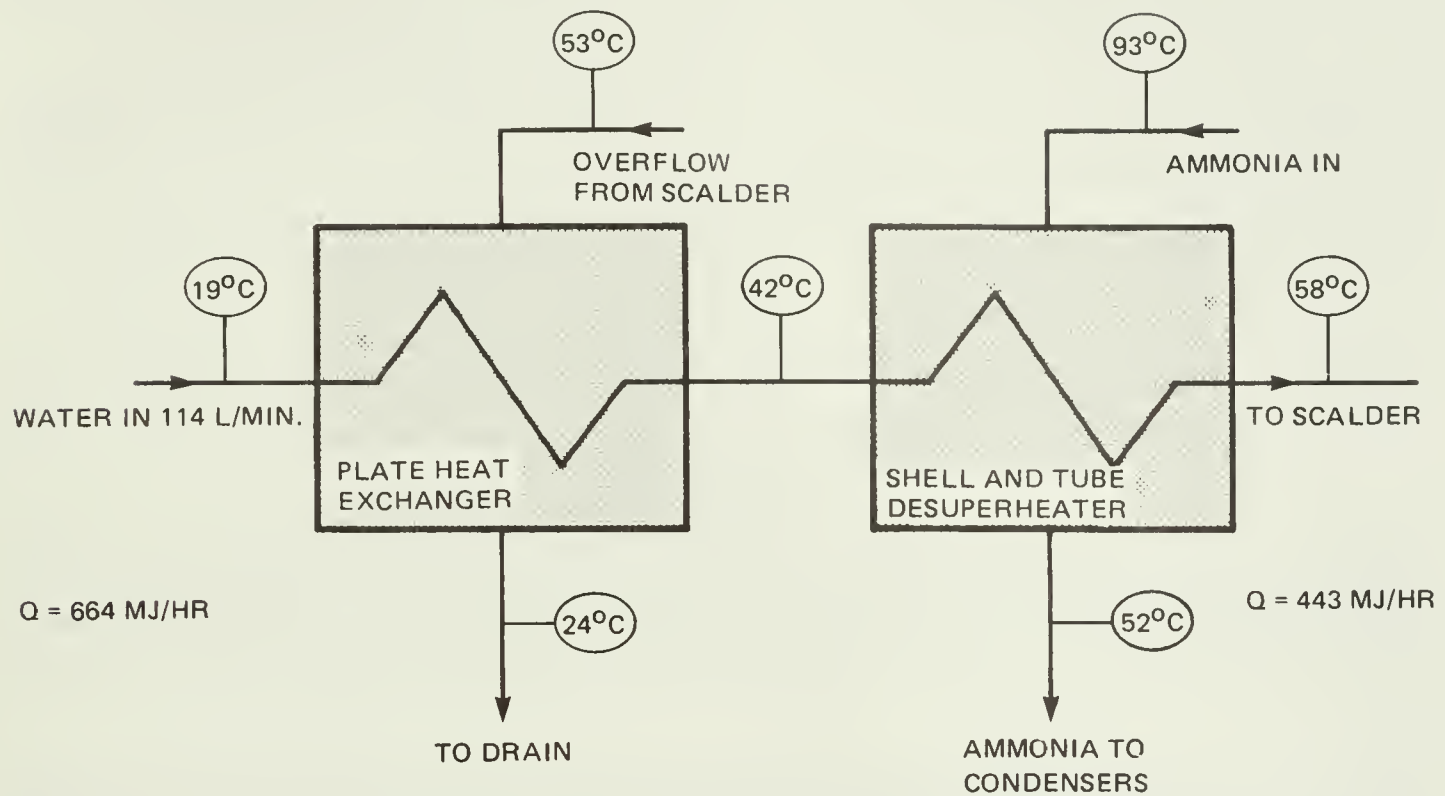
Project costs	
Recuperator and controls	\$ 225 000
Installation and auxiliaries	\$ <u>175 275</u>
Total installed cost	\$ 400 275
Operating costs	
Pre-demonstration annual fuel costs	\$1 489 600
(annual natural gas consumption)	
(9.8 × 10 ⁶ m ³ @ \$152/10 ³ m ³)	
Post-demonstration annual fuel costs	\$1 311 000
(8.625 × 10 ⁶ m ³ @ \$152/10 ³ m ³)	
Annual fuel savings	\$ 178 600
(1.175 × 10 ⁶ m ³ @ \$152/10 ³ m ³)	
Added incremental annual costs	\$ 27 900
(utilities and maintenance)	
Net annual savings	\$ 150 700
Simple payback period	2.7 years

Case study no. 3 — poultry scalding and desuperheater

The case of Gold Kist, Inc., in Elligay, Georgia, illustrates an interesting application in the poultry processing industry. The U.S. Department of Energy, the Georgia Institute of Technology and the company undertook a project that included designing, installing and monitoring heat recovery systems connected to both a poultry scalding overflow and a refrigeration condenser using ammonia as the refrigerant.

The scalding tank in which poultry carcasses are immersed must be kept in a constant overflow for sanitation purposes. The poultry scalding overflow is at 53°C at a rate of between 75-115 L/min and contains a high level of suspended solids. In order to prevent fouling of the heat exchanger, the overflow was cascaded over a parabolic screening surface. The exchanger selected was a plate heat exchanger consisting of stainless steel plates. It was selected because of its compactness, high heat transfer coefficients and ease of cleaning.

The ammonia temperature entering the evaporative condensers ranged between 93-105°C and the flow rate was between 3500-3850 kg/h. A shell and tube-type heat exchanger was selected for the desuperheater, with hot ammonia flowing in the tubes.



16. Poultry scalding and desuperheater heat recovery system

Overflow water from the scalding tank is screened and then piped through the plate heat exchanger counterflow to the incoming plant potable water (19°C), which will be used as makeup water for the scalding tank. This makeup water then goes to the desuperheater, where the temperature is raised from 42 to 58°C by the hot counterflowing ammonia. The makeup water then flows to the scalding tank. Table 3 shows the heat recovery systems' performance. Greater benefits can be obtained by installing a hot water storage tank and a recirculating pump to use or store the heat from the ammonia condensers at all times and not just while the scalding tanks are operating.

In food processing plants, contamination of potable water must be avoided. To prevent contamination, a differential pressure-sensing system was specified for the scalding tank overflow heat exchanger, which will shut down the electric wastewater pump if the wastewater pressure rises above the potable water pressure. In addition, a continuous pH monitoring and control system was installed in the water line coming from the ammonia desuperheater to detect any ammonia leakage into the potable water. The researchers calculated a simple payback period in an analysis of actual operating costs (see Table 3).

TABLE 3 Actual financial analysis (Case study no. 3)

System	Energy savings (MJ/h)	Capital cost installed (\$)	Energy cost installed (\$)	Simple payback period (years)
Overflow heat recovery system	664	13 287	16 921	0.78
Refrigeration heat recovery system	443	29 038	11 515	2.5
Combined systems	1107	42 325	28 436	1.5

Case study no. 4 — hog singer

Ever since energy became an important concern in the agri-food industry, the singeing operation in hog slaughtering has frequently been singled out as a major area of energy loss. In a normal singeing operation, the heat energy produces a wall of flame that is used to singe the hog carcasses as they pass through it. As a general rule, the surplus energy serves no useful purpose but does make this part of the plant very hot.

The managers of the Abattoir Olivier Bienvenue in Saint-Valérien, Quebec, were concerned about these energy losses and asked the firm Sonairtech Inc. to design a plant-integrated heat recovery system for the hog singer. A brief description of the system follows:

1. Air-water recovery

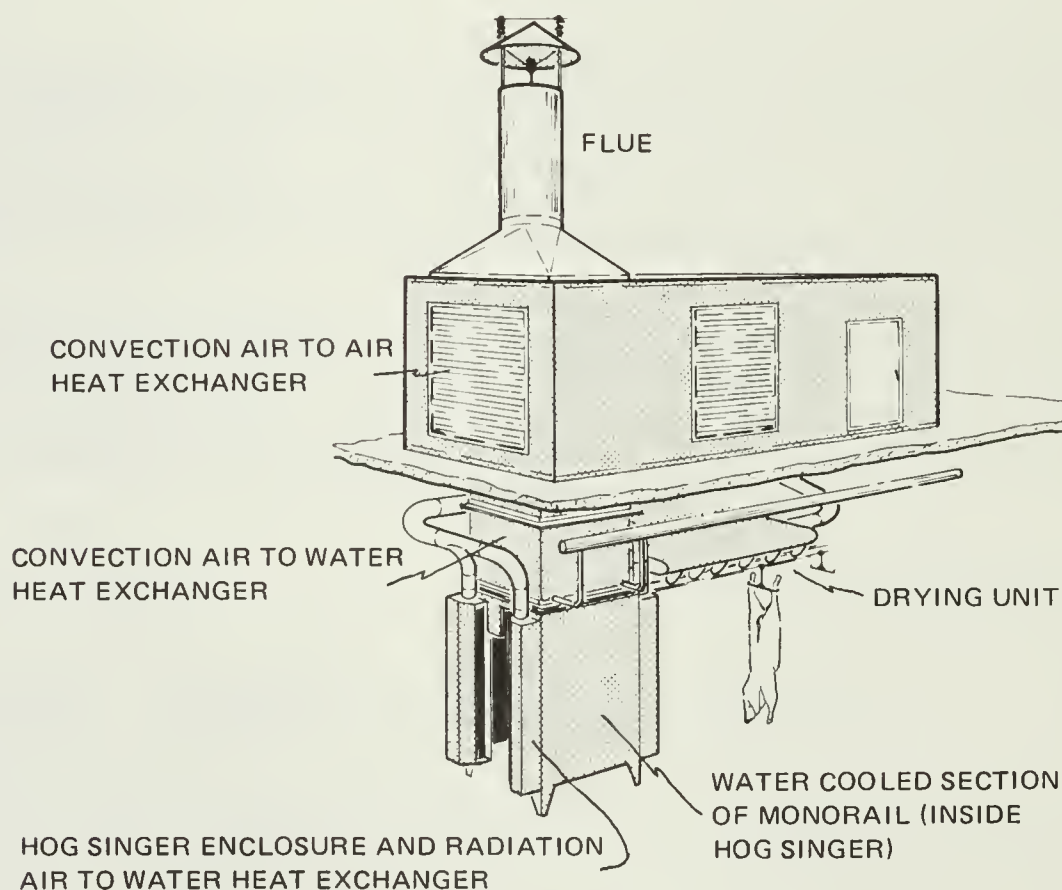
Two modules provide heat recovery:

- (a) Radiant heat recovery panels were installed on the two inner sides of the singer structure.
- (b) An air-water recovery unit (finned tube heat exchanger) was installed above the singer. Hot gases circulate through the unit, which recovers a large proportion of their heat.

During the winter, cold water from the storage tank is circulated directly through these recovery units, reaching an average temperature of 60°C at the outlet. The hot water is used in the slaughtering operation. During the summer, the water is first conveyed to a cooling coil installed in the main duct of the ventilation system for conditioning of the entrance air before it goes to heat recovery units.

2. Air-air recovery

An air-air heat recovery module made of a bank of tubular piping was installed over the air-water exchanger. This unit recovers some of the residual energy for heating air during cold weather, and the hot air is directed to the killing floor to keep it at a comfortable temperature.



17. Hog singer heat recovery system

This system is flexible and can be adapted to hot water needs of 60°C, 80°C or any other desired temperature by controlling the water flow through the exchanger. This will, of course, affect the volume of hot water obtained.

Case study no. 5 — fruit and vegetable processing

Green Giant of Canada Limited has studied and implemented a number of heat exchanger systems in various parts of its fruit and vegetable processing operations. A few of the projects are the following:

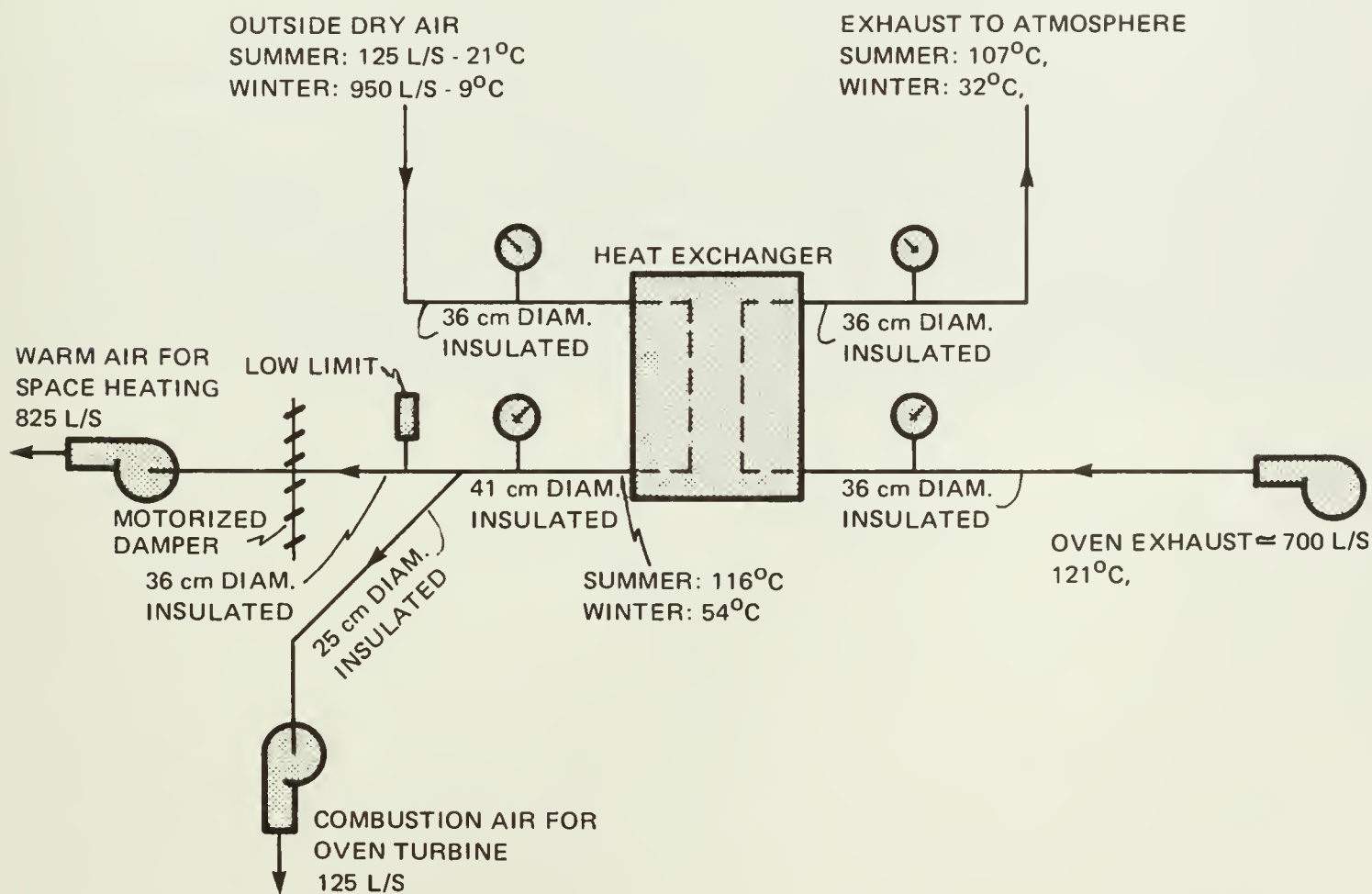
- A shell and tube heat exchanger (costing \$3200 including installation) is used to recover heat from boiler blow down, with an annual savings of \$1573. This represents a simple payback period of approximately 2 years.
- Heat is recovered from the evaporative condensers of the refrigeration system for a cold warehouse. The cost of adopting the evaporative condenser for heating, which included duct work, insulation, dampers and modulating motor drives, amounted to \$10 400. Since more than \$5200 in gas fuel was saved, the project indicated a simple payback period of 2 years.

The projects show that small investments in heat exchangers pay back well and enable plants to reduce energy costs.

Case study no. 6 — bakery oven heat recovery

When a new bakery oven was set up at Boulangerie Moderne & Roussin Inc., in Thetford Mines, Quebec, an air-to-air heat exchanger was installed on the front of the oven exhaust stack to recover the heat. The oven is direct-fired, and large enough to bake 4200 loaves of bread per hour. The oven's 53 Tri-Zone burners operate on propane.

The heat exchanger is a Z-Air, rated at 945 L/s. On one end, 700 L/s of combustion products ($N_2 + CO_2 + H_2O$) enter at $120^\circ C$ and leave at a temperature between $32-107^\circ C$, depending on the fresh air intake rate and temperature. During the summer, 125 L/s of outside fresh air enters the opposite side of the heat exchanger and is preheated to be used as combustion air by the oven turbine and burners. In the winter, 950 L/s of outside air



L/S: LITRES/SECOND

(sometimes below -18°C) enters the heat exchanger and is heated to be used as space heating for the shipping department. A room thermostat and a low-limit thermostat (inserted into the duct) are connected in series to operate the heating fan and motorized damper. The heat recovered is 4.75×10^4 kJ/h for combustion air (summer) and 2.3×10^5 kJ/h for winter heating. During the winter, maximum rates of over 3.2×10^5 kJ/h have been measured. Measurements of propane consumption with a gas meter installed on the oven gave the following results: 975 kJ/kg bread with the heat exchanger; 1000 kJ/kg bread without the heat exchanger. Tests of maximum firing rate of burners with and without the heat exchanger concluded that there was no measurable difference in firing rate.

The heat exchanger cost \$2300, and the total cost including ducts, fan, insulation and installation was \$5000. Installation was completed in April 1982. Propane and fuel oil (for heating) economy is estimated to be \$2125/year. The simple payback period should be approximately 2.5 years, based on 50 hours operation/week. The company was very satisfied with the heat exchanger's performance after the first year of operation. In addition to other benefits outlined, the dry, warm air released by the heat exchanger helps to eliminate humidity and condensation from building walls in the winter.

CONCLUSION

Potential of heat recovery

A report, entitled *Energy Cascading Potential in Canadian Industry*, prepared by the firm Lalonde, Girouard, Letendre & Associates Limited for Energy, Mines and Resources Canada, shows that in 1978 the food and beverage industries consumed $106\,960 \times 10^9$ kJ of energy — $22\,475 \times 10^9$ kJ as heat energy above 260°C . The report shows that 12.5% of the total energy consumed by the food and beverage industries can be practicably recovered by present heat recovery techniques. The authors determined the cascading potential of waste heat streams from the plant but did not evaluate heat recovery within plants. Therefore, the estimates pertain only to heat that is recoverable for use outside the plant from which it was generated. Within plants the extent of heat recovery is potentially much higher than shown in the report.

The authors estimate that 25% of the energy consumed by plants is theoretically recoverable at the plant boundary and that it is practical to recover half of this energy by conventional technology, that is, 12.5%.

In 1980 the cost of fuel and electricity purchased by food and beverage industries was \$422 007 000. Therefore, heat energy that is practical to recover at the plant gate with existing technology is estimated to be worth \$52 750 000. This is only 0.19% of the value of shipments of goods, but it represents 0.6% of the expenses other than materials and supplies. Since many heat exchangers pay back their cost in about 2 years, this represents a substantial increase in profits over the life of the equipment. Given the large potential benefits of recovering the heat energy in the waste energy streams in food and beverage industries, it is important to undertake assessments of the application of new heat recovery technology. Assessments must be both technical and economic and permit comparisons with other investment opportunities.

