ENERGY MANAGEMENT SERIES

9

FOR INDUSTRY COMMERCE AND INSTITUTIONS

Heating & Cooling Equipment (Steam & Water)

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canada

PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture, a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples of how to save energy.

For further information concerning the manuals listed below or material used at seminars/workshops including actual case studies, please write to:

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INTRODUCTION

Many heat exchange processes in use today were installed when the cost of fuel was very low, and energy management was not seriously considered. Because of this, many existing heat exchange processes are not energy efficient. The high cost of today's fuels has resulted in a greater awareness of Energy Management techniques which can be applied to present operations. This module describes how energy and dollars can be saved with the modification of installation arrangements and operating procedures.

Purpose

The following summarizes the purpose of this module.

- Introduce the subject of heating and cooling equipment (steam and water) used in the Industrial, Commercial and Institutional sectors.
- Provide an awareness of the potential cost savings available with the implementation of Energy Management Opportunities.
- Provide methods of establishing energy and cost savings. This is demonstrated through the use of equations, calculations and worksheets applied to specific worked examples.
- Provide a series of Energy Management Opportunities from which typical energy and cost savings can be calculated.

This module provides information which can be used to assist in identifying Energy Management Opportunities related to heat transfer equipment. Potential energy and cost savings can then be calculated.

Contents

In order to provide continuity of presentation the contents have been subdivided into the following sections.

- *Fundamentals* of heating and cooling equipment (steam and water) with examples, where necessary, to provide a basic understanding of the concepts used to develop the equations and calculations.
- *Equipment/Systems* describes typical heating and cooling equipment (steam and water) used in the Industrial, Commercial and Institutional sectors.
- *Energy Management Opportunities* are described and supported by estimated figures for energy and cost savings and simple payback calculations.
- Appendices which include a glossary of terms, tables, conversion factors, and blank worksheets.

FUNDAMENTALS

All heating and cooling equipment (steam and water) operates on the basis that energy, in the form of heat, flows from a higher to a lower temperature level.

In any heat transfer situation, the objective is to maximize the heat flow where the heating or cooling is required and minimize it in all other areas. Numerous Energy Management Opportunities exist within any heat transfer and distribution system. Certain basic concepts of heat transfer must be understood for the analysis of energy use, and are presented in this module.

Energy in Steam

When water is heated at atmospheric pressure, the temperature rises to 100°C. This is the highest temperature at which water can exist at this pressure. The addition of further heat does not raise the water temperature, but converts the water to steam. The heat, absorbed by the water in raising the temperature to the boiling point, is called *sensible heat*. The heat required to convert water to steam at the same temperature is called *latent heat*.

When water is heated at a pressure above atmospheric, the boiling point will be higher than 100°C and the sensible heat required will be greater. For every pressure there is a corresponding boiling temperature, and at this temperature the water contains a fixed, known amount of heat. The greater the pressure, the higher the boiling temperature and heat content. If the pressure is reduced, the heat content decreases, and the water temperature falls to the boiling temperature corresponding to the new pressure. This means that a certain amount of sensible heat is released from the water. This excess heat will be absorbed by the water in the form of latent heat, causing part of the water to *flash* into steam. An example of this is the discharge of condensate from a steam trap.

Heat Energy

Heat is a form of energy. The level of heat energy contained in an object is represented by its temperature. The higher the temperature the more energy an object will possess. If more energy is added to most objects the temperature will increase until its boiling point is reached. Some substances react differently at specific temperatures. For example, if heat is added to a block of ice it will melt and form water without an increase in temperature. Similarly, the addition of heat to water could result in boiling without an increase in temperature. The unit of energy in common use in the "SI system (System International) of Units," which is the basic system of measurement adopted in Canada, is the joule (J).

Heat

Energy in the form of heat, work, and electricity can be converted from one form to another only in the following manner.

- Mechanical energy to electrical energy is possible using an electric generator; 50% to 95% efficient.
- Mechanical energy to heat energy is possible, but not practical.
- Electrical energy to heat energy is possible using a heating element; 100% efficient for a heating element.
- Electrical energy to mechanical energy is possible using an electric motor; 50% to 95% efficient.
- Heat energy to mechanical energy is possible using an engine; maximum 40% efficient.
- Heat energy to electrical energy is possible using thermocouples, but not practical.

Energy is expressed in the units of calorie, joule, and watt-hour.

Energy Units

A calorie is the amount of heat required to raise the temperature of one gram of water 1°C. The calorie is not recognized by the SI system.

A joule is the SI unit of work equivalent to a force of one newton acting through a distance of one metre.

A watt-hour is the amount of electrical energy expended by the passage of one ampere of current across a potential drop of one volt, for a period of one hour.

The relationship between a joule, a watt-hour and a calorie is:

1 calorie = 4.1855 joules
1 watt-hour = 3600 joules

It is also correct to say that a watt is the rate of flow of energy of 1 joule per second.

Change of State

Temperature is a measure of the heat energy stored in an object. Water at atmospheric pressure boils at 100°C and ice melts at 0°C. When the temperature of an object is decreased to −273°C or 0 K (absolute zero) the object contains no heat energy. As heat energy is added, the temperature will increase until a change of state takes place.

Most substances undergo a change of state at a definite temperature, without an increase in temperature, until they are completely transformed. Typical examples are ice melting, or water boiling. Figure 1 illustrates the change of state process.

For most pure substances there is a specific *melting and freezing* temperature. External pressure has little or no effect on this temperature, so that melting and freezing does not occur at any other temperature.

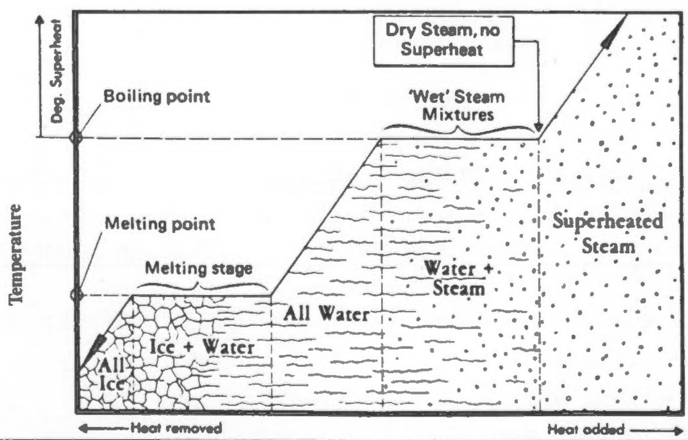
Ice, with the addition of heat, begins to melt at 0°C . The amount of heat necessary to melt one kilogram of ice at 0°C to one kilogram of water at 0°C is called the *latent heat of fusion* of water (334.92 kJ/kg). The removal of the same amount of heat from one kilogram of water at 0°C will change it into one kilogram of ice at 0°C.

The latent heat of fusion of most pure substances is found in physical property tables. The latent heat of fusion of mixtures and impure substances must be determined experimentally.

Unlike freezing and melting, *evaporation* takes place at any temperature. Evaporation is the gaseous escape of molecules from the surface of a liquid. The rate of evaporation reaches a maximum when the liquid boils. Once the boiling point temperature of a liquid is reached, additional heat energy is required to convert the liquid to a gas (e.g. water to steam). This quantity of heat is called the *latent heat of vaporization*. For water, the latent heat of vaporization is 2256.9 kJ/kg at 101.325 kPa(absolute) and 100°C.

Water, alcohol, and gasoline evaporate at all temperatures, with an increased rate of evaporation occurring at higher temperatures. The evaporated gases exert a pressure called the *vapor pressure*. As the temperature of a liquid rises, there is a greater loss of liquid from the surface: this increases the vapor pressure. Once the vapor pressure reaches the pressure of the surrounding gases, boiling occurs. The boiling of water at atmospheric pressure generates steam at 101.325 kPa(absolute). If the pressure on the surface is increased, boiling takes place at an elevated temperature.

Water can evaporate and boil below atmospheric pressure. Examples are the use of vacuum evaporators to concentrate sugar solutions, orange juice, or milk, where excess water is boiled off at temperatures of 40 to 60°C. This is done to help preserve the flavour of the concentrate.



Example of Change of State
Figure 1

Saturated Steam

When steam leaves the surface of boiling water, in an open or pressurized vessel, it is called *saturated steam*. Removal of heat from this steam will cause it to condense into water. Steam, leaving the surface of boiling water, is soon cooled by the surrounding air and condenses. The condensed steam appears in the form of droplets over the water surface. In a steam pipe, the droplets form larger drops which fall to the bottom of the pipe to form condensate, which is subsequently removed by steam traps.

Superheated Steam

Superheated steam is produced when saturated steam is heated to a temperature higher than the saturation temperature. Since superheated steam does not have any free water, the value of its enthalpy (heat content) can be read directly from superheated steam tables at the point corresponding to the temperature and pressure. The amount of superheat in steam is expressed in degrees of superheat (the number of degrees Celsius to which the steam is heated above the saturation temperature).

Superheated steam is not ideal for heating applications. Constant superheat temperature is difficult to maintain and the heat carrying capacity per unit volume is lower. Increased pipe sizes are required to carry the same weight of steam. Heat transfer performance can be increased by *desuperheating* the steam. The most common method of desuperheating is by spraying water into the steam.

Quality of Steam

When saturated steam leaves the surface of water in a boiler drum it should be pure steam at saturation temperature and pressure. However, some tiny water droplets escape with the steam. The ratio of the mass of pure vapor to the total mass is called the quality of steam or dryness fraction.

Quality of steam can be expressed by the equation:

$$\text{Quality (x)} = \frac{\text{mass of vapor}}{\text{total mass}}$$

If the quality of steam is 1.0, this means that there is no free moisture in the steam. This is referred to as dry and saturated steam. As the steam cools, its quality deteriorates. The percentage of water by mass in the steam may be determined by the equation:

$$\text{Per cent water} = 100\% - (\text{quality} \times 100).$$

For example, if the quality of steam is calculated to be 0.98 then,

$$\begin{aligned}\text{Per cent water} &= 100 - (0.98 \times 100) \\ &= 100 - 98 \\ &= 2\%\end{aligned}$$

Quality has meaning only when the steam is in a saturated state, at saturation pressure, and temperature.

Steam Tables

Steam tables are used to express the quantity of energy available in water or steam (Tables 1 and 2). They are also used to determine the saturation temperatures and specific volumes of steam and water at various pressures. The following explanations of steam and water properties will assist in using the steam tables.

- Pressure, (kPa). The pressure used in steam tables is the saturation pressure expressed as kPa(absolute). The gauge pressure is always 101.325 kPa lower than the absolute pressure because it does not take atmospheric pressure into account. To obtain absolute pressure, a value of 101.325 kPa must be added to the gauge pressure.
- Saturation Temperature, (°C). Saturation temperature is the temperature at which boiling will take place to produce steam at a given pressure. For example, if a boiler produces saturated steam at 374.68 kPa(gauge) it will operate at a temperature of 150°C.
- Specific Volume of Saturated Liquid, v_f (m^3/kg). This value is the volume in cubic metres occupied by one kilogram of water at the saturation temperature. It can be seen that this value does not change drastically

over a wide range of temperatures. The increase in specific volume with increase in temperature is the reciprocal of the decrease in density at the same increase in temperature. The density of water is 1000 kg/m^3 at room temperature.

- Specific Volume of Saturated Steam, v_g (m^3/kg). The specific volume of saturated steam is the volume in cubic metres occupied by one kilogram of dry saturated steam at the corresponding pressure.
- Enthalpy (kJ/kg). When a steam table is formulated it is assumed that water at 0°C contains no energy. The total energy contained in water, steam or a mixture of both is called the enthalpy of the fluid and is expressed in kilojoules per kilogram. Under the enthalpy heading there are three columns identifying enthalpy of the liquid (h_f), enthalpy of evaporation (h_{fg}), and enthalpy of steam (h_g).

The *enthalpy of liquid* (h_f) is a measure of the amount of heat energy contained in the water at a specific temperature.

The *enthalpy of evaporation* (h_{fg}) (correctly called the latent heat of vaporization) is the quantity of heat energy required to convert one kg of water to one kg of steam at the given pressure.

The *enthalpy of steam* (h_g) is the total heat energy contained in dry saturated steam at the given pressure. This quantity of energy is the sum of the enthalpy of the liquid (h_f) and the amount of energy required to evaporate one kilogram of water at the temperature in question (h_{fg}).

The three previous figures for enthalpy may be expressed

$$h_g = h_f + h_{fg}$$

Where, h_g = Enthalpy of the steam (kJ/kg)

h_f = Enthalpy of the liquid (kJ/kg)

h_{fg} = Enthalpy of evaporation (kJ/kg)

This relationship holds true for saturated steam at any pressure.

Transport of Steam

Steam is produced in one or more boilers, usually, in an area remote from the steam using equipment. The steam must be distributed through an arrangement of piping and valves to reach the final destination. Unless there is a clear understanding of the basic principles behind the transport of steam, costly mistakes can be made.

In transporting steam through piping these data must be known.

- Temperature and pressure of steam.
- Quantity of steam required.
- Distance over which steam is transported.

In sizing steam distribution piping it is recommended that the velocity of the steam be kept within practical limits. Good practice suggests a steam velocity of 40 to 60 m/s with a maximum of 75 m/s. If the pipe is too large, unnecessary heat loss owing to larger exposed surface areas, and a higher cost of piping and insulation will result. If the pipe is too small, there will be excessive noise in the pipeline due to excess velocity, as well as a loss of pressure and capacity.

The velocity of saturated steam in a pipe can be determined using the equation:

$$V = \frac{w \times v_g}{A \times 3600}$$

Where, V = Velocity of steam (m/s)

w = Rate of flow of steam (kg/h)

A = Inside area of pipe (m^2)

v_g = Specific volume of saturated steam at the operating pressure (m^3/kg)

3600 = Conversion from hours to seconds

Worksheet 9-1 is provided for this calculation. An example of the use of this worksheet follows.

Steam Velocity Calculation

Worksheet 9-1

Company: XYZ CO. LTD. Date: FEB. 20. 1985

Location: ANYTOWN By: MBE

Steam pipe internal diameter 0.1541 m

Steam flow (w) 13,608 kg/h

Specific volume of steam (v_g) 0.25888 m^3/kg

Cross sectional area of pipe (A) $= \frac{3.142 \times (\text{internal dia})^2}{4}$

$= \frac{3.142 \times (0.1541)^2}{4}$

$= 0.0187$ m^2

Velocity (V) $= \frac{w \times v_g}{A \times 3600}$

$= \frac{13608 \times 0.25888}{0.0187 \times 3600}$

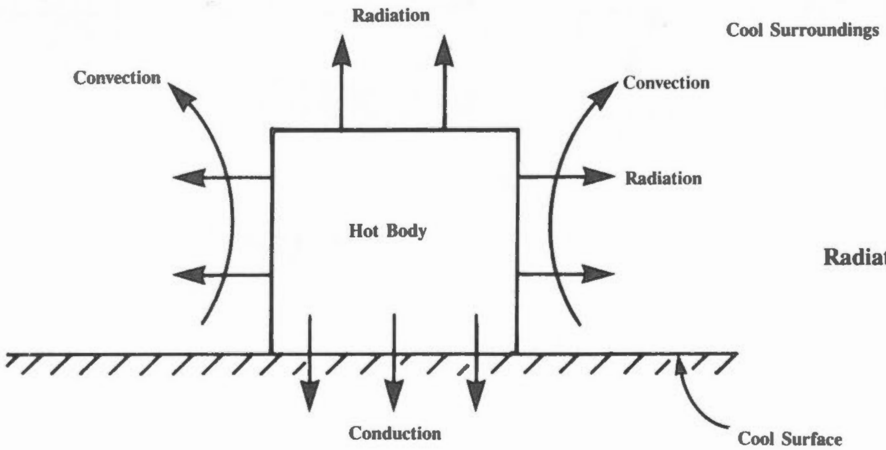
$= 52.33$ m/s

For steam mains, velocity should fall between 40 m/s and 60 m/s. If velocity exceeds 75 m/s flow should be reduced or pipe should be increased in size.

Methods of Heat Transfer

A hot object loses heat in three ways. (Figure 2)

- Radiation to the surroundings.
- Convection to the fluid surrounding it.
- Conduction to other bodies that are in contact with it.



Radiation - Convection - Conduction
Figure 2

Radiation

Radiation is a process by which heat flows from a higher temperature body to a lower temperature body when the two bodies are not in contact. The energy transmitted in this manner is termed radiant heat. All bodies emit radiant heat continuously. The intensity of the emission depends on the temperature and nature of the surface.

When radiation waves encounter some other body, their energy is absorbed near the surface. Heat transfer by radiation becomes increasingly important as the temperature of an object rises. At temperatures approximating those of the atmosphere, radiant heating may often be neglected.

Convection

Convection is the process of energy transfer by the combined action of heat conduction, energy storage, and mixing motion. Convection is the most important mechanism of energy transfer between a solid surface and a liquid or a gas.

The transfer of energy by convection takes place in several steps. First, heat will flow by conduction from the surface to the adjacent particles of fluid. The energy transferred will increase the temperature and the internal energy of the fluid particles. The fluid particles will move to a region of lower temperature, where they will mix with, and transfer a part of their energy to, other particles. The flow in this case is of fluid, as well as energy. The net effect is a transport of energy, and since it occurs in the direction of a temperature gradient, it is referred to as *heat flow by convection*.

Convection heat transfer is classified into *free convection* and *forced convection*. When the mixing motion takes place, merely as a result of a density difference caused by temperature gradients, it is called free or natural convection. When the mixing motion is induced by some external agency, such as a pump or a blower, the process is called forced convection.

The effectiveness of heat transfer by convection is largely dependent upon the mixing motion of the fluid. Convection heat transfer is based on the characteristics of fluid flow. Heat transfer by convection cannot take place in a vacuum.

Conduction

Conduction is the process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (solid, liquid or gaseous), or between different mediums in direct physical contact. In conduction heat flow, the energy is transmitted by direct molecular contact without appreciable displacement of the molecules. The observable effect of heat conduction is an equalization of temperature. However, if differences in temperature are maintained by the addition or removal of heat at different points, a continuous flow of heat will be established from the hotter to the cooler region.

Conduction is the only method of heat flow in opaque solids. Conduction is also important in fluids, but in nonsolid mediums it is usually combined with convection, and in some cases, with radiation.

Condensation Processes

Two types of condensation may occur either alone or in combination. These are filmwise and dropwise condensation.

Filmwise Condensation

When a pure saturated vapor strikes a surface of lower temperature vapor condenses, and a film forms on the surface. If the condensate flows along the surface because of gravity, and a condition of streamline flow exists throughout the film thickness, then heat transfer through the film is by conduction. Since the heat transfer is by conduction, the thickness of the condensing film has a direct effect on the quantity of heat transferred. The thickness of the film depends on the rate at which condensate is removed. On a vertical surface, because of drainage, the thickness of the film will be greater at the bottom than at the top. The thickness of the film will increase as the surface is inclined from the vertical position.

Film temperature is the average of the surface and vapor temperatures. An increase in the film temperature decreases the film viscosity and thickness. This is because the drainage velocity increases with a decrease in the film viscosity. The film thickness is reduced by an appreciable velocity of the vapor owing to the frictional drag between the vapor and the condensate. Vapor should flow in the same direction as the condensate. As heat transfer increases, owing to an increase in the temperature difference between the vapor and the surface, the thickness of the condensate film increases. The surface conductance of heat transfer decreases with an increase in temperature difference, which is an unusual relationship.

The theoretical equations for conductance of heat transfer for filmwise condensation involve the thermal conductivity, viscosity, and density of the condensate, the temperature difference between the vapor and the surface, and certain dimensions of the surface, such as height for vertical surfaces, and diameter for horizontal tubes. These equations may be found in text books covering the subject of heat transfer.

Dropwise Condensation

On surfaces contaminated with a substance that prevents the condensate from wetting the surface, steam condenses in drops, and not as a film. Examples are benzyl mircaptan on copper or brass, and oleic acid on copper, brass, nickel or chromium. Under these conditions a large part of the surface, not covered by an insulating film of water, is free for unobstructed heat transfer. This is known as dropwise condensation. Conductances from dropwise condensation are 4 to 8 times as high as the conductances for filmwise condensation. Since the occurrence of dropwise condensation is rare, it is best to perform heat transfer calculations using filmwise condensation coefficients which may be found in heat transfer text books.

Steam Traps

The purpose of installing steam traps is to obtain fast heating of the product and equipment by keeping the steam lines and equipment free of condensate, air and noncondensible gases. A steam trap is a valve device that discharges condensate and air from a steam line or piece of equipment without discharging steam. When starting up equipment and steam systems, lines and equipment are full of air which must be flushed out. During continuous operation a small amount of air and noncondensible gases, which enter the system with the boiler feedwater, must also be vented.

Some steam traps have built-in strainers to provide protection from dirt and scale. Unless removed, this material may cause the trap to jam in an open position, allowing the free flow of steam into the condensate collection system. Traps are also available with check valve features to guard against condensate backflow. Details may be obtained from trap manufacturers and catalogues. The following text discusses the basic types of steam traps which will be encountered.

Temperature-Sensitive (Float and Thermostatic) Trap

There are two types of temperature-sensitive steam traps. The first type operates from the movement of a liquid filled bellows, and the second by the movement of a bimetallic element. These traps are activated by temperature differential. Both types are open when cold, and discharge air and condensate at start up. Steam is in direct contact with the valve, but there is a time delay with both types on closing. Operation of temperature-sensitive traps is improved if a large dripleg is used to allow time for the condensate to cool. These units are susceptible to damage by water hammer. They are usually economic at steam pressures greater than 41 kPa(gauge).

Impulse Traps

Impulse traps are also referred to as "thermodynamic" or "controlled disc" traps. The preferred applications for these units are those where the pressure is in excess of 56 kPa(gauge) and the downstream pressure is less than one half of the upstream pressure. They are not affected by water hammer.

Density-Sensitive Trap

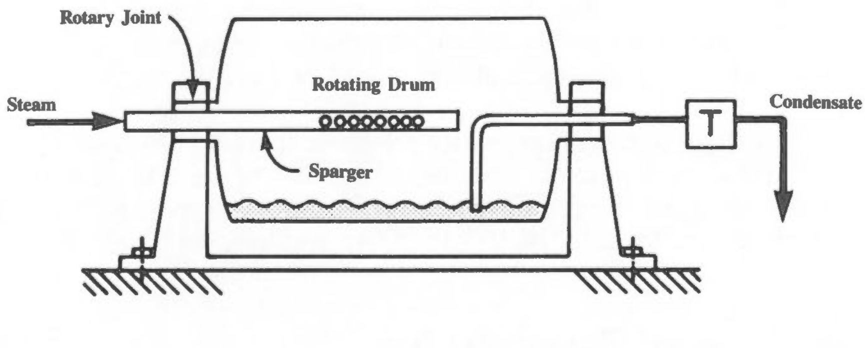
Density-sensitive traps are made in "float" and "bucket" designs. The float trap is able to discharge condensate continuously, but this trap will not discharge air unless it is fitted with a temperature sensitive vent. Water hammer may cause float traps to fail.

The inverted bucket trap is probably the most commonly used trap. The trap is open when cold, but will not discharge large quantities of air at start up unless fitted with a temperature- sensitive vent. The action in discharging condensate is rapid.

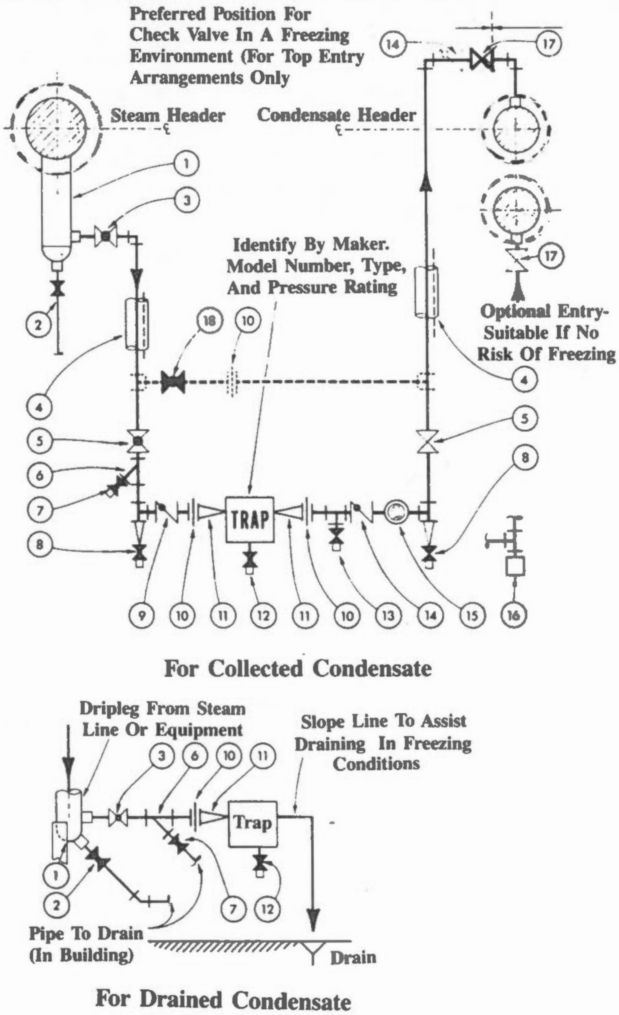
Trapping Techniques

Figure 3, illustrates the recommended steam trap piping arrangements for the majority of steam heated equipment. The following should be considered whenever steam traps are being installed.

- Group traps in an orderly arrangement for ease of maintenance and servicing.
- Pipe, valves and fittings should be the same size as the trap connections, but never smaller than NPS 3/4.
- Normally, traps are installed below the equipment or device that the trap serves.
- Each item of steam using equipment should be trapped separately.
- Traps should be provided where there are low points in steam mains. Condensate, which collects during start up, can then be discharged from the mains.
- Where possible, depending on heat exchanger nozzle configuration, locate a dripleg at the mid point of heat exchanger shells. Locate dual driplegs at or near each end of a heat exchanger.
- For installations in freezing conditions where condensate is not collected, choose traps such as thermostatic that will not pocket water and which can be installed vertically to allow draining by gravity. Otherwise, select a trap that can be fitted with an automatic draining device by the manufacturer.
- Where freezing conditions exist, avoid long horizontal discharge lines as ice can form in the line downstream of the trap. Keep discharge lines short, and in the event that the condensate is not being collected, slope them downward to allow self draining.
- For steam heated equipment using large quantities of steam consider the installation of a steam separator in the supply line. Steam separators are further discussed in this module.
- Syphon removal of condensate is required for rotating equipment. The pressure of the steam is used to force (syphon) the condensate up a tube into the trap (Figure 4).



Trapping Arrangement for Rotating Drum
Figure 4



Key

1		Dripleg from steam header, or line to equipment, or line from steam-fed equipment.
2		Dripleg valve for periodically blowing down sediment. For safety, valve should be piped to a drain or to grade.
3		Isolating valve to be located close to dripleg.
4	★	Insulation. Needed in a cold environment if there is a risk of condensate freezing as a result of shutdown or intermittent operation in extreme cold. Tracing may also be required-if steam is not constantly available for this purpose, electric tracing would be necessary.
5	★	Isolating valve, required only if valves (3) and (17) are out of reach, or if a bypass is used - see note (18).
6		Strainer, normally fitted in lines to traps of less than 2-inch size. A strainer may be an integral feature of the trap.
7	★	Valve for blowing strainer sediment to atmosphere plug for safety.
8	★	Manually operated drain valve for use in freezing conditions when the trap is positioned horizontally - see note (16).
9	★	Check valve, primarily required in lines using bucket traps to prevent loss of seal water if differential pressure across trap reverses due to blowing down the the line or strainer upstream of the trap.
10		Unions for removing trap, etc.
11	★	Swages for adapting trap to size of line.
12	★	Blowdown valve for a trap with a built-in Strainer [Alternative to (6)].
13	★	Test valve shows if a faulty trap is passing steam. Sometimes, body of trap has a tapped port for fitting this valve.
14	★	Check valve prevents backflow through trap if condensate is being returned to a header from more than one trap. In the lower position, the valve has the assistance of a column of water to help it close and to give it a water seal. Required if several traps discharge into a single header which is or may be under pressure.
15	★	Sight glass allows visual check that trap is discharging correctly into a pressurized condensate return, but is seldom used because the glass may erode, presenting a risk of explosion.
16	★	Temperature-sensitive (automatic) drain allows line to empty, preventing damage to piping in a cold environment [See note (4)]. If valve (14) is overhead, the automatic drain may be fitted to the trap - some trap bodies provide for this.
17		Isolating valve at header.
18	★	By-pass not recommended as it can be left open. It is better to Provide a standby trap.

★ Asterisk indicates that the equipment is optional and is not essential to the basic trap piping design.

Figure 3

Steam Trap Leakage

In any steam distribution system with steam heated equipment, it is estimated that, unless there is a good preventive maintenance program which includes routine steam trap maintenance, as many as 25 per cent of the traps may be leaking. If this is equated to the quantity of steam wasted, it becomes obvious that trap maintenance pays dividends. However, the method of determining trap leakage is not easy.

Consider a trap discharging to atmosphere. The condensate discharge flow will be continuous from float and thermostatic traps, and intermittent from bucket and disc traps. Because the steam trap is discharging to atmosphere, flash steam will be generated. It is very difficult to establish whether the discharge is flash steam or steam due to trap leakage. If the steam blows out continuously in a "blue" stream, it is leakage. If steam floats out intermittently in a "whitish cloud", it is flash steam.

Unfortunately, the steam is not visible if the trap discharges to a condensate collection system. In this case the following methods are available to evaluate the possibility of trap leakage.

- Using a listening device or steel rod held to the ear, listen to the trap discharge line. Continuous discharge can normally be recognized by the high velocity sound of steam blowing through the trap. This method requires experience, and it may not work well in areas with high background noise. A stethoscope is a typical listening device.
- Using a pyrometer, establish the temperature of the pipe at the trap inlet and discharge. The trap may be blowing steam if the discharge pipe temperature is nearly as high as the inlet pipe temperature.
- Install sight glasses in the trap discharge pipe and visually monitor the trap discharge. *Caution must be taken since the glass may erode with time, presenting a risk of explosion.*

Additional trap information may be found in Steam and Condensate Systems, Module 8.

Steam Leaks

Steam leaks are another major source of energy and dollar wastage. Table 3 indicates the quantity of steam wasted per month for various sized orifices (holes) and pressures when steam is leaking to atmosphere.

In well insulated piping steam leaks may be difficult to locate. Signs of leakage are soaked insulation, water dripping from insulation covering, and, of course, a visible steam plume. In the majority of instances, leaks are found at valves or flanged joints in a piping system, and can be repaired by either tightening a bolted connection, replacing a gasket, or repacking a valve gland.

An example of the magnitude of steam leak costs is given on Worksheet 9-2 which follows.

Flash Steam and Water Hammer

When hot condensate under pressure is released to a lower pressure return line, the condensate immediately boils. This is referred to as flashing and the steam produced is flash steam. Higher temperature condensate and/or a lower temperature discharge line, causes the rate of flashing to increase. This flashing can be severe if the condensate comes from high pressure steam. Since only a portion of the condensate flashes to steam, the possibility exists that flash steam may force the liquid condensate through the condensate piping in "slugs". These slugs of condensate travel through the system like a "battering ram" and can result in damage to pipe, fittings, regulating valves, and equipment. Water hammer occurs when slugs of water move through the system and encounter obstructions. Details covering calculation of flash steam quantity are provided in Steam and Condensate Systems, Module 8.

Steam Separators

In distribution systems separators remove condensate from steam. Usually, separators are installed on the upstream side of equipment where dry steam is mandatory, or in secondary steam distribution piping where fairly large percentages of entrained condensate may be present. The rate of heat transfer in the equipment will be improved by removing condensate from the steam distribution system.

Condensate Discharge Capacity

The capability of a steam trap to discharge the condensate, which is produced during cold start up and normal operation, is important. When steam is turned on and the equipment is cold, the rate at which condensate is produced is much greater than when the equipment is functioning at operating temperature.

Steam trap sizing is based on the quantity of condensate produced during steady state operating conditions, with the application of a safety factor to allow for the start up condensate load. Depending on the application, the safety factor will be between 2 and 10. For example, a trap with a capacity of 200 kg/h is not adequate for a 200 kg/h capacity coil at 793 kPa differential pressure. Under start up conditions the condensate formed could be more than 200 kg/h or the pressure differential could drop. In either case, the coil would flood with condensate to decrease the heat transfer rate. A great deal of documentation on steam trap sizing has been prepared by various steam trap manufacturers. The sizing formulae for the specific application should be discussed with suppliers or manufacturers.

Steam Loss To Atmosphere
Worksheet 9-2

Company: XYZ CO. LTD. Date: FEB. 20, 1985

Location: ANYTOWN By: MBE

Equipment PROCESS WATER HEAT EXCHANGER

Estimated leak diameter 2.38 mm

Steam pressure 689 kPa(gauge)

Steam loss 13.47 kg/h (Table 3)

Operation: Hours per day 24

Days per week 7

Weeks per year 52

Steam cost: $ 22 /1000 kg (obtain from steam generator operator)

Steam lost = 13.47 kg/h x 24 h/day x 7 day/week x 52 week/yr

= 117674 kg/yr

Potential dollar savings

= 117674 kg/yr x $ 22 /1000 kg

= $ 2,589 per year

General Heat Transfer Equation

The general heat transfer equation is:

$$Q = U \cdot A \cdot DT$$

Where, Q = Rate of heat transfer (Watts)

U = Overall coefficient of heat transfer [Watts/(m²·°C)]

A = Surface area available to transfer heat (m²)

DT = Temperature difference between the hot and cold fluids (°C)

Values for U for various heating and cooling applications can be found in Figure 5. For applications other than those indicated, published tables are available listing U values.

HEATING APPLICATIONS		CLEAN SURFACE COEFFICIENTS		DESIGN COEFFICIENTS Considering Usual Fouling in this Service	
HOT SIDE	COLD SIDE	Nat. Convect.	Forc. Convec.	Nat. Convect.	Forc. Convect.
1. Steam	Watery solution	250-500	300-550	100-200	150-275
2. Steam	Light oils	50 - 70	110-140	40 - 45	60-110
3. Steam	Medium lube oil	40 - 60	100-130	25 - 40	50-100
4. Steam	Bunker C or #6 fuel oil	20 - 40	70 - 90	10 - 30	60 - 80
5. Steam	Tar or asphalt	15 - 35	50 - 70	15 - 25	40 - 60
6. Steam	Molten sulphur	35 - 45	60 - 80	4 - 15	50 - 70
7. Steam	Molten paraffin	35 - 45	45 - 55	25 - 35	40 - 50
8. Steam	Air or gases	2 - 4	5 - 10	1 - 3	4 - 8
9. Steam	Molasses or corn syrup	20 - 40	70 - 90	15 - 30	60 - 80
10. High temp. hot water	Watery solutions	80-100	100-225	70-100	110-160
11. High temp. ht. transfer oil	Tar or asphalt	12 - 30	45 - 65	10 - 20	30 - 50
12. Therminol	Tar or asphalt	15 - 30	50 - 60	12 - 20	30 - 50
COOLING APPLICATIONS					
COLD SIDE	HOT SIDE				
13. Water	Watery solution	80-100	150-200	65-125	105-200
14. Water	Quench oil	10 - 15	25 - 45	7 - 10	15 - 25
15. Water	Medium lube oil	8 - 12	20 - 30	5 - 8	10 - 20
16. Water	Molasses or corn syrup	7 - 10	18 - 26	4 - 7	8 - 15
17. Water	Air or gases	2 - 4	5 - 10	1 - 3	4 - 8
18. Freon or ammonia (dir. expan.)	Water solution	35 - 45	60 - 90	20 - 35	40 - 60
19. Calcium or sodium brine	Watery solution	100-120	175-200	50 - 75	80-125

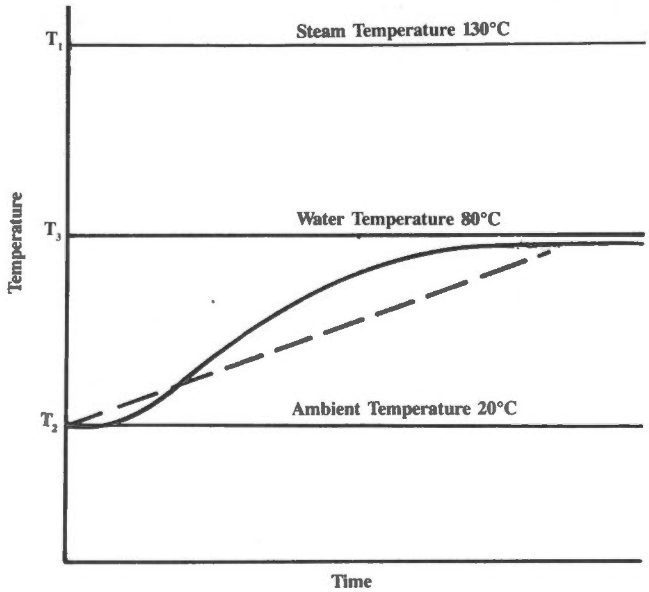
Note: 1 Btu/(h · ft²·°F) = 5.68 W/(m²·°C)

Average Overall Heat Transfer Coefficients U = Btu/(h · ft²·°F)
Figure 5

Log Mean Temperature Difference (LMTD)

In any heat transfer heating calculation a correct understanding of the term DT is important. Consider the simple task of heating a tank of water with a steam heated coil suspended in the water (Figure 6). The water is to be heated from the ambient temperature of 20°C to 80°C with 172.25 kPa(gauge) steam at 130°C.

From Figure 6, the thermal gradient available at the start of the process is $T_1 - T_2 = 130°C - 20°C = 110°C$. As the water heats up, the thermal gradient reduces until the water temperature reaches 80°C, and the thermal gradient is $T_1 - T_3 = 130°C - 80°C = 50°C$. It is necessary to determine the average mean temperature, DT, that can be used for the entire heating cycle. If the water temperature increases uniformly, as shown by the dashed line, the arithmetic average of the starting and final temperature difference would apply.



Typical Heating Curve
Figure 6

$$\frac{(T_1 - T_2) + (T_1 - T_3)}{2} = \frac{110°C + 50°C}{2}$$

$$= 80°C$$

However, the usual heating curve is as shown by the solid line. For greater accuracy, it is necessary to use the logarithmic mean temperature difference (LMTD). Using the same data this can be determined accurately by the following equation:

$$LMTD = \frac{DT_1 - DT_2}{\ln\left(\frac{DT_1}{DT_2}\right)}$$

Where LMTD = Log mean temperature difference (°C)

DT_1 = Greater temperature difference between hot and cold fluid (°C)

DT_2 = Lesser temperature difference between hot and cold fluid (°C)

Worksheet 9-3 is provided for this calculation and has been completed for the previous example. This calculated value is the correct one to use as DT in the formula

$Q = U \cdot A \cdot DT.$

Log mean temperature difference (Table 4) has been calculated from the above equation for values of T_1 between 0°C and 400°C, and T_2 between 5°C and 240°C. For values outside this range the equation must be used.

Effect of Insulation on Heat Transfer

The quantity of heat required for heating is the heat needed to raise an object to the desired temperature, plus the heat lost to the surrounding area. For example, in a storage tank application, the total heat required is the sum of the heat needed to raise the stored product to the required temperature, plus the heat loss from the tank and liquid surfaces to atmosphere. Where the function of the equipment is to maintain the temperature of the stored product at the incoming temperature, the heat required is equal to the heat loss. Applying insulation to the exterior surface of the equipment reduces the rate of heat transfer to the surroundings, since the value of U in U·A·DT will be less and will reduce Q.

Heat loss from insulated equipment and piping can be established by the use of Tables 5 and 6, and worksheets 9-4 and 9-5. Reduction of the heat loss by the application of insulation is covered in Process Insulation, Module 1.

Examples of the use of worksheets 9-4 and 9-5 follow.

Effect of Air Movement on Heat Transfer

The effect of air movement over the exterior surface of a tank or equipment is to increase the rate at which heat is lost to the surroundings. This is because, under a no wind situation, a condition approximating a steady state temperature gradient forms around the exterior surface. Wind removes this steady state temperature gradient, and the heat transfer rate increases.

Published data concerning U factors at various temperature differentials and wind velocities is available and should be used.

Calculation Of LMTD

Worksheet 9-3

Company: XYZ CO. LTD. Date: FEB. 20, 1985

Location: ANYTOWN By: MBE

Heating Application

Original temperature of liquid (T_2) 20 °C

Final temperature of liquid (T_3) 80 °C

Steam temperature (T_1) 130 °C

Greater temperature difference $= T_1 - T_2$

$= 130 - 20$

$= 110$ °C (DT_1)

Lesser temperature difference $= T_1 - T_3$

$130 - 80$

$= 50$ °C (DT_2)

LMTD

$$= \frac{DT_1 - DT_2}{\ln\left(\frac{DT_1}{DT_2}\right)}$$

$$= \frac{110 - 50}{\ln \frac{110}{50}}$$

$$= \frac{60}{2.306 \log 2.2}$$

$$= \frac{60}{0.79}$$

$= 75.95$ °C

Heat Loss From Piping

Worksheet 9-4

Company: XYZ Co. LTD. Date: FEB. 20, 1985

Location: ANYTOWN By: MBE

Pipe diameter 4 NPS Pipe length 100 m

Pipe temperature 150 °C Operating hours per year 8760 h

Proposed insulation type FIBERGLASS Proposed insulation thickness 51 mm

	Uninsulated	Insulated
Heat loss per metre	725 Wh/(m·h)(Table 6)	57 Wh/(m·h)(Module 1)
Total heat loss/h = Heat loss/metre x length	725 x 100	57 x 100
	72500 Wh/h	5700 Wh/h
Annual heat loss = Heat loss/h x h/yr	72500 x 8760	5700 x 8760
	635 100 000 Wh/yr (1)	49 932 000 Wh/yr (2)

Reduction in heat loss due to addition of insulation = (1) − (2)

= 635 100 000 − 49 932 000

= 585 168 000 Wh/yr

or 585 168 000 Wh/yr x 3.6 kJ/Wh

= 2 106 604 800 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Heat Loss From Equipment

Worksheet 9-5

Company: XYZ CO. LTD. Date: FEB. 20, 1985

Location: ANYTOWN By: MBE

Equipment: WATER STORAGE TANK #2

Operating hours per year: 2688 h

Surface area: 21.206 m^2

Proposed insulation type: FIBERGLASS

Product temperature: 80 °C

Proposed insulation thickness: 51 mm

	Uninsulated	Insulated
Heat loss =	750 Wh/(m^2·h)(Table 5)	33.3 Wh/(m^2·h)(Module 1)
Total heat loss/h = Surface area x Heat loss	21.206 x 750	21.206 x 33.3
	15 905 Wh/h	706 Wh/h
Annual heat loss = Heat loss/h x h/yr	15905 x 2688	706 x 2688
	42.8×10^6 Wh/yr (1)	1.9×10^6 Wh/yr (2)

Reduction in heat loss due to addition of insulation = (1) − (2)

= 42.8×10^6 − 1.9×10^6

= 40.9×10^6 Wh/yr

or 40.9×10^6 Wh/yr x 3.6 kJ/Wh

= 147×10^6 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Steam Heating

Normally, saturated steam is used in heating applications. The use of low pressure steam for steam locomotives, steam hammers, and steam engines has declined drastically over the years, and will not be considered in this module.

Two basic types of heating occur in steam heated equipment. These are direct and indirect heating.

With direct heating, the product or material to be heated is in direct contact with the steam, and, in most cases, no condensate is recovered. An example of direct heating is the heating of a liquid by directly injecting it with steam. The steam and condensate mix with the product. If steam injection is used to heat an aqueous solution, an allowance must be made for the diluting effect of the condensate.

Indirect heating, separates the steam and product. In most cases the condensate from the steam is recovered and reused for boiler feed water or other hot water requirements. Examples of indirect heating follow.

- Steam to liquid heat exchanger.
- Product heating in storage tank.
- Air heater.

It must be noted that situations may occur where condensate is not recovered from indirect heated equipment. In instances such as the heating of vegetable oil or glucose in heat exchangers, a failure in the heat exchanger could allow the heated material to mix with the condensate. If this condensate was then returned to be used as boiler feedwater, the product mixed with the condensate would foul the internal heat transfer surfaces of the boiler. This would reduce the boiler efficiency, or in extreme cases, cause the boiler to explode. Thus, each situation must be individually considered. If condensate is not reused, other uses for the heat energy in the condensate should be considered. The module equations are based on the use of dry saturated steam.

Direct Steam Heating

In most direct steam heating applications (Figure 7) the material to be heated is in a vessel at atmospheric pressure. The maximum temperature to which the liquid can be raised is its boiling point. Any addition of steam to a boiling liquid will not produce an increase in temperature.

In the use of steam for direct heating applications there are some practical and theoretical considerations. First, consider the theory behind direct steam heating.

M = Weight of liquid (kg)

c = Specific heat of liquid [kJ/(kg·°C)]

T_1 = Temperature of liquid to be heated (°C)

T_2 = Final temperature of heated liquid (°C)

w = Rate of steam flow (kg/h)

h_g = Enthalpy of steam (kJ/kg)

t = Time required to reach temperature T_2 (minutes)

h_f = Enthalpy of water at temperature T_2 (kJ/kg)

Q_1 = Heat loss to surroundings [kJ/(°C·s)]

Q_2 = Heat carried with lost vapor [kJ/(°C·s)]

$$\text{Heat input into the vessel} = \frac{w}{60} \times (h_g - h_f) \times t \text{ (kJ)}$$

$$\text{Heat output from vessel} = (Q_1 + Q_2) \times 60 \times t \times \frac{(T_2 - T_1)}{2} \text{ (kJ)}$$

Heat gained by liquid = $(T_2 - T_1) \times M \times c$ (kJ)

Heat gained = Heat input − Heat output

$$(T_2 - T_1) \times M \times c = \frac{w}{60} \times (h_g - h_f) \times t - \left[(Q_1 + Q_2) \times 60 \times t \times \frac{(T_2 - T_1)}{2}\right]$$

All the values in the preceding equation, except Q_1 and Q_2, can be determined by using standard measuring devices and published physical constants. Theoretical methods of determining $Q_1 + Q_2$ are beyond the scope of this module, so a practical method is provided.

To determine the heat loss to surroundings from a heated tank, raise the temperature of the tank and its contents to a temperature midway between T_1 and T_2, stop all heating, and measure the temperature loss over a period of time.

Heat loss to surroundings and by evaporation = Heat loss by liquid.

DT = Drop in temperature (°C)
t = Time in minutes for the measured drop in temperature to occur.

Heat loss = $DT \times M \times c$ (kJ)

Rate of heat loss to surroundings and evaporation = $Q_1 + Q_2$

$$= \frac{DT \times M \times c}{t} \text{(kJ/min)}$$

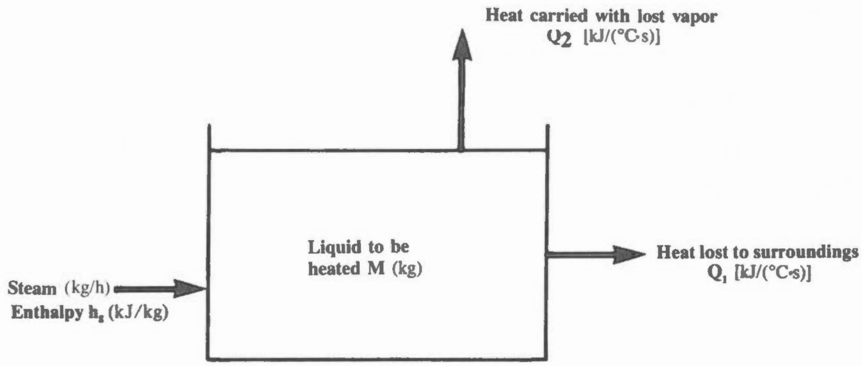
This method will not be applicable if the liquid is boiled, or the process started from a frozen state.

Practical Considerations in Direct Steam Heating

Direct steam heating is economical and fast, but can prove very dangerous if proper precautions are not taken. Several safety precautions are necessary.

- The vessel should be designed for the steam conditions and properly vented. Heat will be lost in the vapor, but attempts to enclose the vessel could result in excess pressure build up.
- Never attempt to heat a liquid using a steam hose or a wand because the hose or wand may whip dangerously.
- Take extreme care in heating other than water solutions with steam.
- Do not heat a liquid after the boiling point has been reached.

Direct steam heating is a noisy process. This is caused by the sudden collapse of steam bubbles formed in the liquid. Mixing valves and eductors mix and agitate the liquid, and also significantly reduce the noise.

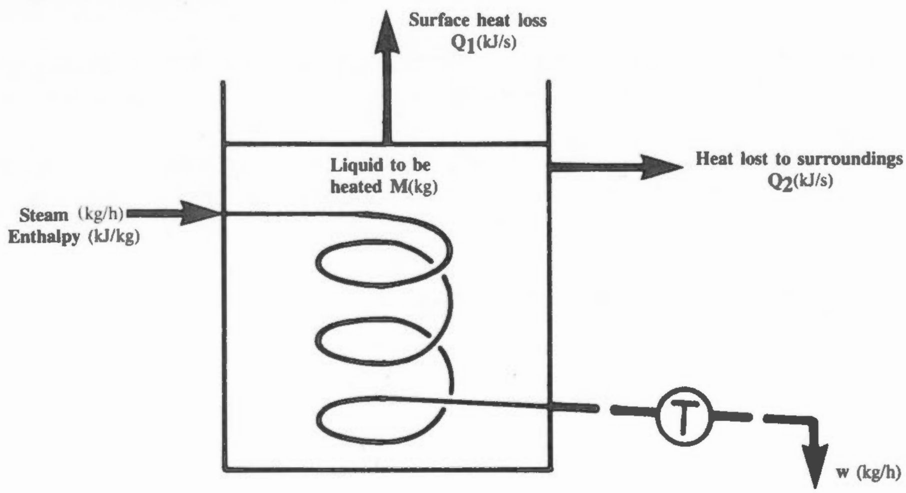


Direct Steam Heating
Figure 7

Indirect Steam Heating

The three basic types of indirect steam heated equipment are the steam coil, jacketed vessels, and heat exchangers. Normally for jacketed vessels or steam coils the liquid to be heated is not flowing. For heat exchangers the steam and liquid are flowing.

Steam Coils (Figure 8)



Heating Using a Steam Coil
Figure 8

The information required to establish heat loss in steam coil applications follows:

w = Steam flow rate (kg/h)

h_g = Enthalpy of steam supplied (kJ/kg)

h_f = Enthalpy of condensate returned (kJ/kg)

M = Weight of liquid in tank (kg)

c = Specific heat of liquid [kJ/(kg·°C)]

Q_1 = Heat loss by evaporation (kJ/s)

Q_2 = Heat loss to surroundings (kJ/s)

T_1 = Temperature of liquid to be heated (°C)

T_2 = Final temperature of heated liquid (°C)

t = Time required to heat the liquid to T_2 (s)

3600 = Conversion from hours to seconds.

$$\text{Heat input} = \frac{w}{3600} \text{ x } t \text{ x } (h_g - h_f) \text{ (kJ)}$$

$$\text{Heat gained} = M \text{ x } (T_2 - T_1) \text{ x } c \text{ (kJ)}$$

$$\text{Heat lost} = (Q_1 + Q_2) \text{ x } t \text{ (kJ)}$$

$$\text{Heat input} = \text{Heat gained} + \text{Heat lost}$$

$$\frac{w}{3600} \text{ x } t \text{ x } (h_g - h_f) = [M \text{ x } (T_2 - T_1) \text{ x } c] + [(Q_1 + Q_2) \text{ x } t]$$

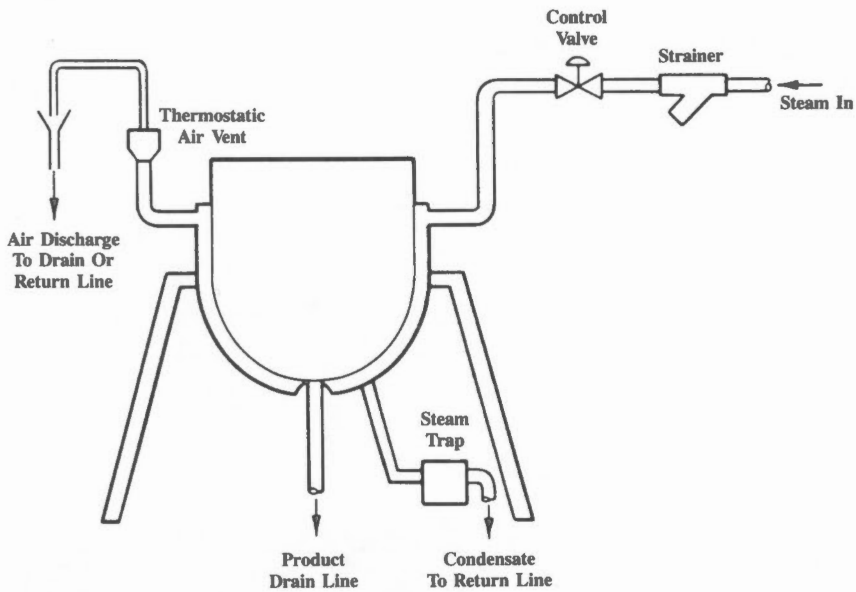
All of the values except $(Q_1 + Q_2)$ can be obtained with measuring instruments, and from tables. The value of $(Q_1 + Q_2)$ can be determined experimentally using the method described for indirect heating. There are a few precautions that must be taken in conducting the investigations.

- Results obtained near the liquid boiling point will not be valid because of the excessive heat loss by evaporation.
- The test must be carried out with the vessel more than half full so that the heat loss to the surroundings (Q_2) is not understated.
- The temperature of the condensate should be measured before it reaches the steam trap.

Jacketed Vessels

A jacketed vessel (Figure 9) consists of an inner and outer shell. The space between the shells is filled with steam to heat the contents of the inner vessel. Jacketed vessels are used to heat and maintain a product at a fixed temperature such as required for the cooking of soups or jams.

Jacketed vessels are pressure vessels and must be designed and constructed in accordance with the applicable codes. It is important to note that the outside surfaces of jacketed vessels approach the steam temperature and should be carefully insulated. Failure to do so will result in excessive loss of heat, and create a potential personnel burn hazard.



Jacketed Vessel
Figure 9

Since most jacketed vessels are used to maintain a substance at high temperatures for considerable periods of time, a theoretical analysis illustrating such an example follows.

w = Steam flow rate (kg/h)

h_g = Enthalpy of steam (kJ/kg)

h_f = Enthalpy of condensate (kJ/kg)

M_1 = Product in (kg)

M_2 = Product out (kg)

Q_2 = Heat lost to atmosphere by vessel surface (kJ/s)

t = Heating time (s)

3600 = Conversion from hours to seconds

It is assumed that the product temperature is close to the boiling point. If not, the steam coil experiment previously covered can be used to determine the various constants.

Heat input = Heat loss by boiling + Heat lost to atmosphere.

$$\text{Heat input} = \frac{W}{3600} \times t \times (h_g - h_f) \text{ (kJ)}$$

$$\text{Heat lost to atmosphere} = Q_2 \times t \text{ (kJ)}$$

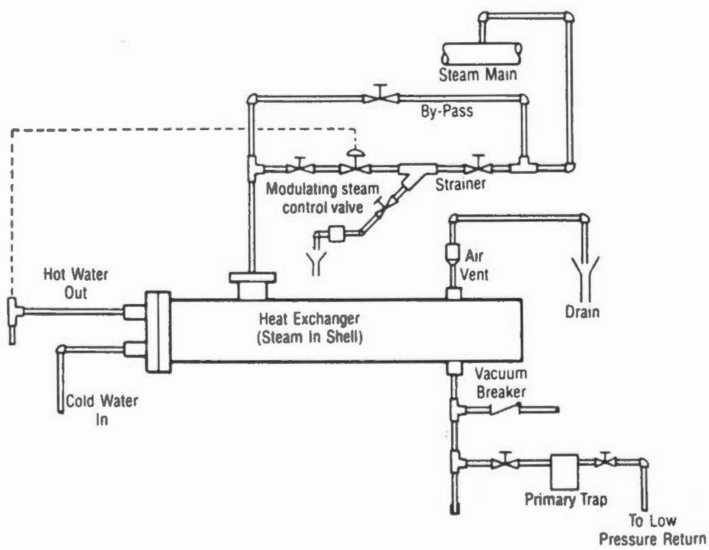
$$\text{Heat loss by boiling} = (M_1 - M_2) \times h_g \text{ (kJ)}$$

$$\frac{W}{3600} \times t \times (h_g - h_f) = [(M_1 - M_2) \times h_g] + (Q_2 \times t)$$

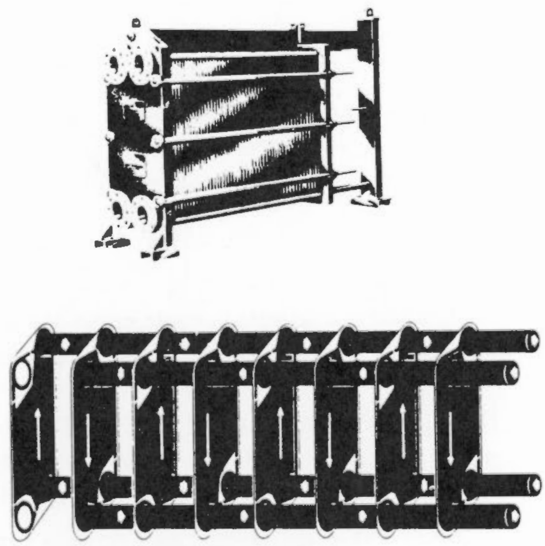
To determine the value of Q_2 at the boiling point, perform the previous experiment with the vessel ⅔ to ¾ full, using a higher boiling point mineral oil or vegetable oil. Raise the temperature to the boiling point of the material to be heated.

Heat Exchangers

For purposes of this module, heat exchangers are defined as either shell and tube (Figure 10), or plate and frame (Figure 11) units. Heat exchangers are used to heat or cool a flowing medium. When a heat exchanger is in use, steady state conditions prevail. Before providing an analysis of heat exchangers, a discussion of the various types of heat exchangers and their uses is provided.



Typical Heat Exhanger - Shell and Tube
Figure 10



Typical Heat Exchanger - Plate and Frame
Figure 11

Most heat exchangers have four connections. Two are used for the product and the others are used for the heating or cooling medium. Heat exchangers are used for these functions:

- Heat a liquid using either steam or a hot liquid.
- Cool a liquid using another liquid.
- Condense a vapor using a cold liquid.

When using a shell and tube heat exchanger it is recommended that the flows are counter current to achieve the best heat transfer. Normally the dirtier or corrosive fluid flows through the tubes, and the shell side (the outside of the tubes) is kept clean. This is because it is less costly to fabricate the tubes from non corrosive material.

A building heating converter where steam is used to heat water is a commonly used example of a heat exchanger.

The heat loss to atmosphere from the exterior of a heat exchanger is small compared to the heat transfer that takes place inside, particularly when the shell is insulated. Failure to insulate the shell will not only result in heat loss but also present a burn hazard.

Consider a heat exchanger heating water using dry saturated steam

w_1 = Rate of steam flow (kg/h)

w_2 = Rate of water flow (kg/h)

h_g = Enthalpy of steam (kJ/kg)

h_f = Enthalpy of condensate (kJ/kg)

T_1 = Temperature of water in (°C)

T_2 = Temperature of water out (°C)

Q = Heat loss to atmosphere (kJ/s)

3600 = Conversion from hours to seconds

$$\text{Heat input} = \frac{w_1}{3600} \times (h_g - h_f) \text{ (kJ/s)}$$

$$\text{Heat output} = \frac{w_2}{3600} \times (T_2 - T_1) \times 4.1855 \text{ (kJ/s)}$$

Heat loss = Q (kJ/s)

Heat input = Heat output + Heat loss

$$\frac{w_1}{3600} \times (h_g - h_f) = \left[\frac{w_2}{3600} \times (T_2 - T_1) \times 4.1855\right] + Q$$

As explained earlier, Q will be very small, but it can be determined experimentally:

Let the heat exchanger operate normally until steady state conditions are met. Shut off the steam supply valve and the hot water outlet valve. Let the exchanger cool for 5 minutes. Observe the water temperature. Open the steam supply and collect the condensate for the next 10 minutes. Record the temperature of the water. The mean amount of heat lost to the atmosphere can now be determined:

M_1 = Weight of condensate collected over 10 minutes (kg)

M_2 = Water side capacity of heat exchanger (kg)

M_3 = Weight of heat exchanger (kg)

c_1 = Specific heat of the heat exchanger material [kJ/(kg·°C)]

4.1855 = Specific heat of water [kJ/(kg·°C)]

T_1 = Temperature of water at the beginning of the 10 min. heating time (°C)

T_2 = Temperature of water at the end of the 10 min. heating time (°C)

$$\text{Heat supplied} = (h_g - h_f) \times M_1 \text{ (kJ)}$$

$$\text{Heat gained in 10 min.} = [(M_2 \times 4.1855) + (M_3 \times c_1)] \times (T_2 - T_1) \text{ (kJ)}$$

$$\text{Heat loss in 10 min.} = 10 \times 60 \times Q \text{ (kJ)}$$

Heat supplied = Heat gained + Heat loss

$$(h_g - h_f) \times M_1 = (M_2 \times 4.1855) + (M_3 \times c_1)] \times (T_2 - T_1) + 10 \times Q$$

Rate of heat loss by exchanger = Q(kJ/sec).

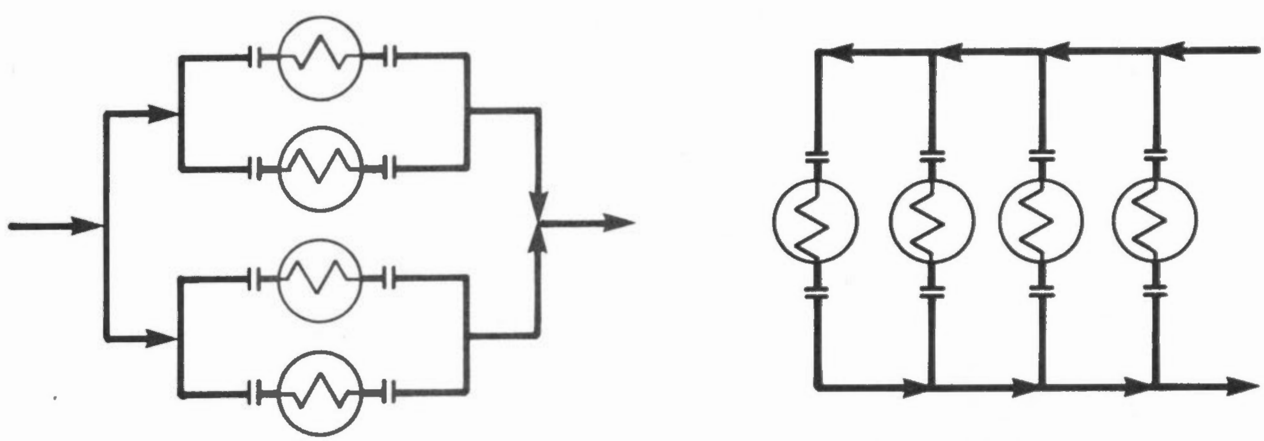
Some practical considerations regarding this experiment:

- The cooling time of 5 minutes and the heating time of 10 minutes are approximate and must be established according to actual conditions. The objective is to keep the increase in temperature between 5 and 10°C.
- It is assumed that the shell and tubes of the heat exchanger are made of the same material. If not, their individual weights and specific heats must be used.

Heat Exchanger Performance

The final sizing and selection of a heat exchanger is done by the heat exchanger manufacturer. The following are examples of how a properly selected heat exchanger may not perform well.

- *Flow not connected properly.* It is important that the fluids flow in a counter current manner. The heating medium should enter at the top and leave from the bottom. Conversely, the cooler fluid should enter at the bottom and leave from the top. Any variation of these principles will result in poor performance and costly accidents. To achieve a good counter current flow, the steam inlet and the hot fluid outlet should be placed close together.
- *Improper piping arrangement.* It is common to see several heat exchangers arranged in parallel. In this case, the fluid distribution is important. The piping must be arranged to give a constant flow resistance from the header to each of the exchangers. This is not applicable to steam distribution, as the factor governing the flow of steam is the removal of condensate, and not the inlet piping. Figure 12 indicates good and poor heat exchanger piping.



Good Arrangement
Hydraulically Balanced
Optimum Performance

Poor Arrangement
Hydraulically Unbalanced
Poor Performance

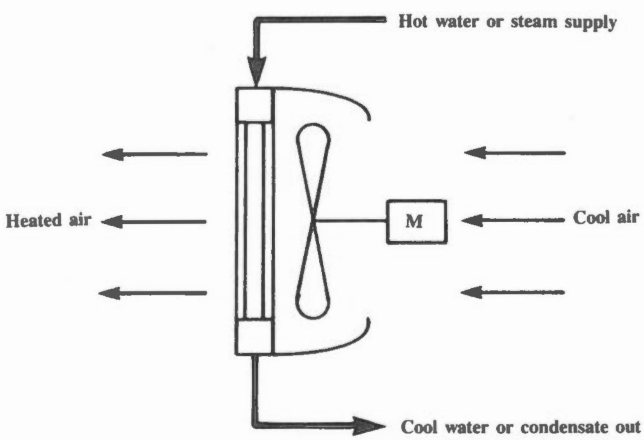
Multiple Heat Exchanger Piping
Figure 12

- *Poor Trapping Arrangement.* In heat exchangers that use steam as a heating media, the removal of condensate as soon as it is formed is important. Failure to do so will result in the accumulation of condensate inside the heat exchanger. The condensate is a poor conductor of heat and will greatly reduce the heat transfer rate. Condensate removal may be hampered by malfunctioning or undersized traps, excessive trap back pressure, or a poor trapping arrangement. Poor condensate removal can be detected by carefully opening the low point of the trap drain and watching for a large discharge of flashing condensate. This is proof of condensate accumulation.

- *Poor Venting.* Any collection of gases on the steam or shell sides of a heat exchanger will hamper effective heat transfer. Dissolved gases carried by the steam could collect at high points to reduce conductivity. In smaller exchangers, where the piping is usually small, gases are carried away by the fluid. Manual or automatic vents must be provided at the high points in larger exchangers to eliminate the gases. In large exhaust steam condensers where the steam pressure is lower than atmospheric,mechanical or steam powered eductors are provided to remove the gases present.
- *Scaling and Fouling.* The most common problem associated with heat exchangers is scaling and fouling, which causes reduced heat transfer and restricted flow. The heat exchanger fluid flow which is most likely to deposit slime or scale should be piped through the tubes. Deposition is detected by a loss of performance and flow, and prevention is achieved by proper water treatment. Companies specializing in such treatment should be consulted to recommend treatment of water supplies.
  In some circumstances, scaling and fouling cannot be prevented. In such cases, periodic chemical and/or mechanical cleaning will be necessary. Exchangers should be arranged in such a way that the heads can be opened for mechanical cleaning without removing any other equipment or piping. Several cleanings or severe scaling may make it necessary to replace the entire tube bundle. In such instances, the tube bundle, together with the tube sheet, is removed from the shell and a new unit is installed.
- *Leakage.* When heat exchangers corrode with age, a rupture may occur between the tube sheet and the tube. This may be difficult to detect, remaining unnoticed for extended periods, particularly if the exchanger is water to water, or water to steam. The problem associated with leakage is contamination. To avoid contamination, it is customary to keep the cleaner fluid at a higher pressure. However, this may not always be practical. A heat exchanger should be repaired or retubed as soon as a leak is detected.

Unit Heaters

Unit heaters (Figure 13) are heat exchangers that use steam or hot water forced through metal tubes, to heat air blown over the tubes.



Typical Unit Heater
Figure 13

Normally, tubes are finned or passed through thin metal plates to increase the surface area and heat transfer rate. A low room temperature signal from a thermostat starts the fan, and blows air over the heated surfaces, increasing the heat transfer rate to the air. As soon as the thermostat senses the desired temperature, the fan is shut off.

If the unit heater is steam heated, a steam trap controls the steam flow, cutting the flow as soon as the removal of heat from the steam stops.

Hot water circulates constantly in most hot water heated unit heaters. In some new large water heated unit heaters a solenoid valve shuts off the water supply when the fan stops.

Poor unit heater operation can be associated with:

- Malfunction of control system.
- Malfunction of steam traps.
- Air lock in the system.
- Corroded and scaled tubes.
- Dust covered or fouled fins and tube exterior.
- Malfunctioning fan and motor.

The theory behind the operation of a unit heater follows to provide a better understanding of its application and use. Consider a hot water heated unit heater.

fa = Air flow (m^3/h)

v_g = Specific volume of air (m^3/kg)

cp = Specific heat of air at constant pressure (kJ/(kg·°C))

T_{A1} = Air temperature in (°C)

T_{A2} = Air temperature out (°C)

w = Water flow (kg/h)

T_{W1} = Water temperature in (°C)

T_{W2} = Water temperature out (°C)

$$\text{Heat input rate} = w \times (T_{W1} - T_{W2}) \times 4.1855 \text{ (kJ/h)}$$

$$\text{Heat output rate} = \frac{fa}{v_g} \times cp \times (T_{A2} - T_{A1}) \text{ (kJ/h)}$$

$$\text{Heat input rate} = \text{Heat output rate}$$

$$w \times (T_{W1} - T_{W2}) \times 4.1855 = \frac{fa}{v_g} \times cp \times (T_{A2} - T_{A1})$$

Consider a steam heated unit heater instead of the above hot water heated unit.

fa = Air flow (m^3/h)

v_g = Specific volume of air (m^3/kg)

cp = Specific heat of air at constant pressure [kJ/(kg·°C)]

T_{A1} = Air temperature in (°C)

T_{A2} = Air temperature out (°C)

w = Steam flow = Condensate flow (kg/h)

h_g = Enthalpy of steam (kJ/kg)

h_f = Enthalpy of condensate (kJ/kg)

$$\text{Heat input} = w \times (h_g - h_f) \text{ (kJ/h)}$$

$$\text{Heat output} = \frac{fa}{v_g} \times cp \times (T_{A2} - T_{A1}) \text{ (kJ/h)}$$

$$\text{Heat input} = \text{Heat output}$$

$$w \times (h_g - h_f) = \frac{fa}{v_g} \times cp \times (T_{A2} - T_{A1})$$

With this or the previous equation it is possible to calculate steam or water usage and operating cost for steam or water heated unit heaters.

Water Cooled Equipment

Water cooled equipment operates under the same laws of thermodynamics and heat transfer as steam heated equipment. Energy in the form of heat flows from a higher temperature level to a lower temperature level. The range of temperatures under which water can be used is limited. At atmospheric pressure, water freezes at 0°C and boils at 100°C. Normal municipal water supply temperature varies from about 4°C in winter to 10°C in the summer months. If municipal water is the source of cooling water, the temperature variation must be considered when selecting the heat exchanger, pump, piping and controls. Cooling water may be used for direct and indirect cooling applications.

Direct Cooling

In direct cooling applications, cooling water is brought into direct contact with the item or product. Usually this is reserved for the cooling of solid products where the product is submerged in a tank containing water, and/or moved through a water spray. In these cases, the final temperature of the product is not critical, and neither is the water quantity and temperature.

Another method of direct cooling is the direct introduction of water into an aqueous product. This cools and dilutes the product.

Indirect Cooling

Indirect cooling is the most common method of water cooling. The cooling water and the product to be cooled are separated by a membrane, and heat transfer from the product to the cooling water takes place across this membrane. Typical examples of indirect cooling are cooling coils in tanks or other vessels, cooling coils in air handling equipment, heat exchangers and jacketed vessels.

Source of Cooling Water

Cooling water can be obtained from the municipal water system, wells, and surface sources such as lakes, ponds, rivers, and streams. In many cases, the water is used, without treatment, in a once through system. It is then discharged to a municipal sewage system, or returned to the source. Owing to fluctuations in source water temperature, care must be taken in selecting equipment, to ensure that it is capable of accepting the variation in flow required to handle the differing heat transfer requirements.

In a closed loop system the cooling water is reused, and only small quantities of make-up water are added to account for system losses. Usually, these systems are equipped with some type of heat rejection device such as an evaporative cooling pond, cooling tower, or a chiller that rejects the heat picked up by the water, and returns the water temperature to that required for the cooling operations. Normally, they also include some form of chemical treatment, to eliminate, or at least reduce, the scaling or slime growth problems caused by water borne impurities. Additional information about cooling towers and chillers is found in Refrigeration and Heat Pumps, Module 11.

Heat Transfer

In theory, it should be possible to cool 10 L/s of 30°C product to 25°C by using 10 L/s of 20°C cooling water when its temperature increases to 25°C. However, in practical terms, this is not possible. Items such as physical limitations of equipment size, inefficiencies in heat transfer rates owing to scaling, and heat gain from surroundings, require a more practical approach. In normal practice, a reasonable heat exchanger "approach temperature" between the cooling water and the fluid to be cooled is 3°C to 5°C.

An equation which can be used to calculate the approximate amount of heat transfer from or to a water stream is:

$$Q = f_w \times (T_1 - T_2) \times 15$$

Where, Q = Total heat transmitted (MJ/h)

f_w = Water flow (L/s)

T_1 = Temperature of incoming water (°C)

T_2 = Temperature of outgoing water (°C)

15 = multiplier which accounts for the specific heat of water and the conversion to common units.

For example, a product stream, flowing at 5 L/s enters a heat exchanger at 30°C and leaves the heat exchanger at 25°C. The heat released is:

$$Q = f_w \times (T_1 - T_2) \times 15$$

$$= 5 \times (30 - 25) \times 15$$

$$= 5 \times 5 \times 15$$

$$= 375 \text{ MJ/h}$$

If the heat exchanger heat transfer efficiency is 100 per cent, the cooling water stream must pick up 375 MJ/h of heat energy. A realistic number for heat exchanger heat transfer efficiency would be 85 per cent.

$$\text{Therefore cooling water flow} = \frac{375}{.85} = 441.18 \text{ MJ/h.}$$

If the incoming cooling water temperature is 15°C and an approach temperature of 5°C is used, then

$$441.18 = f_w \times (15 - 20) \times 15$$

$$441.18 = f_w \times -5 \times 15$$

$$441.18 = -75 \times f_w$$

$$f_w = \frac{441.18}{-75}$$

$$= -5.88 \text{ L/s}$$

In this instance, the negative sign may be dropped since it indicates only that heat energy is being accepted by the cooling water.

In conclusion, it will require 5.88 L/s of cooling water at 15°C when the temperature increases to 20°C, to cool 5 L/s of product from 30°C to 25°C in a heat exchanger with an 85 per cent heat transfer efficiency.

Energy Audit Methods

Energy Management Opportunities exist in heating and cooling equipment (steam and water) in Industrial, Commercial and Institutional facilities. Many of these opportunities are recognizable during a walk through audit of the facility. This audit is usually more meaningful if a "fresh pair of eyes" generally familiar with energy management is involved. Typical energy saving items noted during a walk through audit are steam leaking at connections, water leaking, or damaged insulation. Alert management, operating staff and good maintenance procedures can, with a little effort, reduce energy usage and save money.

Not all items noted in the walk through audit are as easy to analyze as those described. For example it may be noted that a stream of cooling water, after being used for the cooling application, is directed to drain. There may be some heat energy in the water, and the economics of recovering this heat energy must be investigated thoroughly. This leads to certain key questions.

- How much heat energy is available in the waste stream?
- Is there a use for this energy?
- What is the capital cost involved to recover the energy?
- Will the energy and associated cost savings pay for the equipment required to recover the energy?

A diagnostic audit is required to mathematically determine the heat energy available in the waste stream, how much energy could be recovered, and if there is a use for this recovered energy in the facility. The quantity of recoverable energy which could be reused establishes the dollar savings. With this, plus the estimated cost to supply and install the heat recovery equipment, simple payback calculations can establish the financial viability of the opportunity.

The implementation of Energy Management Opportunities can be divided into three categories:

- *Housekeeping*, refers to an energy management action that is *repeated on a regular basis and never less than once a year.*
- *Low cost*, refers to an energy management action that is *done once and for which the cost is not considered great.*
- *Retrofit*, refers to an energy management action that is *done once and for which the cost is significant.*

It must be noted that the dollar division between low cost and retrofit is normally a function of the size, type and financial policy of the organization.

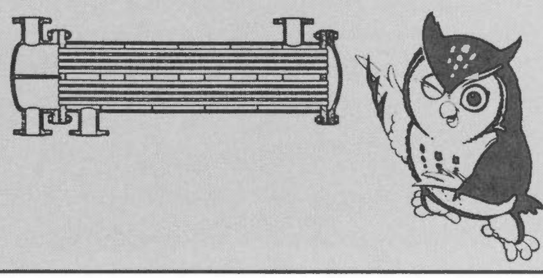
Summary

There are numerous opportunities for energy and dollar savings in heating and cooling equipment (steam and water). Alert management, design, operating, and maintenance staff learning to recognize these opportunities can make major advances in realizing the savings.

Steam leaks including those associated with improperly maintained steam traps, inadequate piping and equipment insulation, and the loss of energy in waste streams account for unnecessary energy and dollar losses. Learning to identify and then reduce these losses is good energy management.

Energy management must be approached with an open mind to explore previously accepted inefficient practices. The opportunities listed in the Energy Management Opportunities section of this module may generate similar or additional items which are specific to a facility. A fresh pair of eyes, or an added awareness on the part of the staff managing, operating, or maintaining a facility, combined with a little imagination and/or expert assistance, can pay large dividends in energy and cost reduction.

EQUIPMENT SYSTEMS



This section describes typical heating and cooling equipment (steam and water) which may be encountered in the Industrial, Commercial and Institutional sectors. Typical steam consumption rates for steam heated equipment are provided in Table 7. The following text subdivides the equipment into three categories.

- Steam Heated Equipment.
- Combination Steam Heated and Water Cooled Equipment.
- Water Cooled Equipment.

Steam Heated Equipment

Typical equipment in this category is discussed in the following text.

Rotary Dryers

Steam heated rotary dryers are frequently used in industry. Examples are dryers used in the corn wet milling process, and rotary cookers. Normally, the speed of rotation is slow. This equipment is divided into two classifications, which vary significantly in function and operation. In one case, the product is dried by being brought into contact with the surface of a steam filled cylinder. In the other, the product is held inside a rotating cylinder where steam filled tubes or pipes are used to dry the product by direct contact of the product with the tubes or pipes. In some cases, the rotating cylinder is surrounded with a steam jacket, to increase the heat transfer surface.

Rotary steam filled cylinder dryers are used extensively in the paper, textile, plastic, and food industries, and include such items as grain dryers, laundry ironers, and paper machine dryer. In this equipment steam pressure can reach 1100 kPa(gauge).

Rotary cylinder dryers with internal steam pipes are widely used in the meat packing, food, and chemical process industries, and include such items as grain dryers and rotary cookers. Steam flow can vary widely depending on the specific type of equipment used and the application. The steam pressure can reach 1100 kPa(gauge).

Evaporators

Evaporators reduce the water content of a product by the use of heat. They are commonly found in the paper, food, chemical, and textile industries. An evaporator is a special application of the shell and tube heat exchanger, where the product is in the tube while the steam is in the shell. The heated product enters a separating chamber where the vapor is drawn off for possible use elsewhere. The resulting concentrated product is pumped to another operation.

Multiple evaporator stages are often used and the triple effect evaporator is the most common. The vapor from the first stage is used as the heat source for the second stage, and this process is repeated for the third stage. The vapor from the third stage could eventually be used to preheat the incoming feed or to supply heat to some other application. The steam requirements of evaporators can vary from 500 to 50,000 kg/h while pressures may reach 1200 kPa(gauge).

Space Heating Equipment

Steam heated space heating equipment is used for general building heating. Typical units encountered include unit heaters, air handling units, finned radiation units, and pipe coils. In some cases, air is forced over the heated surface by a fan to increase the heat transfer rate to the air and to move the heated air to the required location. Usually, steam pressures are low, in the range of 2 to 7 kPa(gauge), however, pressures as high as 700 kPa(gauge) may be found.

Process Air Heaters

Process air heaters are specialized types of space heaters used specifically to heat air for process applications. Typical applications would be to provide high temperature air for paper or lumber drying, and preheating combustion air for boilers. Process and tunnel dryers are typical process air heaters. These units can operate at very high air temperatures up to 300°C.

Absorption Refrigeration Machines

An absorption refrigeration machine chills water for air conditioning or process applications by evaporating a material such as lithium bromide. Steam is used to provide the source of heat for the evaporation. Details concerning absorption refrigeration machines are found in Refrigeration and Heat Pumps, Module 11.

Stationary Steam Chamber Equipment

This type of equipment includes platen presses as used for plywood or other sheet manufacturing, steam jacketed molds for rubber and plastic parts manufacturing, autoclaves for curing and sterilizing, and retorts for cooking applications. Three equipment classifications of stationary steam chamber equipment follow:

- Equipment where the product is confined in a steam jacketed press. Products produced could be toys, battery cases, and steering wheels.
- Equipment where steam is introduced directly into the product chamber. Typical applications are sterilizers for clothing and surgical dressings, autoclaves used in the production of plastics, and the cooking of products sealed in tin cans.
- Equipment where the product is in a chamber, and steam is in an external jacket. Applications are sterilizers and autoclaves, where the steam does not come into contact with the product. Ranges of steam pressure and steam flow rates can vary widely,depending on the specific application.

Vulcanizing Equipment

Vulcanizing equipment is used in the rubber and plastic industries for product curing, and may be direct or indirect heated. Normal tire vulcanizing is accomplished by the use of tire molds in direct contact with steam heated platens. Spot repairing is often done using an open steam process where steam is in contact with the product. Normally, steam pressure would not exceed 1050 kPa(gauge). Steam flow could vary between 2 and 60 kg/h.

Combination Steam Heated and Water Cooled Equipment

Typical equipment in this category is discussed in the following text.

Heat Exchangers

Heat exchangers are used in indirect heating and cooling applications. These may be shell and tube or plate type units. Pressure/temperature ratings and steam or water flow requirements vary widely, depending on the application.

Storage Tanks

Tanks are used for storage of liquids or solids, where the temperature of the material must be increased, decreased or maintained at a specific level. Heating may be either direct or indirect depending on the product. Normally, cooling is done using the indirect method. Heating or cooling may be by coils or other devices submerged in the stored product, or by coils applied to the tank surface. As with heat exchangers, pressure and temperature ratings, steam and water flow requirements vary widely.

Jacketed Kettles

Usually jacketed kettles are used as steam cookers, or concentrators. Typical users of these units are meat packers, the paper industry, sugar refiners, rendering plants, and fruit and vegetable processors. Steam pressure could vary from 1 to 1000 kPa(gauge) and the steam flow rates could vary from almost zero to 5000 kg/h. Although not as common, these units may also be used in cooling applications where cooling water is circulated through the jacket to either cool a product, or to maintain a product at a desired temperature. This would be typical of a process where a reaction is exothermic (i.e. giving off heat), and the specific process requirement was to maintain constant temperature.

Molding Die Equipment

Equipment for die molding is often designed for heating and cooling. Steam is used to preheat the die prior to operation, while, during operation, cooling water is used to maintain the die at operating temperature.

Water Cooled Equipment

Typical equipment in this category is discussed in the following text.

Water Cooled Compressors

Depending on the type of compressor and the number of stages, cooling water may be used for intercoolers and aftercoolers. For additional information on compressors, refer to Compressors and Turbines, Module 14.

Water Cooling Baths

In water cooling baths the product is submerged. Normally, the temperature of the cooling bath is not critical and is suitably maintained by adding water continuously while allowing excess to overflow, or by dumping and refilling as required.

Refrigerated Chillers

Refrigerated chillers use chilled water or a glycol solution to provide cooling for applications such as refrigeration and air conditioning. For additional information on this equipment refer to Refrigeration and Heat Pumps, Module 11.

Cooling Spray Tunnels

This is equipment where the product to be cooled is mechanically moved through a tunnel while cooling water is sprayed on the product.

General Water Cooled Equipment

Some equipment is cooled by water flowing into a cavity and then overflowing to a collection system. The water removes the heat energy and maintains the equipment at the desired temperature. Mills and calenders used in the rubber industry are typical of this type of equipment.

It must be noted that many of the water cooling systems in use today are closed loop systems where the water is recirculated. After gaining heat energy, the water is passed through a cooling tower, evaporative cooling pond, or other such device, where the heat it has gained is rejected to atmosphere.

ENERGY MANAGEMENT OPPORTUNITIES

Energy Management Opportunities is a term that represents the ways that energy can be used wisely to save money. A number of typical Energy Management Opportunities subdivided into Housekeeping, Low Cost, and Retrofit categories are outlined in this section with worked examples to illustrate the potential energy savings. This is not a complete listing of the opportunities available for heating and cooling equipment(steam and water). However, it is intended to provide ideas for management, operating and maintenance personnel to allow them to identify other opportunities that are applicable to a particular facility. Appropriate modules in this series should be considered for Energy Management Opportunities existing within other types of equipment and systems.

The following text briefly highlights several Energy Management Opportunities and is followed by worked examples or explanatory text for illustrative purposes.

Housekeeping Opportunities

Implemented housekeeping opportunities are Energy Management actions that are done on a regular basis and never less than once a year. The following are typical Energy Management Opportunities in this category.

1. Seal leaks at valves, fittings, and gaskets.
2. Repair damaged insulation.
3. Maintain temperature and pressure controls.
4. Maintain steam traps.
5. Clean heat transfer surfaces.
6. Ensure that steam quality is adequate for the application.
7. Esure that steam pressure and temperature ranges are within the tolerances specified for the equipment.
8. Ensure that steam traps are correctly sized to remove all condensate.
9. Ensure that heating coils are sloping from the steam inlet to the steam trap to prevent the coils from flooding with condensate.

Housekeeping Worked Examples

1. Repair Leaks

During a walk through audit it was noted that there was a steam leak at the flanged connection of the steam supply to a heat exchanger. The steam pressure at this point was 689 kPa(gauge) and the size of the leak was estimated to be 6.35 mm. diameter.

From worksheet 9-2 the potential savings are calculated to be $12,632 per year.

The leak can be eliminated with a gasket replacement estimated to cost $100, including labour and material. The work can be scheduled when the plant is not operating.

$$\text{Simple payback} = \frac{\$100}{\$12,632}$$

$$= 0.0079 \text{ years (3 days)}$$

2. Repair Insulation

During a walk through audit it was noted that insulation was missing from a storage tank holding 80°C water. It had been removed to allow the tank to be relocated and only the lower half of the insulation had been replaced. The tank was 3 metres in diameter, and 3 metres high, with a flat top. The ambient temperature was 21°C. Normally the water temperature was controlled at 80°C using 689 kPa(gauge) steam. There was no wind effect. This condition existed for 2688 hours per year.

$$\text{Uninsulated area of tank} = (3.14 \times d \times h) + (3.14 \times r^2)$$

$$= (3.14 \times 3 \times 1.5) + (3.14 \times 1.5^2)$$

$$= 14.137 + 7.069$$

$$= 21.206 \text{ m}^2$$

From worksheet 9-5 if the tank insulation were repaired the annual reduction in heat loss = 147 000 000 kJ

Energy available per kg of steam at 689 kPa(gauge) = 2048.3 kJ/kg

Cost of steam = $22/1000 kg

$$\text{Energy losses} = \frac{147\,000\,000 \text{ kJ}}{2048.3 \text{ kJ/kg}}$$

$$= 71\,767 \text{ kg}$$

$$\text{Annual dollar savings} = 71\,767 \times \$22/1000 \text{ kg}$$

$$= \$1,579$$

Estimated cost of insulation installed is $500.

$$\text{Simple payback} = \frac{\$\ 500}{\$1,579}$$

$$= 0.318 \text{ years (4 months)}$$

3. Maintain Instruments

Correct and timely maintenance of instrumentation and control devices is one method of ensuring that proper conditions are being met, and deteriorating conditions are brought to the attention of operators and maintenance staff. For example, if pressure, temperature, and flow indicators are not correct, it is difficult to establish if required conditions are being met. (Nor can actual energy use be calculated). The correct setting of temperature and pressure controllers is equally important. Metering, Measuring and Monitoring, Module 15, and Automatic Controls, Module 16, should be consulted regarding this subject.

4. Maintain Steam Traps

A large steam consuming company found that it was difficult to identify traps which were faulty. Particular problems were encountered where many traps were piped to a common condensate receiver.

In an attempt to improve the ability to locate leaking traps, a contact pyrometer was purchased. This was used to measure the surface temperature of the trap discharge piping. Certain criteria, depending on the type of trap and the steam conditions, were developed to link the discharge piping temperature with the amount of leakage. This technique was used as part of the steam trap preventive maintenance program.

It was estimated that potential energy savings in reducing trap leakage could amount to 400 kg/h of steam.

Annual dollar savings = 400 kg/h x 8760 h/yr x $22/1000 kg

= $77,088/year

The cost of locating and repairing the leaking steam traps was estimated to be $20,000 per year.

$$\text{Simple payback} = \frac{\$20,000}{\$77,088}$$

= 0.26 years (3 months)

5. Clean Heat Transfer Surfaces

Cleaning heat transfer surfaces of accumulated sludge, scale, or other deposits will ensure that maximum heat transfer takes place.

6. Check Steam Quality

It is important to ensure that equipment receives dry steam at a quality close to 1.0. In dry saturated steam, the quality is 1.0, since all the water vapor has been converted to steam. In many instances, the quality of the steam leaving a boiler or other steam generating device is approximately 1.0. However, as the steam travels through the distribution system, condensation takes place and the quality is reduced. Unless proper trapping techniques are applied to the steam distribution system to eliminate the condensate, this condensate will enter the equipment. If this happens, heat transfer rates will be reduced, and the equipment may flood with condensate.

7. Reducing Steam Temperature and Pressure

An energy audit of a facility indicated that although steam was being generated in the boiler house at 1550 kPa(gauge), the highest pressure required was 1050 kPa(gauge). The equipment that required the high pressure steam had been removed several years ago.

The company attempted to reduce the boiler pressure in planned stages to 1050 kPa(gauge). At each stage feed-back was obtained from all departments regarding any detrimental effects from the lower pressure.

At 1150 kPa(gauge), owing to lower pressure and higher firing rates, the engineers had difficulty controlling boiler fans which were steam turbine driven. On this basis, a new operating pressure of 1250 kPa(gauge) was established. The lower boiler pressure resulted in reduced steam line heat losses and reduced losses through leaks and traps. Energy savings were estimated at 6.087×10^6 MJ/yr. One m^3 of natural gas contains 37.2 MJ of energy and the boiler efficiency is 80 per cent.

$$\text{Natural gas saved} = \frac{6.087 \times 10^6}{37.2 \times 0.8}$$

$= 204\ 536\ m^3$ per year

Cost of natural gas is $\$0.14/m^3$.

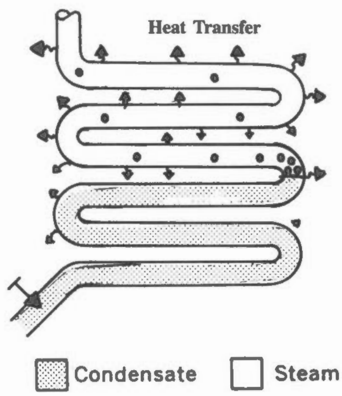
Annual dollar savings $= 204\ 536\ m^3/yr \times \$0.14/m^3$

= $28,635/year

8. Check Steam Trap Sizing

Condensate remaining in a heat transfer unit, such as a coil or heat exchanger, takes up space, and reduces the physical space available for steam to contact the heat transfer surfaces (Figure 14). Normally, this condition is caused by undersized or nonfunctioning steam traps used to discharge condensate from the steam heated equipment. To avoid flooding, trap sizing must take into account the larger quantity of condensate that will be generated under equipment start up conditions. Condensate flooding of heat transfer units reduces heat transfer effectiveness, and, in the case of a heating application, extends the time required to reach a specified product temperature. Sometimes, in an attempt to overcome this problem, a decision is reached to increase steam pressure and temperature. If this is done, additional energy is required to produce the higher pressure and temperature steam. If the trap problem were corrected, this additional energy would not be required.

Manufacturers of steam traps should be consulted regarding steam trap selection and sizing.



Partially Flooded Steam Coil
Figure 14

9. Slope Heating Coils to Remove Condensate

Flooding of heat transfer equipment with condensate reduces the surface available for heat transfer between the steam and the product to be heated. This may be caused by improper design or installation of coils. Coils should always be designed and installed so that there is a continuous downward slope from the heat exchanger steam connection to the steam trap to eliminate pockets of condensate forming in low spots of the coil causing the following problems.

- Coil flooding and reduced heat transfer.
- Water hammer caused by slugs of condensate being forced through the system with the resultant possibility of equipment damage.

If heat transfer performance is below expectations, and if steam traps appear to be functioning properly, pocketing within the coils should be investigated.

Low Cost Opportunities

Implemented low cost opportunities are Energy Management actions that are done once and for which the cost is not considered great. The following are typical Energy Management Opportunities in this category.

1. Shut down equipment when not required.
2. Provide lockable type covers for control equipment such as thermostats to prevent unauthorized tampering.
3. Operate equipment at or near capacity whenever possible. Avoid running multiple units at reduced capacity.
4. Add thermostatic air vents.
5. Add measuring and monitoring equipment to provide operating data to assist in improving the system operation.
6. Assess location of control devices to ensure best operation.

Low Cost Worked Examples

1. Shut Down Equipment

During a walk through audit it was noted that a steam heater supplying hot air to a drying tunnel was operating even though the tunnel was not in use. Subsequent investigation established that the heater system ran for 8760 hours per year, although the tunnel only operated 6000 hours per year. Steam used for the heater was 689 kPa(gauge), dry and saturated. Steam flow to the unit was measured at 200 kg/h. The cost of steam was $22/1000 kg.

Annual steam savings = (8760 - 6000) h/yr x 200 kg/h

= 2760 x 200

= 552 000 kg/yr

Annual dollar savings = 552 000 kg/yr x $22/1000/kg

= $12,144

It was decided to install a relay and solenoid valve to shut off the steam when the drying tunnel was not in operation. Estimated cost to supply, install, and wire the hardware was $500.

$$\text{Simple payback} = \frac{\$500}{\$12{,}144}$$

= 0.041 years (15 days)

2. Lock Controls

In reviewing energy use throughout a production facility it was noted that thermostats for controlling space heating unit heaters were set to maintain a temperature of 23.3°C in the workplace, even though it had been agreed with the production staff that 21.1°C was acceptable. In fact, some employees were turning on exhaust fans to reduce the space temperature, thus exhausting heated air. Ten heaters were involved, each with an air flow of 236 L/s. The space heating units heated outside air from an average winter temperature of -10°C, using steam at 180 kPa(absolute). Condensate from the heating coils was discharged to an atmospheric condensate tank. The estimated heating season was 3500 hours. The cost of steam was $22/1000 kg.

Steam required for 23.3°C temperature (per heater)

$$w \times (h_g - h_f) = \frac{fa}{v_g} \times cp \times (T_2 - T_1)$$

$$w = \frac{\frac{fa}{v_g} \times cp \times (T_2 - T_1)}{(h_g - h_f)}$$

$$= \frac{\frac{236}{.831} \times 1.006 \times (23.3 - (-10))}{(2701.5 - 490.7)}$$

= 4.3 kg/h

For 10 units this equals 43 kg/h of steam

Steam required for 21.1°C temperature (per heater)

$$w \times (h_g - h_f) = \frac{fa}{v_g} \times cp \times (T_2 - T_1)$$

$$w = \frac{\frac{fa}{v_g} \times cp \times (T_2 - T_1)}{(h_g - h_f)}$$

$$= \frac{\frac{236}{.831} \times 1.006 \times (21.1 - (-10))}{(2701.5 - 490.7)}$$

$$= 4.02 \text{ kg/h}$$

For 10 units this equals 40.2 kg/h of steam.

Annual steam savings = 3500 x (43 - 40.2)

= 3500 x 2.8

= 9800 kg/yr

Annual dollar savings = 9800 x $22/1000

= $216

Estimated cost to supply and install lockable covers on 10 thermostats is $500.

$$\text{Simple payback} = \frac{\$500}{\$216}$$

$$= 2.31 \text{ years}$$

3. Operate Equipment at Capacity

Steam heated equipment is often used at less than design capacity. Production schedules should be reviewed to establish whether some equipment could be shut down to allow the remaining equipment to operate at design capacity. Operating equipment at design capacity usually offers certain benefits.

- Under normal conditions, equipment working at design capacity operates at its point of highest efficiency.
- Heat loss will be reduced. Four vessels, each half full of a product to be heated, will, in most instances, lose almost twice as much heat energy to the surroundings as two full vessels. If the vessels are located in an area where the heat loss can be used to supplement building heating, then the quantity of heat required for building heating can be reduced. However, if the vessels are located outside, the lost heat energy cannot be used and energy and dollars are lost.

4. Install Thermostatic Air Vents

Air enters steam heated equipment in two ways. The first is that no matter how steam is generated, some amount of air is present in the boiler feedwater. The second is that as a steam system is being filled, either initially, or after having been shut down, air will be present in the steam line.

When air or any other noncondensible gas is present in a steam space, the steam cannot be maintained at saturation temperature. The following chart indicates the effect of air on the temperature of a steam/air mixture.

Pressure kPa(gauge)	Saturated Steam Temp (°C)	Steam-Air Mixture Temperature		
		5% Air	10% Air	15% Air
14	104°C	102°C	100.5°C	99°C
34	108°C	107°C	105.5°C	104°C
69	115°C	114°C	112°C	110°C
138	126°C	124°C	122°C	121°C

Thermostatic air vents do an excellent job of removing air from steam systems. For best steam system performance the vents must be located so that air flows easily to them.

5. Add Measuring and Monitoring Equipment

Without measuring and monitoring equipment (Module 15) installed in heating or cooling equipment, it is most difficult to establish if equipment is operating within specification. For example, unless a thermometer is installed in a vessel which is being used to heat or cool a liquid, errors in the operation of a temperature controller may not be detected.

The thermometer would provide feedback to an operator who could confirm the action of the temperature controller.

6. Assess Control Device Locations

The location of heating or cooling control devices is important. The thermostats for controlling building heating in a receiving department may be located on exterior walls of the building. Because of their location, they are subjected to conditions which cause them to sense a lower temperature than actually in the area. On this basis the thermostats will demand more heat than is required for comfort. By relocating the thermostats to an interior wall or column, a more representative temperature will be sensed and energy use reduced.

Retrofit Opportunities

Implemented retrofit opportunities are Energy Management actions which are done once and for which the cost is significant. Many of the opportunities in this category will require detailed analysis by specialists, and cannot be covered in this module. Worked examples are provided for some of the listed Energy Management Opportunities, while in other cases there is only commentary. The following are typical Energy Management Opportunities in the retrofit category.

1. Convert from direct to indirect steam heated equipment and recover the condensate.
2. Install/upgrade insulation on equipment.
3. Relocate steam heated equipment from central building areas to areas with exterior exposures so that heat loss from the equipment can assist in heating the area.
4. Review general building heating concepts as opposed to task heating concepts.
5. Modify processes, if possible, to stabilize steam or water demand.
6. Investigate scheduling of process operations in an attempt to reduce peak steam or water demands.
7. Evaluate waste water streams leaving a facility for heat recovery opportunities.

Retrofit Worked Examples

1. Convert from Indirect to Direct Steam Heating

During a walk through audit it was noted that steam was issuing from the atmospheric vent of a direct steam heated water tank. Water was being heated to 60°C in this tank by the direct injection of saturated steam at 200 kPa(absolute). The operation consisted of filling the tank with 6000 kg of water at 10°C, heating it in one hour to 60°C and maintaining the water at this temperature for one additional hour. The heated water was then pumped to a process operation where it was held in intermediate storage and used at the rate of 0.5 L/s.

Experimentation indicated that the steam flow to heat the contents of the tank was 300 kg/h average.

A heat exchanger, to heat the water on an as required basis, was evaluated. This would eliminate the loss of steam through the tank vent, and allow the removal of the storage and intermediate tanks. It would also reduce the quantity of chemicals used to treat the feedwater.

The heat exchanger would heat 0.5 L/s of 10°C water to 60°C using saturated steam at 200 kPa(absolute). Steam enthalpy is 2201.6 kJ/kg. Condensate would be discharged to an existing vented condensate receiver and then returned to the boiler. Heat exchanger efficiency is 80 per cent. The cost of steam is $22/1000 kg.

$$\text{Heat required by water } Q = f_W \times (T_1 - T_2) \times 15$$

$$= 0.5 \times (60 - 10) \times 15$$

$$= 375 \text{ MJ/h}$$

$$\text{Heat required from steam} = \frac{375}{0.8}$$

$$= 468.75 \text{ MJ/h}$$

$$\text{Steam required} = \frac{468.75 \times 1000}{2201.6}$$

$$= 213 \text{ kg/h}$$

$$\text{Steam savings per hour} = 300 - 213$$

$$= 87 \text{ kg/h}$$

The system operates 7500 hours per year

$$\text{Annual steam savings} = 87 \times 7500$$

$$= 652\ 500 \text{ kg/yr}$$

The required boiler feedwater would be reduced in accordance with the steam savings and this would reduce the treatment cost by $200 per year.

$$\text{Annual dollar savings} = (652\ 500 \times \$22/1000) + \$200$$

$$= \$14{,}355 + \$200$$

$$= \$14{,}555$$

The scrap recovery value on existing tanks, pump and piping is estimated to be $2,000. The estimated cost of the heat exchanger is $8,000.

$$\text{Simple payback} = \frac{\$8{,}000 - \$2{,}000}{\$14{,}555} = \frac{\$\ 6{,}000}{\$14{,}555}$$

$$= 0.41 \text{ years (5 months)}$$

2. Install/Upgrade Insulation

During a walk through audit it was realized that an electrically heated outdoor storage tank, holding product at 75°C, had no insulation. The surface area of the tank was 60 m^2. The tank was operated 6000 hours per year.

The cost of electricity is $0.05 per kWh.

It is proposed to insulate the sides of the tank with 51 mm of fiberglass insulation with an aluminum jacket.

From worksheet 9-5 annual energy savings by adding insulation are 204 x 10^6 W/yr.

$$\text{Annual dollar savings} = \frac{204 \times 10^6 \times \$0.05}{1000}$$

$$= \$10,200$$

The estimated cost to insulate the tank is $2,000

$$\text{Simple payback} = \frac{\$\ 2,000}{\$10,200}$$

$$= 0.196 \text{ years (3 months)}$$

3. Use Equipment Heat Loss for Building Heating

Steam heated equipment insulated to normal insulation standards loses heat to the surroundings. This heat loss can often be used to advantage to reduce the heat required to maintain building temperatures. When steam heated equipment is concentrated in one location the resulting heat must sometimes be exhausted from the building to maintain acceptable building temperatures. Under these circumstances, it may then be advantageous to consider relocating some of the steam heated equipment to other sections of the building to reduce the heating requirements there, and reduce the quantity of air being exhausted from the original location.

4. Review Building Heating

Often an entire building or facility is maintained at 20°C in the winter months even though there may be areas where this temperature could be reduced. An example would be a receiving department which is only occupied for a short period each day. The only requirement for this area is that the temperature be maintained above freezing except for one small office which is staffed 6 hours per day. The possibility of heating the office using electric heaters and reducing the temperature of the remaining area to 5°C should be investigated. The result would be a saving in energy.

5. Stabilize Steam and Water Demand

During a walk through audit it was realized that in a once through water cooling operation, 5 L/s of water was cooled from 40°C to 20°C and discharged to a storage tank. Water was withdrawn from the storage tank at a rate of 2 L/s. Because of the difference in the flow requirements, the cooling operation was operated on a start/stop basis. It was decided to investigate the possibility of eliminating the intermediate storage, convert to a circulating system, and cool the water at the rate of 2 L/s. The cooling operation took place in a heat exchanger which had been designed with an 80 per cent heat transfer efficiency. Cooling water inlet temperature was 10°C, and the heat exchanger outlet temperature was 15°C.

<u>Cooling water required at 5 L/s process water flow rate</u>

Heat rejection rate of process water $Q = f_W \times (T_1 - T_2) \times 15$

$$= 5 \times (40 - 20) \times 15$$

$$= 5 \times 20 \times 15$$

$$= 1500 \text{ MJ/h}$$

Cooling water heat gain design rate $Q = \frac{1500}{0.8}$

$= 1875$ MJ/h

Cooling water flow required $f_W = \frac{Q}{(T_1 - T_2) \times 15}$

$= \frac{1875}{(15 - 10) \times 15}$

$= \frac{1875}{5 \times 15}$

$= 25$ L/s

Cooling water required at 2 L/s process water flow rate

Heat rejection rate of process water $Q = f_W \times (T_1 - T_2) \times 15$

$= 2 \times (40 - 20) \times 15$

$= 2 \times 20 \times 15$

$= 600$ MJ/h

Cooling water gain design rate $Q = \frac{600}{0.8}$

$= 750$ MJ/h

Cooling water flow required $f_W = \frac{Q}{(T_1 - T_2) \times 15}$

$= \frac{750}{(15 - 10) \times 15}$

$= \frac{750}{5 \times 15} = 10$ L/s

The reduction in cooling water flow rate owing to the change in operation is 25 L/s − 10 L/s = 15 L/s.

This lower flow rate would reduce the pumping cost. The energy requirements for the equipment used to reject the heat gained by the cooling water to bring its temperature back to the required 10°C would be reduced.

6. Review Process Scheduling Versus Peak Demand

In many industrial plants little or no consideration is given to energy use when establishing production schedules. If energy use was included as one of the criteria, more consideration would be given to production schedule levelling. This, in turn, may reduce peak demands on steam heated and water cooled equipment.

7. Waste Stream Heat Recovery

Waste streams leaving a facility may contain heat energy that can be recaptured and used to reduce energy requirements. A waste stream of cooling water was discharged to sewer because of potential contamination. The waste flow stream was 20 L/s at 30°C. The facility also has a requirement to heat 15 L/s of process water from 20°C to 80°C using a steam to process water heat exchanger. The heat exchanger used 700 kPa(absolute) dry and saturated steam.

There is an opportunity to recover some of the heat energy in the waste stream by preheating the process water prior to it entering the steam to process water heat exchanger. This can be done with the installation of a second heat exchanger.

A 5°C decrease in temperature has been assumed for the waste water stream. Heat exchanger heat transfer efficiency is 80 per cent for the existing and proposed heat exchangers.

The existing and proposed systems are shown schematically in Figure 15.

Worksheets 9-7 and 9-8 are used to perform the calculations. The result of using the heat available in the waste stream is a reduction in energy use of 4 320 000 kg/yr of 700 kPa(absolute) dry and saturated steam with a dollar saving of $95,040 per year. If the heat recovery equipment cost is $40,000, the simple payback period is 0.42 years (5 months).

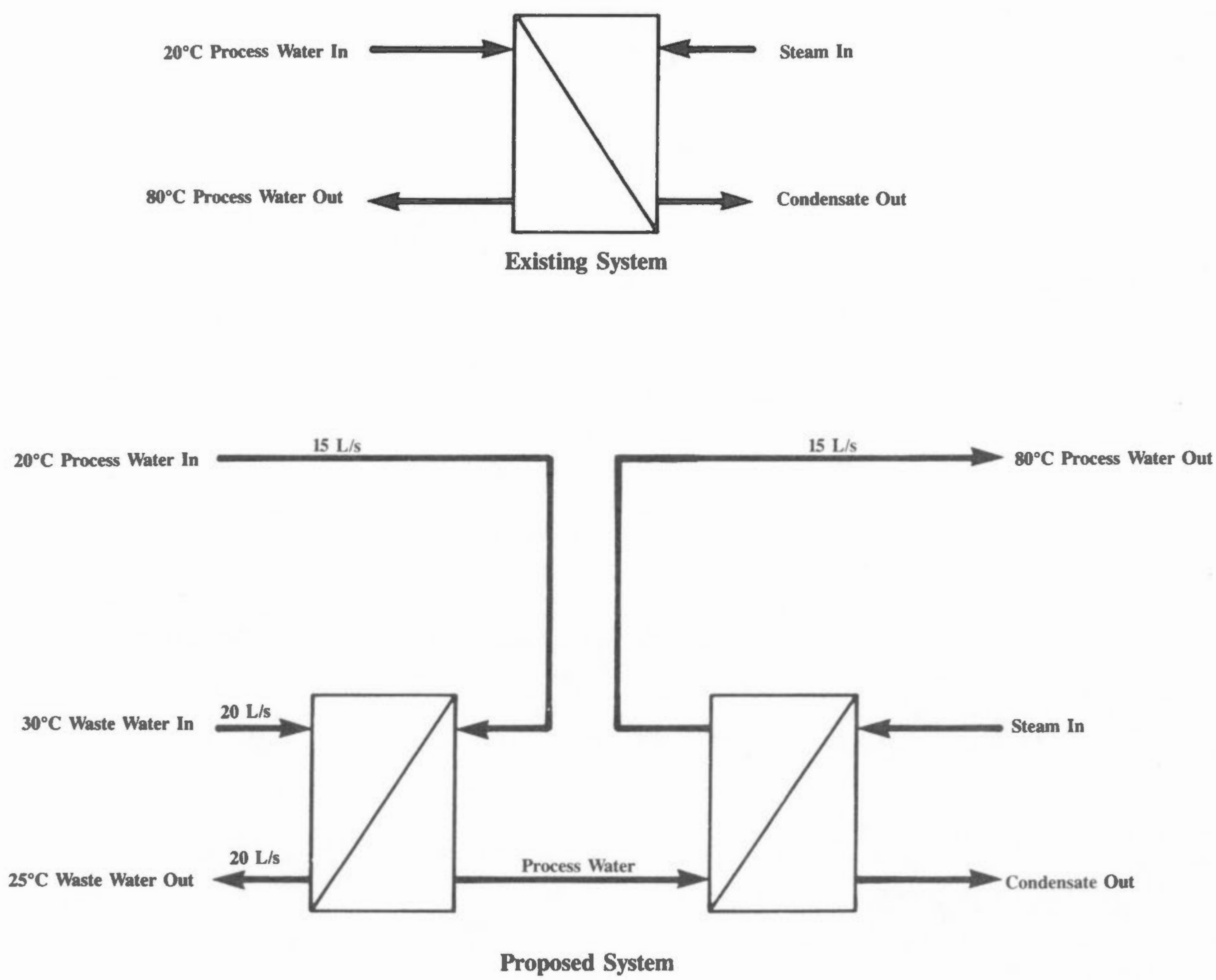


Figure 15

Steam Loss To Atmosphere
Worksheet 9-2

Company: XYZ CO. LTD. Date: FEB. 20, 1985

HOUSEKEEPING EXAMPLE 1 - REPAIR LEAKS

Location: ANYTOWN By: MBE

Equipment HOT WATER HEAT EXCHANGER #1

Estimated leak diameter 6.35 mm

Steam pressure 689 kPa(gauge)

Steam loss 95.7 kg/h (Table 3)

Operation: Hours per day 24

Days per week 5

Weeks per year 50

Steam cost: $ 22 /1000 kg (obtain from steam generator operator)

Steam lost = 95.7 kg/h x 24 h/day x 5 day/week x 50 week/yr

= 574200 kg/yr

Potential dollar savings

= 574200 kg/yr x $ 22 /1000 kg

= $ 12,632 per year

Heat Loss From Equipment

Worksheet 9-5

Company: ABD CO. LTD
HOUSEKEEPING - EXAMPLE 2 - INSULATION

Date: FEB 20, 1985

Location: ANYTOWN

By: MBE

Equipment WATER STORAGE TANK #2

Operating hours per year 2688 h

Surface area 21.21 m^2

Proposed insulation type FIBERGLASS

Product temperature 80 °C

Proposed insulation thickness 51 mm

Uninsulated	Insulated
Heat loss = 750 Wh/(m^2h)(Table 5)	33.3 Wh/(m^2h)(Module 1)
Total heat loss/h = Surface area x Heat loss	Surface area x Heat loss
21.21 x 750	21.21 x 33.3
15907.5 Wh/h	706.3 Wh/h
Annual heat loss = Heat loss/h x h/yr	Heat loss/h x h/yr
15907.5 x 2688	706.3 x 2688
42.76×10^6 Wh/yr (1)	1.9×10^6 Wh/yr (2)

Reduction in heat loss due to addition of insulation = (1) − (2)

= $42.76 \times 10^6 - 1.9 \times 10^6$

= 40.86×10^6 Wh/yr

or 40.86×10^6 Wh/yr x 3.6 kJ/Wh

= 147×10^6 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Heat Loss From Equipment

Worksheet 9-5

Company: ABD CO. LTD. RETROFIT - EXAMPLE 2 - INSTALL/UPGRADE INSULATION   Date: FEB. 20, 1985

Location: ANYTOWN   By: MBE

Equipment PRODUCT #1 STORAGE TANK   Operating hours per year 6000 h

Surface area 60 m^2 Proposed insulation type FIBERGLASS

Product temperature 75 °C   Proposed insulation thickness 51 mm

	Uninsulated	Insulated
Heat loss =	600 Wh/(m^2h)(Table 5)	33.3 Wh/(m^2h)(Module 1)
Total heat loss/h =	Surface area x Heat loss	Surface area x Heat loss
	60 x 600	60 x 33.3
	36000 Wh/h	1998 Wh/h
Annual heat loss =	Heat loss/h x h/yr	Heat loss/h x h/yr
	36000 x 6000	1998 x 6000
	216×10^6 Wh/yr (1)	11.988×10^6 Wh/yr (2)

Reduction in heat loss due to addition of insulation = (1) − (2)

= $216 \times 10^6 - 11.988 \times 10^6$

= 204×10^6 Wh/yr

or 204×10^6 Wh/yr x 3.6 kJ/Wh

= 734.4×10^6 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Heat Energy Available From Waste Water Stream To preheat A Water Stream

(Approximate Method)
Worksheet 9-7

Company: ABD CO. LTD. R   Date: FEB. 20, 1985
RETROFIT-EXAMPLE 7- WASTE STEAM HEAT RECOVERY
Location: ANYTOWN   By: MBE

Waste Water Stream: COOLING WATER TO SEWER

- Water flow (f_W) 20 L/s
- Present water temperature (T_1) 30 °C
- Proposed water leaving temperature (T_2) (Discussions must be held with heat exchanger manufacturer to establish this figure) 25 °C
- Heat available Q (MJ/h)

$$Q = f_W \times (T_1 - T_2) \times 15$$

$$= 20 \times (30 - 25) \times 15$$

$$= 1500 \text{ MJ/h}$$

$$\text{or } \frac{1500}{3600}$$

$$= 0.416 \text{ MJ/s}$$

Proposed heat exchanger efficiency (from heat exchanger manufacturer) 80 %

Heat available = 0.416 MJ/s x 80 %

= 0.333 MJ/s (1)

Heat Energy Available From Waste Water Stream
To Preheat A Water Stream

(Approximate Method)
Worksheet 9-7
Page 2 of 2

Company: ABD CO. LTD. R
RETROFIT - EXAMPLE 7 - WASTE STEAM HEAT RECOVERY
Date: FEB. 20, 1985

Location: ANYTOWN
By: MBE

Process Stream

Water flow (f_W) 15 L/s

Entering water temperature (T_1) 20 °C

Required water temperature (T_2) 80 °C

Heat required Q (MJ/h)

$$Q = f_W \times (T_1 - T_2) \times 15$$

$$= 15 \times (20 - 80) \times 15$$

$$= -13500 \text{ MJ/h}$$

$$\text{or } \frac{13500}{3600} \text{ (drop negative sign)}$$

$$= 3.75 \text{ MJ/s} \qquad (2)$$

Reduction of heat energy required for final heating of process water stream

$$= (2) \text{ MJ/s} - (1) \text{ MJ/s}$$

$$= 3.75 - 0.333$$

$$= 3.417 \text{ MJ/s} \qquad (3)$$

Steam Requirements To Heat Water In Steam To Water Heat Exchanger

(Approximate Method)

Worksheet 9-8

Company: ABD CO. LTD. R   Date: FEB. 20, 1985

RETROFIT- EXAMPLE 7- WASTE STEAM HEAT RECOVERY

Location: ANYTOWN   By: MBE

Steam

Pressure	598.7	kPa(gauge)	
Temperature	164.96	°C	
Enthalpy	2762	kJ/kg	(1)

Condensate

Pressure	598.7	kPa(gauge)	
Temperature	164.96	°C	
Enthalpy	697.1	kJ/kg	(2)

Heat available from Steam = (1) − (2)

= 2762 − 697.1

= 2064.9 kJ/kg (3)

Heat exchanger efficiency (obtain from heat exchanger manufacturer) 80 % (4)

Heat available to process water = (3) x (4)

= 2064.9 x 0.80

= 1651.9 kJ/kg

or $\frac{1651.9 \text{ kJ/kg}}{1000 \text{ kJ/MJ}}$

= 1.6519 MJ/kg (5)

Steam required by process steam (no heat recovery) = $\frac{\text{worksheet 9-7 (2)}}{\text{worksheet 9-8 (5)}}$

= $\frac{3.75 \text{ MJ/s}}{1.6519 \text{ MJ/kg}}$

= 2.27 kg/s (6)

Steam Requirements To Heat Water in Steam To Water Heat Exchanger

(Approximate Method)
Worksheet 9-8

Company: ABD CO. LTD. R — RETROFIT-EXAMPLE 9-WASTE STEAM HEAT RECOVERY   Date: FEB. 20, 1985

Location: ANYTOWN   By: MBE

Steam required by process stream (with heat recovery) = worksheet 9-7 (3) / worksheet 9-8 (5)

= 3.417 MJ/s / 1.6519 MJ/kg

= 2.07 kg/s (7)

Steam savings due to waste heat recovery = (6) − (7)

= 2.27 − 2.07

= 0.20 kg/s (8)

Hours of operation per year = 6000 h (9)

Annual steam savings due to heat recovery = (8) x (9) x 3600

= 0.20 x 6000 x 3600

= 4 320 000 kg/yr (10)

Steam cost = $ 22 /1000 kg (11)

Annual dollar savings = (10) x (11)

= 4320000 x 22/1000

= $ 95,040 per year (12)

Installed cost of heat recovery equipment = $ 40,000 (13)

Simple payback = (13) / (12)

= 40,000 / 95,040

= 0.42 years

APPENDICES

A Glossary of Terms
B Tables
C Common Conversions
D Worksheets

Glossary

Absolute Pressure — Any pressure where the base for measurement is full vacuum. Expressed as kPa(absolute).

Audit, diagnostic — The analysis of a potential opportunity to save energy which could involve the assessment of the current process operation, records, calculation of savings, and estimates of capital and operating costs so that the financial viability can be established.

Audit, walk through — The visual inspection of a facility to observe how energy is used or wasted.

Energy — The capacity for doing work; taking a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical, and chemical; in customary units, measured in kilowatt-hours (kWh) or megajoules (MJ).

Energy Intensity — The amount of energy required to produce a product or group of products expressed in energy used per unit of production.

Energy Management Opportunities, housekeeping — Activities which should be done on a regular basis and never less than once per year. This includes preventive maintenance programs.

Energy Management Opportunities, low cost — Improvements that are implemented once (i.e. not repeated on an annual basis) and for which the cost is not considered to be great.

Energy Management Opportunities, retrofit — Improvements that are implemented once, and for which the cost is considered to be significant.

Energy Type — A specific fuel or energy form used by the facility (Examples are Oil, Electricity, andNatural Gas).

Energy, variable — The energy associated with production which varies with production output.

Energy, waste — Energy which is lost without being fully utilized. It may include the energy in the form of steam, exhaust gases, discharge water or even refuse.

Enthalpy — Enthalpy is a measure of the heat energy per unit mass of a material. Units are expressed as kJ/kg.

Flash Steam — Flash steam is steam generated when condensate is released to a pressure lower than that at which it is formed. When the pressure is reduced a certain amount of sensible heat in the condensate is released. This excess heat is absorbed in the form of latent heat causing part of the condensate to "flash" into steam.

Gauge Pressure — Any pressure where the base for measurement is atmospheric pressure expressed as kPa(gauge). Note: kPa(gauge) + atmospheric pressure = kPa(absolute).

Heat Energy — A form of energy that is transferred from a point of higher temperature to a point of lower temperature expressed as MJ/kg.

Heat Exchanger Approach Temperature — A temperature differential between the hot and cold fluids used in heat exchanger design as a practical limit for heat transfer to take place. Normally considered to be 3°C to 5°C.

Insulation — Insulation is a material of low thermal conductivity used to reduce the transfer of heat.

Latent Heat — Latent heat is the quantity of heat expressed in kJ/kg required to change one kilogram of water to one kilogram of steam at the same pressure. This same amount of heat is released when the steam is condensed back into a kilogram of water.

Pressure Vessel — A vessel designed to operate at pressures greater or lower than atmospheric pressure.

Saturated Steam — Saturated steam is pure steam at the temperature that corresponds to the boiling temperature of water at a specific pressure.

Sensible Heat — Heat which, when supplied to or removed from a substance, produces a change in temperature which is measurable by a thermometer.

SI Systems — The basic system of measurement adopted in Canada. The name, Systeme international d'unites (International System of Units) is abbreviated SI in all languages.

Specific Gravity — Specific gravity is a number which indicates the weight of a fixed volume of a material compared to the mass volume of water. If the specific gravity is greater than 1.0 the material is heavier than water. If the specific gravity is less than 1.0 the material is lighter than water.

Thermal Conductance (C) — Thermal conductance is the thermal transmission in unit time through unit area of a particular body or assembly having defined surfaces, when unit average temperature difference is established between the surfaces expressed as $W/(m^2 \cdot {}^\circ C)$.

Thermal Resistance (R) — Thermal resistance is the reciprocal of thermal conductance expressed as $(m^2 \cdot {}^\circ C)/W$.

Thermal Transmittance (U) — Thermal transmittance is the thermal transmission in unit time through unit area of a particular body or assembly, including its boundary films, divided by the difference between the temperatures or either side of the body or assembly expressed as $W/(m^2 \cdot {}^\circ C)$

Total Heat of Steam — Total heat of steam is the sum of the latent heat plus sensible heat expressed in kJ/kg.

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (TEMPERATURE)

TABLE 1

Temperature °C t	Temperature K T	Press. kPa p	Volume, m³/kg Water v_f	Volume, m³/kg Evap. v_{fg}	Volume, m³/kg Steam v_g	Enthalpy, kJ/kg Water h_f	Enthalpy, kJ/kg Evap. h_{fg}	Enthalpy, kJ/kg Steam h_g	Entropy, kJ/kg K Water s_f	Entropy, kJ/kg K Evap. s_{fg}	Entropy, kJ/kg K Steam s_g
0.	273.15	0,6108	0.0010002	206,30	206,31	-0,04	2501,6	2501,6	-0,0002	9,1579	9,1577
0.01	273.16	0,6112	0.0010002	206,16	206,16	0,00	2501,6	2501,6	0,0000	9,1575	9,1575
1.0	274.15	0,6566	0.0010001	192,61	192,61	4,17	2499,2	2503,4	0,0153	9,1158	9,1311
2.0	275.15	0,7055	0.0010001	179,92	179,92	8,39	2496,8	2505,2	0,0306	9,0741	9,1047
3.0	276.15	0,7575	0.0010001	168,17	168,17	12,60	2494,5	2507,1	0,0459	9,0326	9,0785
4.0	277.15	0.8129	0.0010000	157,27	157,27	16,80	2492,1	2508,9	0,0611	8,9915	9,0526
5.0	278.15	0,8718	0.0010000	147,16	147,16	21,01	2489,7	2510,7	0,0762	8,9507	9,0269
6.0	279.15	0,9345	0.0010000	137,78	137,78	25,21	2487,4	2512,6	0,0913	8,9102	9,0015
7.0	280.15	1,0012	0.0010001	129,06	129,06	29,41	2485,0	2514,4	0,1063	8,8699	8,9762
8.0	281.15	1,0720	0.0010001	120,96	120,97	33,60	2482,6	2516,2	0,1213	8,8300	8,9513
9.0	282.15	1,1472	0.0010002	113,43	113,44	37,80	2480,3	2518,1	0,1362	8,7903	8,9265
10.0	283.15	1,2270	0.0010003	106,43	106,43	41,99	2477,9	2519,9	0,1510	8,7510	8,9020
12.0	285.15	1,4014	0.0010004	93,83	93,84	50,38	2473,2	2523,6	0,1805	8,6731	8,8536
14.0	287.15	1,5973	0.0010007	82,90	82,90	58,75	2468,5	2527,2	0,2098	8,5963	8,8060
16.0	289.15	1,8168	0.0010010	73,38	73,38	67,13	2463,8	2530,9	0,2388	8,5205	8,7593
18.0	291.15	2,0624	0.0010013	65,09	65,09	75,50	2459,0	2534,5	0,2677	8,4458	8,7135
20.0	293.15	2.337	0.0010017	57,84	57,84	83,86	2454,3	2538,2	0,2963	8,3721	8,6684
22.0	295.15	2.642	0.0010022	51,49	51,49	92,23	2449,6	2541,8	0,3247	8,2994	8,6241
24.0	297.15	2,982	0.0010026	45,92	45,93	100,59	2444,9	2545,5	0,3530	8,2277	8,5806
26.0	299.15	3.360	0.0010032	41.03	41,03	108,95	2440,2	2549,1	0,3810	8,1569	8,5379
28.0	301.15	3.778	0.0010037	36,73	36,73	117,31	2435,4	2552,7	0,4088	8,0870	8,4959
30.0	303.15	4,241	0.0010043	32,93	32,93	125.66	2430,7	2556,4	0,4365	8,0181	8,4546
32.0	305.15	4,753	0.0010049	29,57	29,57	134,02	2425,9	2560,0	0,4640	7,9500	8,4140
34.0	307.15	5.318	0.0010056	26.60	26,60	142.34	2421,2	2563,6	0,4913	7,8828	8,3740
36.0	309.15	5,940	0.0010063	23,97	23,97	150.74	2416,4	2567,2	0,5184	7,8164	8,3348
38.0	311.15	6,624	0.0010070	21.63	21.63	159.09	2411,7	2570,8	0,5453	7,7509	8,2962
40.0	313.15	7.375	0.0010078	19,545	19.546	167,45	2406,9	2574,4	0,5721	7,6861	8,2583
42.0	315.15	8.198	0.0010086	17,691	17.692	175,81	2402,1	2577,9	0,5987	7,6222	8,2209
44.0	317.15	9.100	0.0010094	16,035	16.036	184,17	2397,3	2581,5	0,6252	7,5590	8,1842
46.0	319.15	10.086	0.0010103	14,556	14.557	192,53	2392.5	2585,1	0,6514	7,4966	8,1481
48.0	321.15	11.162	0.0010112	13,232	13.233	200.89	2387,7	2588,6	0,6776	7,4350	8,1125
50.0	323.15	12.335	0.0010121	12,045	12.046	209,26	2382,9	2592,2	0,7035	7,3741	8,0776
52.0	325.15	13.613	0.0010131	10,979	10.980	217,62	2378,1	2595,7	0,7293	7,3138	8,0432
54.0	327.15	15.002	0.0010140	10,021	10.022	225.99	2373,2	2599,2	0,7550	7,2543	8,0093
56.0	329.15	16.511	0.0010150	9,158	9.159	234,35	2368,4	2602,7	0,7804	7,1955	7,9759
58.0	331.15	18.147	0.0010161	8,380	8,381	242.72	2363,5	2606,2	0,8058	7,1373	7,9431
60.0	333.15	19.920	0.0010171	7,678	7.679	251,09	2358,6	2609.7	0,8310	7,0798	7,9108
62.0	335.15	21.838	0.0010182	7,043	7.044	259,46	2353,7	2613,2	0,8560	7,0230	7,8790
64.0	337.15	23.912	0.0010193	6,468	6.469	267.84	2348,9	2616,6	0,8809	6,9667	7,8477
66.0	339.15	26.150	0.0010205	5,947	5.948	276.21	2343,9	2620.1	0,9057	6,9111	7,8168
68.0	341.15	28.563	0.0010217	5,475	5.476	284.59	2338,9	2623,5	0,9303	6,8561	7,7864
70.0	343.15	31.16	0.0010228	5,045	5.046	292.97	2334,0	2626,9	0,9548	6,8017	7,7565
72.0	345.15	33.96	0.0010241	4,655	4.656	301.36	2329,0	2630,3	0,9792	6,7478	7,7270
74.0	347.15	36.96	0.0010253	4,299	4.300	309.74	2324,0	2633,7	1,0034	6,6945	7,6979
76.0	349.15	40.19	0.0010266	3,975	3.976	318,13	2318,9	2637.1	1,0275	6,6418	7,6693
78.0	351.15	43.65	0.0010279	3,679	3.680	326.52	2313,9	2640.4	1,0514	6,5896	7,6410
80.0	353.15	47.36	0.0010292	3.408	3.409	334.92	2308,8	2643,8	1,0753	6,5380	7,6132
82.0	355.15	51.33	0.0010305	3,161	3.162	343.31	2303,8	2647,1	1,0990	6,4868	7,5858
84.0	357.15	55.57	0.0010319	2,934	2.935	351,71	2298,6	2650,4	1,1225	6,4362	7,5588
86.0	359.15	60.11	0.0010333	2,726	2.727	360.12	2293,5	2653,6	1,1460	6,3861	7,5321
88.0	361.15	64.95	0.0010347	2,535	2.536	368.53	2288,4	2656.9	1,1693	6,3365	7,5058
90.0	363.15	70.11	0.0010361	2.3603	2.3613	376.94	2283,2	2660.1	1.1925	6,2873	7,4799
92.0	365.15	75.61	0.0010376	2,1992	2,2002	385,36	2278,0	2663,4	1,2156	6,2387	7,4543
94.0	367.15	81.46	0.0010391	2,0509	2,0519	393,78	2272,9	2666,6	1,2386	6,1905	7,4291
96.0	369.15	87.69	0.0010406	1,9143	1,9153	402,20	2267,5	2669,7	1,2615	6,1427	7,4042
98.0	371.15	94.30	0.0010421	1.7883	1,7893	410.63	2262,2	2672,9	1,2842	6,0954	7,3796
100.0	373.15	101.33	0.0010437	1.6720	1.6730	419.06	2256,9	2676.0	1.3069	6,0485	7,3554

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (TEMPERATURE)

TABLE 1

Temperature °C t	Temperature K T	Press. kPa p	Volume, m³/kg Water v_f	Volume, m³/kg Evap. v_{fg}	Volume, m³/kg Steam v_g	Enthalpy, kJ/kg Water h_f	Enthalpy, kJ/kg Evap. h_{fg}	Enthalpy, kJ/kg Steam h_g	Entropy, kJ/kg K Water s_f	Entropy, kJ/kg K Evap. s_{fg}	Entropy, kJ/kg K Steam s_g
100.0	373.15	101.33	0.0010437	1.6720	1.6730	419.06	2256.9	2676.0	1.3069	6.0485	7.3554
105.0	378.15	120.80	0.0010477	1.4182	1.4193	440.17	2243.6	2683.7	1.3630	5.9331	7.2962
110.0	383.15	143.27	0.0010519	1.2089	1.2099	461.32	2230.0	2691.3	1.4185	5.8203	7.2388
115.0	388.15	169.06	0.0010562	1.0352	1.0363	482.50	2216.2	2698.7	1.4733	5.7099	7.1832
120.0	393.15	198.54	0.0010606	0.8905	0.8915	503.72	2202.2	2706.0	1.5276	5.6017	7.1293
125.0	398.15	232.1	0.0010652	0.7692	0.7702	524.99	2188.0	2713.0	1.5813	5.4957	7.0769
130.0	403.15	270.1	0.0010700	0.6671	0.6681	546.31	2173.6	2719.9	1.6344	5.3917	7.0261
135.0	408.15	313.1	0.0010750	0.5807	0.5818	567.68	2158.9	2726.6	1.6869	5.2897	6.9766
140.0	413.15	361.4	0.0010801	0.5074	0.5085	589.10	2144.0	2733.1	1.7390	5.1894	6.9284
145.0	418.15	415.5	0.0010853	0.4449	0.4460	610.59	2128.7	2739.3	1.7906	5.0910	6.8815
150.0	423.15	476.0	0.0010908	0.3914	0.3924	632.15	2113.2	2745.4	1.8416	4.9941	6.8358
155.0	428.15	543.3	0.0010964	0.3453	0.3464	653.77	2097.4	2751.2	1.8923	4.8989	6.7911
160.0	433.15	618.1	0.0011022	0.3057	0.3068	675.47	2081.3	2756.7	1.9425	4.8050	6.7475
165.0	438.15	700.8	0.0011082	0.2713	0.2724	697.25	2064.8	2762.0	1.9923	4.7126	6.7048
170.0	443.15	792.0	0.0011145	0.2414	0.2426	719.12	2047.9	2767.1	2.0416	4.6214	6.6630
175.0	448.15	892.4	0.0011209	0.21542	0.21654	741.07	2030.7	2771.8	2.0906	4.5314	6.6221
180.0	453.15	1002.7	0.0011275	0.19267	0.19380	763.12	2013.2	2776.3	2.1393	4.4426	6.5819
185.0	458.15	1123.3	0.0011344	0.17272	0.17386	785.26	1995.2	2780.4	2.1876	4.3548	6.5424
190.0	463.15	1255.1	0.0011415	0.15517	0.15632	807.52	1976.7	2784.3	2.2356	4.2680	6.5036
195.0	468.15	1398.7	0.0011489	0.13969	0.14084	829.88	1957.9	2787.8	2.2833	4.1821	6.4654
200.0	473.15	1554.9	0.0011565	0.12600	0.12716	852.37	1938.6	2790.9	2.3307	4.0971	6.4278
205.0	478.15	1724.3	0.0011644	0.11386	0.11503	874.99	1918.8	2793.8	2.3778	4.0128	6.3906
210.0	483.15	1907.7	0.0011726	0.10307	0.10424	897.73	1898.5	2796.2	2.4247	3.9293	6.3539
215.0	488.15	2106.0	0.0011811	0.09344	0.09463	920.63	1877.6	2798.3	2.4713	3.8463	6.3176
220.0	493.15	2319.8	0.0011900	0.08485	0.08604	943.67	1856.2	2799.9	2.5178	3.7639	6.2817
225.0	498.15	2550.	0.0011992	0.07715	0.07835	966.88	1834.3	2801.2	2.5641	3.6820	6.2461
230.0	503.15	2798.	0.0012087	0.07024	0.07145	990.27	1811.7	2802.0	2.6102	3.6006	6.2107
235.0	508.15	3063.	0.0012187	0.06403	0.06525	1013.83	1788.5	2802.3	2.6561	3.5194	6.1756
240.0	513.15	3348.	0.0012291	0.05843	0.05965	1037.60	1764.6	2802.2	2.7020	3.4386	6.1406
245.0	518.15	3652.	0.0012399	0.05337	0.05461	1061.58	1740.0	2801.6	2.7478	3.3579	6.1057
250.0	523.15	3978.	0.0012513	0.04879	0.05004	1085.78	1714.7	2800.4	2.7935	3.2773	6.0708
255.0	528.15	4325.	0.0012632	0.04463	0.04590	1110.23	1688.5	2798.7	2.8392	3.1968	6.0359
260.0	533.15	4694.	0.0012756	0.04086	0.04213	1134.94	1661.5	2796.4	2.8848	3.1161	6.0010
265.0	538.15	5088.	0.0012887	0.03742	0.03871	1159.93	1633.5	2793.5	2.9306	3.0353	5.9658
270.0	543.15	5506.	0.0013025	0.03429	0.03559	1185.23	1604.6	2789.9	2.9763	2.9541	5.9304
275.0	548.15	5950.	0.0013170	0.03142	0.03274	1210.86	1574.7	2785.5	3.0222	2.8725	5.8947
280.0	553.15	6420.	0.0013324	0.02879	0.03013	1236.84	1543.6	2780.4	3.0683	2.7903	5.8586
285.0	558.15	6919.	0.0013487	0.02638	0.02773	1263.21	1511.3	2774.5	3.1146	2.7074	5.8220
290.0	563.15	7446.	0.0013659	0.02417	0.02554	1290.01	1477.6	2767.6	3.1611	2.6237	5.7848
295.0	568.15	8004.	0.0013844	0.02213	0.02351	1317.27	1442.6	2759.8	3.2079	2.5389	5.7469
300.0	573.15	8593.	0.0014041	0.020245	0.021649	1345.05	1406.0	2751.0	3.2552	2.4529	5.7081
305.0	578.15	9214.	0.0014252	0.018502	0.019927	1373.40	1367.7	2741.1	3.3029	2.3656	5.6685
310.0	583.15	9870.	0.0014480	0.016886	0.018334	1402.39	1327.6	2730.0	3.3512	2.2766	5.6278
315.0	588.15	10561.	0.0014726	0.015383	0.016856	1432.09	1285.5	2717.6	3.4002	2.1856	5.5858
320.0	593.15	11289.	0.0014995	0.013980	0.015480	1462.60	1241.1	2703.7	3.4500	2.0923	5.5423
325.0	598.15	12056.	0.0015289	0.012666	0.014195	1494.03	1194.0	2688.0	3.5008	1.9961	5.4969
330.0	603.15	12863.	0.0015615	0.011428	0.012989	1526.52	1143.6	2670.2	3.5528	1.8962	5.4490
335.0	608.15	13712.	0.0015978	0.010256	0.011854	1560.25	1089.5	2649.7	3.6063	1.7916	5.3979
340.0	613.15	14605.	0.0016387	0.009142	0.010780	1595.47	1030.7	2626.2	3.6616	1.6811	5.3427
345.0	618.15	15545.	0.0016858	0.008077	0.009763	1632.52	966.4	2598.9	3.7193	1.5636	5.2828
350.0	623.15	16535.	0.0017411	0.007058	0.008799	1671.94	895.7	2567.7	3.7800	1.4376	5.2177
355.0	628.15	17577.	0.0018085	0.006051	0.007859	1716.63	813.8	2530.4	3.8489	1.2953	5.1442
360.0	633.15	18675.	0.0018959	0.005044	0.006940	1764.17	721.3	2485.4	3.9210	1.1390	5.0600
365.0	638.15	19833.	0.0020160	0.003996	0.006012	1817.96	610.0	2428.0	4.0021	0.9558	4.9579
370.0	643.15	21054.	0.0022136	0.002759	0.004973	1890.21	452.6	2342.8	4.1108	0.7036	4.8144
371.0	644.15	21306.	0.0022778	0.002446	0.004723	1910.50	407.4	2317.9	4.1414	0.6324	4.7738
372.0	645.15	21562.	0.0023636	0.002075	0.004439	1935.57	351.4	2287.0	4.1794	0.5446	4.7240
373.0	646.15	21820.	0.0024963	0.001588	0.004084	1970.50	273.5	2244.0	4.2326	0.4233	4.6559
374.0	647.15	22081.	0.0028427	0.000623	0.003466	2046.72	109.5	2156.2	4.3493	0.1692	4.5185
374.15	647.30	22120.	0.00317	0.0	0.00317	2107.37	0.0	2107.4	4.4429	0.0	4.4429

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (PRESSURE)

TABLE 1

Press. kPa	Temp. °C	Volume, m³/kg			Enthalpy, kJ/kg			Entropy, kJ/kg K			Energy, kJ/kg	
		Water	Evap.	Steam	Water	Evap.	Steam	Water	Evap.	Steam	Water	Steam
p	t	v_f	v_{fg}	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	u_f	u_g
1.0	6.983	0.0010001	129.21	129.21	29.34	2485.0	2514.4	0.1060	8.8706	8.9767	29.33	2385.2
1.1	8.380	0.0010001	118.04	118.04	35.20	2481.7	2516.9	0.1269	8.8149	8.9418	35.20	2387.1
1.2	9.668	0.0010002	108.70	108.70	40.60	2478.7	2519.3	0.1461	8.7640	8.9101	40.60	2388.9
1.3	10.866	0.0010003	100.76	100.76	45.62	2475.9	2521.5	0.1638	8.7171	8.8809	45.62	2390.5
1.4	11.985	0.0010004	93.92	93.92	50.31	2473.2	2523.5	0.1803	8.6737	8.8539	50.31	2392.0
1.5	13.036	0.0010006	87.98	87.98	54.71	2470.7	2525.5	0.1957	8.6332	8.8288	54.71	2393.5
1.6	14.026	0.0010007	82.76	82.77	58.86	2468.4	2527.3	0.2101	8.5952	8.8054	58.86	2394.8
1.8	15.855	0.0010010	74.03	74.03	66.52	2464.1	2530.6	0.2367	8.5260	8.7627	66.52	2397.4
2.0	17.513	0.0010012	67.01	67.01	73.46	2460.2	2533.6	0.2607	8.4639	8.7246	73.46	2399.6
2.2	19.031	0.0010015	61.23	61.23	79.81	2456.6	2536.4	0.2825	8.4077	8.6901	79.81	2401.7
2.4	20.433	0.0010019	56.39	56.39	85.67	2453.3	2539.0	0.3025	8.3563	8.6587	85.67	2403.6
2.6	21.737	0.0010021	52.28	52.28	91.12	2450.2	2541.3	0.3210	8.3089	8.6299	91.12	2405.4
2.8	22.955	0.0010024	48.74	48.74	96.22	2447.3	2543.6	0.3382	8.2650	8.6033	96.21	2407.1
3.0	24.100	0.0010027	45.67	45.67	101.00	2444.6	2545.6	0.3544	8.2241	8.5785	101.00	2408.6
3.5	26.694	0.0010033	39.48	39.48	111.85	2438.5	2550.4	0.3907	8.1325	8.5232	111.84	2412.2
4.0	28.983	0.0010040	34.80	34.80	121.41	2433.1	2554.5	0.4225	8.0530	8.4755	121.41	2415.3
4.5	31.035	0.0010046	31.14	31.14	129.99	2428.2	2558.2	0.4507	7.9827	8.4335	129.98	2418.1
5.0	32.898	0.0010052	28.19	28.19	137.77	2423.8	2561.6	0.4763	7.9197	8.3960	137.77	2420.6
5.5	34.605	0.0010058	25.77	25.77	144.91	2419.8	2564.7	0.4995	7.8626	8.3621	144.90	2422.9
6.0	36.183	0.0010064	23.74	23.74	151.50	2416.0	2567.5	0.5209	7.8104	8.3312	151.50	2425.1
6.5	37.651	0.0010069	22.015	22.016	157.64	2412.5	2570.2	0.5407	7.7622	8.3029	157.63	2427.0
7.0	39.025	0.0010074	20.530	20.531	163.38	2409.2	2572.6	0.5591	7.7176	8.2767	163.37	2428.9
7.5	40.316	0.0010079	19.238	19.239	168.77	2406.2	2574.9	0.5763	7.6760	8.2523	168.76	2430.6
8.0	41.534	0.0010084	18.104	18.105	173.86	2403.2	2577.1	0.5925	7.6370	8.2296	173.86	2432.3
9.0	43.787	0.0010094	16.203	16.204	183.28	2397.9	2581.1	0.6224	7.5657	8.1881	183.27	2435.3
10.	45.833	0.0010102	14.674	14.675	191.83	2392.9	2584.8	0.6493	7.5018	8.1511	191.82	2438.0
11.	47.710	0.0010111	13.415	13.416	199.68	2388.4	2588.1	0.6738	7.4439	8.1177	199.67	2440.5
12.	49.446	0.0010119	12.361	12.362	206.94	2384.3	2591.2	0.6963	7.3909	8.0872	206.93	2442.8
13.	51.062	0.0010126	11.465	11.466	213.70	2380.3	2594.0	0.7172	7.3420	8.0592	213.68	2445.0
14.	52.574	0.0010133	10.693	10.694	220.02	2376.7	2596.7	0.7367	7.2967	8.0334	220.01	2447.0
15.	53.997	0.0010140	10.022	10.023	225.97	2373.2	2599.2	0.7549	7.2544	8.0093	225.96	2448.9
16.	55.341	0.0010147	9.432	9.433	231.59	2370.0	2601.6	0.7721	7.2148	7.9869	231.58	2450.6
18.	57.826	0.0010160	8.444	8.445	241.99	2363.9	2605.9	0.8036	7.1424	7.9460	241.98	2453.9
20.	60.086	0.0010172	7.649	7.650	251.45	2358.4	2609.9	0.8321	7.0774	7.9094	251.43	2456.9
22.	62.162	0.0010183	6.994	6.995	260.14	2353.3	2613.5	0.8581	7.0184	7.8764	260.12	2459.6
24.	64.082	0.0010194	6.446	6.447	268.18	2348.6	2616.8	0.8820	6.9644	7.8464	268.16	2462.1
26.	65.871	0.0010204	5.979	5.980	275.67	2344.2	2619.9	0.9041	6.9147	7.8188	275.65	2464.4
28.	67.547	0.0010214	5.578	5.579	282.69	2340.0	2622.7	0.9248	6.8685	7.7933	282.66	2466.5
30.	69.124	0.0010223	5.228	5.229	289.30	2336.1	2625.4	0.9441	6.8254	7.7695	289.27	2468.6
35.	72.709	0.0010245	4.525	4.526	304.33	2327.2	2631.5	0.9878	6.7288	7.7166	304.29	2473.1
40.	75.886	0.0010265	3.992	3.993	317.65	2319.2	2636.9	1.0261	6.6448	7.6709	317.61	2477.1
45.	78.743	0.0010284	3.575	3.576	329.64	2312.0	2641.7	1.0603	6.5704	7.6307	329.59	2480.7
50.	81.345	0.0010301	3.239	3.240	340.56	2305.4	2646.0	1.0912	6.5035	7.5947	340.51	2484.0
55.	83.737	0.0010317	2.963	2.964	350.61	2299.3	2649.9	1.1194	6.4428	7.5623	350.56	2486.9
60.	85.954	0.0010333	2.731	2.732	359.93	2293.6	2653.6	1.1454	6.3873	7.5327	359.86	2489.7
65.	88.021	0.0010347	2.5335	2.5346	368.62	2288.3	2656.9	1.1696	6.3360	7.5055	368.55	2492.2
70.	89.959	0.0010361	2.3637	2.3647	376.77	2283.3	2660.1	1.1921	6.2883	7.4804	376.70	2494.5
75.	91.785	0.0010375	2.2158	2.2169	384.45	2278.6	2663.0	1.2131	6.2439	7.4570	384.37	2496.7
80.	93.512	0.0010387	2.0859	2.0870	391.72	2274.1	2665.8	1.2330	6.2022	7.4352	391.64	2498.8
90.	96.713	0.0010412	1.8682	1.8692	405.21	2265.6	2670.9	1.2696	6.1258	7.3954	405.11	2502.6
100.	99.632	0.0010434	1.6927	1.6937	417.51	2257.9	2675.4	1.3027	6.0571	7.3598	417.41	2506.1
110.	102.317	0.0010455	1.5482	1.5492	428.84	2250.8	2679.6	1.3330	5.9947	7.3277	428.73	2509.2
120.	104.808	0.0010476	1.4271	1.4281	439.36	2244.1	2683.4	1.3609	5.9375	7.2984	439.24	2512.1
130.	107.133	0.0010495	1.3240	1.3251	449.19	2237.8	2687.0	1.3868	5.8847	7.2715	449.05	2514.7
140.	109.315	0.0010513	1.2353	1.2363	458.42	2231.9	2690.3	1.4109	5.8356	7.2465	458.27	2517.2
150.	111.37	0.0010530	1.1580	1.1590	467.13	2226.2	2693.4	1.4336	5.7898	7.2234	466.97	2519.5
160.	113.32	0.0010547	1.0901	1.0911	475.38	2220.9	2696.2	1.4550	5.7467	7.2017	475.21	2521.7
180.	116.93	0.0010579	0.9762	0.9772	490.70	2210.8	2701.5	1.4944	5.6678	7.1622	490.51	2525.6
200.	120.23	0.0010608	0.8844	0.8854	504.70	2201.6	2706.3	1.5301	5.5967	7.1268	504.49	2529.2
220.	123.27	0.0010636	0.8088	0.8098	517.62	2193.0	2710.6	1.5627	5.5321	7.0949	517.39	2532.4
240.	126.09	0.0010663	0.7454	0.7465	529.63	2184.9	2714.5	1.5929	5.4728	7.0657	529.38	2535.4

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (PRESSURE)

TABLE 1

Press. kPa	Temp. °C	Volume, m^3/kg			Enthalpy, kJ/kg			Entropy, kJ/kg K			Energy, kJ/kg	
		Water	Evap.	Steam	Water	Evap.	Steam	Water	Evap.	Steam	Water	Steam
p	t	v_f	v_{fg}	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	u_f	u_g
240.	126.09	0,0010663	0,7454	0,7465	529,6	2184,9	2714,5	1,5929	5,4728	7,0657	529.38	2535.4
260.	128.73	0,0010688	0,6914	0,6925	540,9	2177,3	2718,2	1,6209	5,4180	7,0389	540.60	2538.1
280.	131.20	0,0010712	0,6450	0,6460	551,4	2170,1	2721,5	1,6471	5,3670	7,0140	551.14	2540.6
300.	133.54	0,0010735	0,6045	0,6056	561,4	2163,2	2724,7	1,6716	5,3193	6,9909	561.11	2543.0
350.	138,87	0,0010789	0,5229	0,5240	584,3	2147,4	2731,6	1,7273	5,2119	6,9392	583.89	2548.2
400.	143.62	0,0010839	0,4611	0,4622	604,7	2133,0	2737,6	1,7764	5,1179	6,8943	604.24	2552.7
450.	147.92	0,0010885	0,4127	0,4138	623,2	2119,7	2742,9	1,8204	5,0343	6,8547	622.67	2556.7
500.	151.84	0,0010928	0,3736	0,3747	640,1	2107,4	2747,5	1,8604	4,9588	6,8192	639.57	2560.2
550.	155.47	0,0010969	0,3414	0,3425	655,8	2095,9	2751,7	1,8970	4,8900	6,7870	655.20	2563.3
600.	158.84	0,0011009	0,3144	0,3155	670,4	2085,0	2755,5	1,9308	4,8267	6,7575	669.76	2566.2
650.	161.99	0,0011046	0,29138	0,29249	684,1	2074,7	2758,9	1,9623	4,7681	6,7304	683.42	2568.7
700.	164.96	0,0011082	0,27157	0,27268	697,1	2064,9	2762,0	1,9918	4,7134	6,7052	696.29	2571.1
750.	167.76	0,0011116	0,25431	0,25543	709,3	2055,5	2764,8	2,0195	4,6621	6,6817	708.47	2573.3
800.	170.41	0,0011150	0,23914	0,24026	720,9	2046,5	2767,5	2,0457	4,6139	6,6596	720.04	2575.3
900.	175.36	0,0011213	0,21369	0,21481	742,6	2029,5	2772,1	2,0941	4,5250	6,6192	741.63	2578.8
1000.	179.88	0,0011274	0,19317	0,19429	762,6	2013,6	2776,2	2,1382	4,4446	6,5828	761.48	2581.9
1100.	184.07	0,0011331	0,17625	0,17738	781,1	1998,5	2779,7	2,1786	4,3711	6,5497	779.88	2584.5
1200.	187.96	0,0011386	0,16206	0,16320	798,4	1984,3	2782,7	2,2161	4,3033	6,5194	797.06	2586.9
1300.	191.61	0,0011438	0,14998	0,15113	814,7	1970,7	2785,4	2,2510	4,2403	6,4913	813.21	2589.0
1400.	195,04	0,0011489	0,13957	0,14072	830,1	1957,7	2787,8	2,2837	4,1814	6,4651	828.47	2590.8
1500.	198.29	0,0011539	0,13050	0,13166	844,7	1945,2	2789,9	2,3145	4,1261	6,4406	842.93	2592.4
1600.	201.37	0,0011586	0,12253	0,12369	858,6	1933,2	2791,7	2,3436	4,0739	6,4175	856.71	2593.8
1800.	207.11	0,0011678	0,10915	0,11032	884,6	1910,3	2794,8	2,3976	3,9775	6,3751	882.47	2596.3
2000.	212,37	0,0011766	0,09836	0,09954	908,6	1888,6	2797,2	2,4469	3,8898	6,3367	906.24	2598.2
2200.	217.24	0,0011850	0,08947	0,09065	931,0	1868,1	2799,1	2,4922	3,8093	6,3015	928.35	2599.6
2400.	221.78	0,0011932	0,08201	0,08320	951,9	1848,5	2800,4	2,5343	3,7347	6,2690	949.07	2600.7
2600.	226.04	0,0012011	0,07565	0,07686	971,7	1829,6	2801,4	2,5736	3,6651	6,2387	968.60	2601.5
2800.	230.05	0,0012088	0,07018	0,07139	990,5	1811,5	2802,0	2,6106	3,5998	6,2104	987.10	2602.1
3000.	233,84	0,0012163	0,06541	0,06663	1008,4	1793,9	2802,3	2,6455	3,5382	6,1837	1004.70	2602.4
3500.	242.54	0,0012345	0,05579	0,05703	1049,8	1752,2	2802,0	2,7253	3,3976	6,1228	1045.44	2602.4
4000.	250.33	0,0012521	0,04850	0,04975	1087,4	1712,9	2800,3	2,7965	3,2720	6,0685	1082.4	2601.3
4500.	257.41	0,0012691	0,04277	0,04404	1122,1	1675,6	2797,7	2,8612	3,1579	6,0191	1116.4	2599.5
5000.	263.91	0,0012858	0,03814	0,03943	1154,5	1639,7	2794,2	2,9206	3,0529	5,9735	1148.0	2597.0
5500.	269.93	0,0013023	0,03433	0,03563	1184,9	1605,0	2789,9	2,9757	2,9552	5,9309	1177.7	2594.0
6000.	275,55	0,0013187	0,03112	0,03244	1213,7	1571,3	2785,0	3,0273	2,8635	5,8908	1205.8	2590.4
6500.	280.82	0,0013350	0,028384	0,029719	1241,1	1538,4	2779,5	3,0759	2,7768	5,8527	1232.5	2586.3
7000.	285.79	0,0013513	0,026022	0,027373	1267,4	1506,0	2773,5	3,1219	2,6943	5,8162	1258.0	2581.8
7500.	290.50	0,0013677	0,023959	0,025327	1292,7	1474,2	2766,9	3,1657	2,6153	5,7811	1282.4	2577.0
8000.	294.97	0,0013842	0,022141	0,023525	1317,1	1442,8	2759,9	3,2076	2,5395	5,7471	1306.0	2571.7
9000.	303.31	0,0014179	0,019078	0,020495	1363,7	1380,9	2744,6	3,2867	2,3953	5,6820	1351.0	2560.1
10000.	310.96	0,0014526	0,016589	0,018041	1408,0	1319,7	2727,7	3,3605	2,2593	5,6198	1393.5	2547.3
11000.	318.05	0,0014887	0,014517	0,016006	1450,6	1258,7	2709,3	3,4304	2,1291	5,5595	1434.2	2533.2
12000.	324.65	0,0015268	0,012756	0,014283	1491,8	1197,4	2689,2	3,4972	2,0030	5,5002	1473.4	2517.8
13000.	330.83	0,0015672	0,011230	0,012797	1532,0	1135,0	2667,0	3,5616	1,8792	5,4408	1511.6	2500.6
14000.	336.64	0,0016106	0,009884	0,011495	1571,6	1070,7	2642,4	3,6242	1,7560	5,3803	1549.1	2481.4
15000.	342.13	0,0016579	0,008682	0,010340	1611,0	1004,0	2615,0	3,6859	1,6320	5,3178	1586.1	2459.9
16000.	347.33	0,0017103	0,007597	0,009308	1650,5	934,3	2584,9	3,7471	1,5060	5,2531	1623.2	2436.0
17000.	352.26	0,0017696	0,006601	0,008371	1691,7	859,9	2551,6	3,8107	1,3748	5,1855	1661.6	2409.3
18000.	356.96	0,0018399	0,005658	0,007498	1734,8	779,1	2513,9	3,8765	1,2362	5,1128	1701.7	2378.9
19000.	361.43	0,0019260	0,004751	0,006678	1778,7	692,0	2470,6	3,9429	1,0903	5,0332	1742.1	2343.8
20000.	365.70	0,0020370	0,003840	0,005877	1826,5	591,9	2418,4	4,0149	0,9263	4,9412	1785.7	2300.8
21000.	369.78	0,0022015	0,002822	0,005023	1886,3	461,3	2347,6	4,1048	0,7175	4,8223	1840.0	2242.1
22000.	373.69	0,0026714	0,001056	0,003728	2011,1	184,5	2195,6	4,2947	0,2852	4,5799	1952.4	2113.6
22120.	374.15	0.00317	0.0	0.00317	2107.4	0.0	2107.4	4.4429	0.0	4.4429	2037.3	2037.3

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

Press. p, kPa (t_s)		0.	20.	40.	60.	80.	100.	120.	140.	160.
	v	0.0010002	135.23	144.47	153.71	162.95	172.19	181.42	190.66	199.89
1.0	h	-0.0	2538.6	2575.9	2613.3	2650.9	2688.6	2726.5	2764.6	2802.9
(6.983)	s	-0.0002	9.0611	9.1842	9.3001	9.4096	9.5136	9.6125	9.7070	9.7975
	v	0.0010002	90.131	96.298	102.46	108.62	114.78	120.94	127.10	133.25
1.5	h	-0.0	2538.4	2575.8	2613.2	2650.8	2688.6	2726.5	2764.6	2802.9
(13.04)	s	-0.0002	8.8736	8.9968	9.1127	9.2223	9.3263	9.4253	9.5198	9.6103
	v	0.0010002	67.582	72.211	76.837	81.459	86.080	90.700	95.319	99.936
2.0	h	-0.0	2538.3	2575.6	2613.1	2650.7	2688.5	2726.4	2764.5	2802.8
(17.51)	s	-0.0002	8.7404	8.8637	8.9797	9.0894	9.1934	9.2924	9.3870	9.4775
	v	0.0010002	0.0010017	48.124	51.211	54.296	57.378	60.460	63.540	66.619
3.0	h	-0.0	83.9	2575.4	2612.9	2650.6	2688.4	2726.3	2764.5	2802.8
(24.10)	s	-0.0002	0.2963	8.6760	8.7922	8.9019	9.0060	9.1051	9.1997	9.2902
	v	0.0010002	0.0010017	36.081	38.398	40.714	43.027	45.339	47.650	49.961
4.0	h	-0.0	83.9	2575.2	2612.7	2650.4	2688.3	2726.2	2764.4	2802.7
(28.98)	s	-0.0002	0.2963	8.5426	8.6589	8.7688	8.8730	8.9721	9.0668	9.1573
	v	0.0010002	0.0010017	28.854	30.711	32.565	34.417	36.267	38.117	39.966
5.0	h	-0.0	83.9	2574.9	2612.6	2650.3	2688.1	2726.1	2764.3	2802.6
(32.90)	s	-0.0002	0.2963	8.4390	8.5555	8.6655	8.7698	8.8690	8.9636	9.0542
	v	0.0010002	0.0010017	24.037	25.586	27.132	28.676	30.219	31.761	33.302
6.0	h	-0.0	83.9	2574.7	2612.4	2650.1	2688.0	2726.0	2764.2	2802.6
(36.18)	s	-0.0002	0.2963	8.3543	8.4709	8.5810	8.6854	8.7846	8.8793	8.9700
	v	0.0010002	0.0010017	0.0010078	19.179	20.341	21.501	22.659	23.816	24.973
8.0	h	-0.0	83.9	167.5	2612.0	2649.8	2687.8	2725.8	2764.1	2802.4
(41.53)	s	-0.0002	0.2963	0.5721	8.3372	8.4476	8.5521	8.6515	8.7463	8.8370
	v	0.0010002	0.0010017	0.0010078	15.336	16.266	17.195	18.123	19.050	19.975
10.0	h	-0.0	83.9	167.5	2611.6	2649.5	2687.5	2725.6	2763.9	2802.3
(45.83)	s	-0.0002	0.2963	0.5721	8.2334	8.3439	8.4486	8.5481	8.6430	8.7338
	v	0.0010002	0.0010017	0.0010078	10.210	10.834	11.455	12.075	12.694	13.312
15.0	h	-0.0	83.9	167.5	2610.6	2648.8	2686.9	2725.1	2763.5	2802.0
(54.00)	s	-0.0002	0.2963	0.5721	8.0440	8.1551	8.2601	8.3599	8.4551	8.5460
	v	0.0010002	0.0010017	0.0010078	0.0010171	8.1172	8.5847	9.0508	9.516	9.980
20.0	h	-0.0	83.9	167.5	251.1	2648.0	2686.3	2724.6	2763.1	2801.6
(60.09)	s	-0.0002	0.2963	0.5721	0.8310	8.0206	8.1261	8.2262	8.3215	8.4127
	v	0.0010002	0.0010017	0.0010078	0.0010171	5.4007	5.7144	6.0267	6.3379	6.6483
30.0	h	-0.0	83.9	167.5	251.1	2646.5	2685.1	2723.6	2762.3	2801.0
(69.12)	s	-0.0002	0.2963	0.5721	0.8310	7.8300	7.9363	8.0370	8.1329	8.2243
	v	0.0010002	0.0010017	0.0010078	0.0010171	4.0424	4.2792	4.5146	4.7489	4.9825
40.0	h	-0.0	83.9	167.5	251.1	2644.9	2683.8	2722.6	2761.4	2800.3
(75.89)	s	-0.0002	0.2963	0.5721	0.8310	7.6937	7.8009	7.9023	7.9985	8.0903
	v	0.0010002	0.0010017	0.0010078	0.0010171	0.0010292	3.4181	3.6074	3.7955	3.9829
50.0	h	0.0	83.9	167.5	251.1	334.9	2682.6	2721.6	2760.6	2799.6
(81.35)	s	-0.0002	0.2963	0.5721	0.8310	1.0753	7.6953	7.7972	7.8940	7.9861
	v	0.0010002	0.0010017	0.0010078	0.0010171	0.0010292	2.8440	3.0025	3.1599	3.3165
60.0	h	0.0	83.9	167.5	251.1	334.9	2681.3	2720.6	2759.8	2798.9
(85.95)	s	-0.0001	0.2963	0.5721	0.8310	1.0752	7.6085	7.7111	7.8083	7.9008
	v	0.0010002	0.0010017	0.0010078	0.0010171	0.0010292	2.1262	2.2464	2.3654	2.4836
80.0	h	0.0	83.9	167.5	251.1	334.9	2678.8	2718.6	2758.1	2797.5
(93.51)	s	-0.0001	0.2963	0.5721	0.8310	1.0752	7.4703	7.5742	7.6723	7.7655
	v	0.0010002	0.0010017	0.0010078	0.0010171	0.0010292	1.6955	1.7927	1.8886	1.9838
100.0	h	0.1	84.0	167.5	251.2	335.0	2676.2	2716.5	2756.4	2796.2
(99.63)	s	-0.0001	0.2963	0.5721	0.8309	1.0752	7.3618	7.4670	7.5662	7.6601
	v	0.0010001	0.0010017	0.0010077	0.0010171	0.0010291	0.0010437	1.1876	1.2529	1.3173
150.0	h	0.1	84.0	167.6	251.2	335.0	419.1	2711.2	2752.2	2792.7
(111.4)	s	-0.0001	0.2963	0.5721	0.8309	1.0752	1.3068	7.2693	7.3709	7.4667
	v	0.0010001	0.0010016	0.0010077	0.0010171	0.0010291	0.0010437	0.0010606	0.9349	0.9840
200.0	h	0.2	84.0	167.6	251.2	335.0	419.1	503.7	2747.8	2789.1
(120.2)	s	-0.0001	0.2963	0.5720	0.8309	1.0752	1.3068	1.5276	7.2298	7.3275
	v	0.0010001	0.0010016	0.0010077	0.0010170	0.0010291	0.0010436	0.0010606	0.6167	0.6506
300.0	h	0.3	84.1	167.7	251.3	335.1	419.2	503.8	2738.8	2781.8
(133.5)	s	-0.0001	0.2962	0.5720	0.8308	1.0751	1.3067	1.5275	7.0254	7.1271
	v	0.0010000	0.0010015	0.0010076	0.0010170	0.0010290	0.0010436	0.0010605	0.0010800	0.4837
400.0	h	0.4	84.2	167.8	251.4	335.2	419.3	503.9	589.1	2774.2
(143.6)	s	-0.0001	0.2962	0.5720	0.8308	1.0750	1.3066	1.5274	1.7389	6.9805

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

180.	200.	220.	240.	260.	280.	300.	320.	340.		Press. p, kPa
209.12	218.35	227.58	236.82	246.05	255.28	264.51	273.74	282.97	v	
2841.4	2880.1	2919.0	2958.1	2997.4	3037.0	3076.8	3116.9	3157.2	h	1.0
9.8843	9.9679	10.0484	10.1262	10.2014	10.2743	10.3450	10.4137	10.4805	s	
139.41	145.56	151.72	157.87	164.03	170.18	176.34	182.49	188.64	v	
2841.4	2880.0	2918.9	2958.1	2997.4	3037.0	3076.8	3116.9	3157.2	h	1.5
9.6972	9.7807	9.8612	9.9390	10.0142	10.0871	10.1578	10.2266	10.2934	s	
104.55	109.17	113.79	118.40	123.02	127.64	132.25	136.87	141.48	v	
2841.3	2880.0	2918.9	2958.0	2997.4	3037.0	3076.8	3116.9	3157.2	h	2.0
9.5643	9.6479	9.7284	9.8062	9.8814	9.9543	10.0251	10.0938	10.1606	s	
69.698	72.777	75.855	78.933	82.010	85.088	88.165	91.242	94.320	v	
2841.3	2880.0	2918.9	2958.0	2997.4	3037.0	3076.8	3116.9	3157.2	h	3.0
9.3771	9.4607	9.5412	9.6190	9.6943	9.7672	9.8379	9.9066	9.9735	s	
52.270	54.580	56.889	59.197	61.506	63.814	66.122	68.430	70.738	v	
2841.2	2879.9	2918.8	2958.0	2997.3	3036.9	3076.8	3116.8	3157.2	h	4.0
9.2443	9.3279	9.4084	9.4862	9.5615	9.6344	9.7051	9.7738	9.8407	s	
41.814	43.661	45.509	47.356	49.203	51.050	52.897	54.743	56.590	v	
2841.2	2879.9	2918.8	2957.9	2997.3	3036.9	3076.7	3116.8	3157.1	h	5.0
9.1412	9.2248	9.3054	9.3832	9.4584	9.5313	9.6021	9.6708	9.7377	s	
34.843	36.383	37.922	39.462	41.001	42.540	44.079	45.618	47.157	v	
2841.1	2879.8	2918.8	2957.9	2997.3	3036.9	3076.7	3116.8	3157.1	h	6.0
9.0569	9.1406	9.2212	9.2990	9.3742	9.4472	9.5179	9.5866	9.6535	s	
26.129	27.284	28.439	29.594	30.749	31.903	33.058	34.212	35.367	v	
2841.0	2879.7	2918.7	2957.8	2997.2	3036.8	3076.7	3116.8	3157.1	h	8.0
8.9240	9.0077	9.0883	9.1661	9.2414	9.3143	9.3851	9.4538	9.5207	s	
20.900	21.825	22.750	23.674	24.598	25.521	26.445	27.369	28.292	v	
2840.9	2879.6	2918.6	2957.8	2997.2	3036.8	3076.6	3116.7	3157.0	h	10.0
8.8208	8.9045	8.9852	9.0630	9.1383	9.2113	9.2820	9.3508	9.4177	s	
13.929	14.546	15.163	15.780	16.396	17.012	17.628	18.244	18.860	v	
2840.6	2879.4	2918.4	2957.6	2997.0	3036.6	3076.5	3116.6	3157.0	h	15.0
8.6332	8.7170	8.7977	8.8757	8.9510	9.0240	9.0948	9.1635	9.2304	s	
10.444	10.907	11.370	11.832	12.295	12.757	13.219	13.681	14.143	v	
2840.3	2879.2	2918.2	2957.4	2996.9	3036.5	3076.4	3116.5	3156.9	h	20.0
8.5000	8.5839	8.6647	8.7426	8.8180	8.8910	8.9618	9.0306	9.0975	s	
6.9582	7.2675	7.5766	7.8854	8.1940	8.5024	8.8108	9.1190	9.4272	v	
2839.8	2878.7	2917.8	2957.1	2996.6	3036.2	3076.1	3116.3	3156.7	h	30.0
8.3119	8.3960	8.4769	8.5550	8.6305	8.7035	8.7744	8.8432	8.9102	s	
5.2154	5.4478	5.6800	5.9118	6.1435	6.3751	6.6065	6.8378	7.0690	v	
2839.2	2878.2	2917.4	2956.7	2996.3	3036.0	3075.9	3116.1	3156.5	h	40.0
8.1782	8.2625	8.3435	8.4217	8.4973	8.5704	8.6413	8.7102	8.7772	s	
4.1697	4.3560	4.5420	4.7277	4.9133	5.0986	5.2839	5.4691	5.6542	v	
2838.6	2877.7	2917.0	2956.4	2995.9	3035.7	3075.7	3115.9	3156.3	h	50.0
8.0742	8.1587	8.2399	8.3182	8.3939	8.4671	8.5380	8.6070	8.6740	s	
3.4726	3.6281	3.7833	3.9383	4.0931	4.2477	4.4022	4.5566	4.7109	v	
2838.1	2877.3	2916.6	2956.0	2995.6	3035.4	3075.4	3115.6	3156.1	h	60.0
7.9891	8.0738	8.1552	8.2336	8.3093	8.3826	8.4536	8.5226	8.5896	s	
2.6011	2.7183	2.8350	2.9515	3.0678	3.1840	3.3000	3.4160	3.5319	v	
2836.9	2876.3	2915.8	2955.3	2995.0	3034.9	3075.0	3115.2	3155.7	h	80.0
7.8544	7.9395	8.0212	8.0998	8.1757	8.2491	8.3202	8.3893	8.4564	s	
2.0783	2.1723	2.2660	2.3595	2.4527	2.5458	2.6387	2.7316	2.8244	v	
2835.8	2875.4	2915.0	2954.6	2994.4	3034.4	3074.5	3114.8	3155.3	h	100.0
7.7495	7.8349	7.9169	7.9958	8.0719	8.1454	8.2166	8.2857	8.3529	s	
1.3811	1.4444	1.5073	1.5700	1.6325	1.6948	1.7570	1.8191	1.8812	v	
2832.9	2872.9	2912.9	2952.9	2992.9	3033.0	3073.3	3113.7	3154.3	h	150.0
7.5574	7.6439	7.7266	7.8061	7.8826	7.9565	8.0280	8.0973	8.1646	s	
1.0325	1.0804	1.1280	1.1753	1.2224	1.2693	1.3162	1.3629	1.4095	v	
2830.0	2870.5	2910.8	2951.1	2991.4	3031.7	3072.1	3112.6	3153.3	h	200.0
7.4196	7.5072	7.5907	7.6707	7.7477	7.8219	7.8937	7.9632	8.0307	s	
0.6837	0.7164	0.7486	0.7805	0.8123	0.8438	0.8753	0.9066	0.9379	v	
2824.0	2865.5	2906.6	2947.5	2988.2	3028.9	3069.7	3110.5	3151.4	h	300.0
7.2222	7.3119	7.3971	7.4783	7.5562	7.6311	7.7034	7.7734	7.8412	s	
0.5093	0.5343	0.5589	0.5831	0.6072	0.6311	0.6549	0.6785	0.7021	v	
2817.8	2860.4	2902.3	2943.9	2985.1	3026.2	3067.2	3108.3	3149.4	h	400.0
7.0788	7.1708	7.2576	7.3402	7.4190	7.4947	7.5675	7.6379	7.7061	s	

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

Press. p, kPa (t_s)		360.	380.	400.	420.	440.	460.	480.	500.	520.
1.0 (6.983)	v	292.20	301.43	310.66	319.89	329.12	338.35	347.58	356.81	366.04
	h	3197.8	3238.6	3279.7	3321.1	3362.7	3404.6	3446.8	3489.2	3531.9
	s	10.5457	10.6091	10.6711	10.7317	10.7909	10.8488	10.9056	10.9612	11.0157
1.5 (13.04)	v	194.80	200.95	207.11	213.26	219.41	225.57	231.72	237.87	244.03
	h	3197.8	3238.6	3279.7	3321.1	3362.7	3404.6	3446.8	3489.2	3531.9
	s	10.3585	10.4220	10.4840	10.5445	10.6037	10.6617	10.7184	10.7741	10.8286
2.0 (17.51)	v	146.10	150.71	155.33	159.94	164.56	169.17	173.79	178.41	183.02
	h	3197.8	3238.6	3279.7	3321.1	3362.7	3404.6	3446.8	3489.2	3531.9
	s	10.2257	10.2892	10.3512	10.4118	10.4710	10.5289	10.5857	10.6413	10.6958
3.0 (24.10)	v	97.397	100.47	103.55	106.63	109.71	112.78	115.86	118.94	122.01
	h	3197.8	3238.6	3279.7	3321.1	3362.7	3404.6	3446.8	3489.2	3531.9
	s	10.0386	10.1021	10.1641	10.2246	10.2838	10.3418	10.3985	10.4541	10.5087
4.0 (28.98)	v	73.046	75.354	77.662	79.970	82.278	84.586	86.893	89.201	91.509
	h	3197.7	3238.6	3279.7	3321.0	3362.7	3404.6	3446.7	3489.2	3531.9
	s	9.9058	9.9693	10.0313	10.0918	10.1510	10.2090	10.2657	10.3214	10.3759
5.0 (32.90)	v	58.436	60.283	62.129	63.975	65.822	67.668	69.514	71.360	73.207
	h	3197.7	3238.6	3279.7	3321.0	3362.7	3404.6	3446.7	3489.2	3531.9
	s	9.8028	9.8663	9.9283	9.9888	10.0480	10.1060	10.1627	10.2184	10.2729
6.0 (36.18)	v	48.696	50.235	51.773	53.312	54.851	56.389	57.928	59.467	61.005
	h	3197.7	3238.5	3279.6	3321.0	3362.6	3404.5	3446.7	3489.2	3531.9
	s	9.7186	9.7821	9.8441	9.9047	9.9639	10.0218	10.0786	10.1342	10.1888
8.0 (41.53)	v	36.521	37.675	38.829	39.983	41.137	42.291	43.445	44.599	45.753
	h	3197.7	3238.5	3279.6	3321.0	3362.6	3404.5	3446.7	3489.1	3531.9
	s	9.5858	9.6493	9.7113	9.7719	9.8311	9.8890	9.9458	10.0014	10.0560
10.0 (45.83)	v	29.216	30.139	31.062	31.986	32.909	33.832	34.756	35.679	36.602
	h	3197.6	3238.5	3279.6	3321.0	3362.6	3404.5	3446.7	3489.1	3531.9
	s	9.4828	9.5463	9.6083	9.6689	9.7281	9.7860	9.8428	9.8984	9.9530
15.0 (54.00)	v	19.475	20.091	20.707	21.323	21.938	22.554	23.169	23.785	24.400
	h	3197.5	3238.4	3279.5	3320.9	3362.5	3404.4	3446.6	3489.1	3531.8
	s	9.2956	9.3591	9.4211	9.4817	9.5409	9.5988	9.6556	9.7112	9.7658
20.0 (60.09)	v	14.605	15.067	15.529	15.991	16.453	16.914	17.376	17.838	18.300
	h	3197.5	3238.3	3279.4	3320.8	3362.5	3404.4	3446.6	3489.0	3531.8
	s	9.1627	9.2262	9.2882	9.3488	9.4081	9.4660	9.5228	9.5784	9.6330
30.0 (69.12)	v	9.7353	10.043	10.351	10.659	10.967	11.275	11.583	11.891	12.199
	h	3197.3	3238.2	3279.3	3320.7	3362.3	3404.2	3446.4	3488.9	3531.6
	s	8.9754	9.0389	9.1010	9.1615	9.2208	9.2788	9.3355	9.3912	9.4458
40.0 (75.89)	v	7.3002	7.5314	7.7625	7.9935	8.2246	8.4556	8.6866	8.9176	9.1485
	h	3197.1	3238.0	3279.1	3320.5	3362.2	3404.1	3446.3	3488.8	3531.5
	s	8.8424	8.9060	8.9680	9.0286	9.0879	9.1459	9.2027	9.2583	9.3129
50.0 (81.35)	v	5.8392	6.0242	6.2091	6.3941	6.5790	6.7638	6.9487	7.1335	7.3183
	h	3196.9	3237.8	3279.0	3320.4	3362.1	3404.0	3446.2	3488.7	3531.4
	s	8.7392	8.8028	8.8649	8.9255	8.9848	9.0428	9.0996	9.1552	9.2098
60.0 (85.95)	v	4.8652	5.0194	5.1736	5.3277	5.4819	5.6360	5.7900	5.9441	6.0981
	h	3196.7	3237.7	3278.8	3320.2	3361.9	3403.9	3446.1	3488.6	3531.3
	s	8.6549	8.7185	8.7806	8.8412	8.9005	8.9585	9.0153	9.0710	9.1256
80.0 (93.51)	v	3.6477	3.7634	3.8792	3.9948	4.1105	4.2261	4.3418	4.4574	4.5729
	h	3196.4	3237.3	3278.5	3320.0	3361.7	3403.6	3445.9	3488.4	3531.1
	s	8.5217	8.5854	8.6475	8.7081	8.7675	8.8255	8.8823	8.9380	8.9926
100.0 (99.63)	v	2.9172	3.0098	3.1025	3.1951	3.2877	3.3803	3.4728	3.5653	3.6578
	h	3196.0	3237.0	3278.2	3319.7	3361.4	3403.4	3445.6	3488.1	3530.9
	s	8.4183	8.4820	8.5442	8.6049	8.6642	8.7223	8.7791	8.8348	8.8894
150.0 (111.4)	v	1.9431	2.0051	2.0669	2.1288	2.1906	2.2524	2.3142	2.3759	2.4377
	h	3195.1	3236.2	3277.5	3319.0	3360.7	3402.8	3445.0	3487.6	3530.4
	s	8.2301	8.2940	8.3562	8.4170	8.4764	8.5345	8.5914	8.6472	8.7018
200.0 (120.2)	v	1.4561	1.5027	1.5492	1.5956	1.6421	1.6885	1.7349	1.7812	1.8276
	h	3194.2	3235.4	3276.7	3318.3	3360.1	3402.1	3444.5	3487.0	3529.9
	s	8.0964	8.1603	8.2226	8.2835	8.3429	8.4011	8.4581	8.5139	8.5686
300.0 (133.5)	v	0.9691	1.0003	1.0314	1.0625	1.0935	1.1245	1.1556	1.1865	1.2175
	h	3192.4	3233.7	3275.2	3316.8	3358.8	3400.9	3443.3	3486.0	3528.9
	s	7.9072	7.9713	8.0338	8.0949	8.1545	8.2128	8.2698	8.3257	8.3805
400.0 (143.6)	v	0.7256	0.7491	0.7725	0.7959	0.8192	0.8426	0.8659	0.8892	0.9125
	h	3190.6	3232.1	3273.6	3315.4	3357.4	3399.7	3442.1	3484.9	3527.8
	s	7.7723	7.8367	7.8994	7.9606	8.0203	8.0787	8.1359	8.1919	8.2468

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

Press. p, kPa		540.	560.	580.	600.	625.	650.	700.	750.	800.
1.0	v	375.27	384.50	393.74	402.97	414.50	426.04	449.12	472.19	495.27
	h	3574.9	3618.2	3661.8	3705.6	3760.8	3816.4	3928.9	4043.0	4158.7
	s	11.0693	11.1218	11.1735	11.2243	11.2866	11.3476	11.4663	11.5807	11.6911
1.5	v	250.18	256.34	262.49	268.64	276.33	284.03	299.41	314.79	330.18
	h	3574.9	3618.2	3661.8	3705.6	3760.8	3816.4	3928.9	4043.0	4158.7
	s	10.8821	10.9347	10.9864	11.0372	11.0995	11.1605	11.2792	11.3935	11.5040
2.0	v	187.64	192.25	196.87	201.48	207.25	213.02	224.56	236.10	247.63
	h	3574.9	3618.2	3661.8	3705.6	3760.8	3816.4	3928.8	4043.0	4158.7
	s	10.7494	10.8019	10.8536	10.9044	10.9667	11.0277	11.1464	11.2608	11.3712
3.0	v	125.09	128.17	131.24	134.32	138.17	142.01	149.70	157.40	165.09
	h	3574.9	3618.2	3661.8	3705.6	3760.8	3816.4	3928.8	4043.0	4158.7
	s	10.5622	10.6148	10.6665	10.7173	10.7796	10.8406	10.9593	11.0736	11.1841
4.0	v	93.817	96.124	98.432	100.74	103.62	106.51	112.28	118.05	123.82
	h	3574.9	3618.2	3661.7	3705.6	3760.8	3816.4	3928.8	4043.0	4158.7
	s	10.4295	10.4820	10.5337	10.5845	10.6468	10.7078	10.8265	10.9409	11.0513
5.0	v	75.053	76.899	78.745	80.592	82.899	85.207	89.822	94.438	99.053
	h	3574.9	3618.2	3661.7	3705.6	3760.7	3816.3	3928.8	4043.0	4158.7
	s	10.3265	10.3790	10.4307	10.4815	10.5438	10.6049	10.7235	10.8379	10.9483
6.0	v	62.544	64.082	65.621	67.159	69.082	71.005	74.852	78.698	82.544
	h	3574.9	3618.2	3661.7	3705.6	3760.7	3816.3	3928.8	4043.0	4158.7
	s	10.2423	10.2949	10.3466	10.3973	10.4596	10.5207	10.6394	10.7537	10.8642
8.0	v	46.907	48.061	49.215	50.369	51.811	53.254	56.138	59.023	61.908
	h	3574.9	3618.2	3661.7	3705.5	3760.7	3816.3	3928.8	4043.0	4158.7
	s	10.1095	10.1621	10.2138	10.2646	10.3269	10.3879	10.5066	10.6210	10.7314
10.0	v	37.525	38.448	39.372	40.295	41.449	42.603	44.910	47.218	49.526
	h	3574.9	3618.1	3661.7	3705.5	3760.7	3816.3	3928.8	4042.9	4158.7
	s	10.0065	10.0591	10.1108	10.1616	10.2239	10.2849	10.4036	10.5180	10.6284
15.0	v	25.016	25.632	26.247	26.863	27.632	28.401	29.940	31.478	33.017
	h	3574.8	3618.1	3661.7	3705.5	3760.7	3816.3	3928.8	4042.9	4158.7
	s	9.8194	9.8719	9.9236	9.9744	10.0367	10.0978	10.2164	10.3308	10.4413
20.0	v	18.761	19.223	19.685	20.146	20.723	21.300	22.455	23.609	24.762
	h	3574.8	3618.0	3661.6	3705.4	3760.6	3816.2	3928.7	4042.9	4158.7
	s	9.6865	9.7391	9.7908	9.8416	9.9039	9.9650	10.0836	10.1980	10.3085
30.0	v	12.507	12.815	13.122	13.430	13.815	14.200	14.969	15.739	16.508
	h	3574.7	3618.0	3661.5	3705.4	3760.6	3816.2	3928.7	4042.8	4158.6
	s	9.4993	9.5519	9.6036	9.6544	9.7167	9.7778	9.8965	10.0109	10.1213
40.0	v	9.3795	9.6104	9.8413	10.072	10.361	10.649	11.227	11.804	12.381
	h	3574.6	3617.9	3661.4	3705.3	3760.5	3816.1	3928.6	4042.8	4158.6
	s	9.3665	9.4191	9.4708	9.5216	9.5839	9.6450	9.7636	9.8780	9.9885
50.0	v	7.5031	7.6878	7.8726	8.0574	8.2883	8.5192	8.9810	9.4427	9.9044
	h	3574.5	3617.8	3661.3	3705.2	3760.4	3816.0	3928.6	4042.7	4158.5
	s	9.2634	9.3160	9.3677	9.4185	9.4808	9.5419	9.6606	9.7750	9.8855
60.0	v	6.2521	6.4062	6.5602	6.7141	6.9066	7.0991	7.4839	7.8687	8.2535
	h	3574.4	3617.7	3661.3	3705.1	3760.3	3816.0	3928.5	4042.7	4158.5
	s	9.1792	9.2318	9.2835	9.3343	9.3966	9.4577	9.5764	9.6908	9.8013
80.0	v	4.6885	4.8040	4.9196	5.0351	5.1795	5.3239	5.6126	5.9013	6.1899
	h	3574.2	3617.5	3661.1	3705.0	3760.2	3815.8	3928.4	4042.6	4158.4
	s	9.0462	9.0988	9.1506	9.2014	9.2637	9.3248	9.4436	9.5580	9.6685
100.0	v	3.7503	3.8428	3.9352	4.0277	4.1432	4.2588	4.4898	4.7208	4.9517
	h	3574.0	3617.3	3660.9	3704.8	3760.0	3815.7	3928.2	4042.5	4158.3
	s	8.9431	8.9957	9.0474	9.0982	9.1606	9.2217	9.3405	9.4549	9.5654
150.0	v	2.4994	2.5611	2.6228	2.6845	2.7616	2.8386	2.9927	3.1468	3.3008
	h	3573.5	3616.9	3660.5	3704.4	3759.6	3815.3	3927.9	4042.2	4158.0
	s	8.7555	8.8082	8.8599	8.9108	8.9732	9.0343	9.1531	9.2676	9.3781
200.0	v	1.8739	1.9202	1.9666	2.0129	2.0707	2.1286	2.2442	2.3598	2.4754
	h	3573.0	3616.4	3660.0	3704.0	3759.3	3815.0	3927.6	4041.9	4157.8
	s	8.6223	8.6750	8.7268	8.7776	8.8401	8.9012	9.0201	9.1346	9.2452
300.0	v	1.2485	1.2794	1.3103	1.3412	1.3799	1.4185	1.4957	1.5728	1.6499
	h	3572.0	3615.5	3659.2	3703.2	3758.5	3814.2	3927.0	4041.4	4157.3
	s	8.4343	8.4870	8.5389	8.5898	8.6523	8.7135	8.8325	8.9471	9.0577
400.0	v	0.9357	0.9590	0.9822	1.0054	1.0344	1.0634	1.1214	1.1793	1.2372
	h	3571.1	3614.6	3658.3	3702.3	3757.7	3813.5	3926.4	4040.8	4156.9
	s	8.3006	8.3534	8.4053	8.4563	8.5189	8.5802	8.6992	8.8139	8.9246

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Press. p, kPa (t_s)		Temperature, t, °C: 0.	20.	40.	60.	80.	100.	120.	140.	160.
500.0	v	0.0010000	0,0010015	0.0010076	0,0010169	0.0010290	0,0010435	0,0010605	0.0010800	0,38347
	h	0.5	84.3	167,9	251,5	335.3	419,4	503,9	589.2	2766.4
(151.8)	s	-0,0001	0.2962	0,5719	0,8307	1,0750	1.3066	1,5273	1.7388	6,8631
600.0	v	0.0009999	0.0010015	0.0010075	0,0010169	0.0010289	0,0010434	0,0010604	0,0010799	0.31655
	h	0.6	84.4	168.0	251,6	335.4	419,4	504,0	589,3	2758.2
(158.8)	s	-0,0001	0.2962	0,5719	0.8307	1,0749	1.3065	1,5272	1.7387	6,7640
800.0	v	0,0009998	0.0010014	0.0010075	0,0010168	0.0010288	0,0010433	0,0010603	0,0010798	0,0011021
	h	0.8	84.6	168.2	251,7	335.5	419,6	504,1	589.4	675.6
(170.4)	s	-0,0001	0.2961	0,5718	0,8306	1.0748	1.3063	1,5270	1.7385	1,9423
1000.0	v	0.0009997	0.0010013	0.0010074	0,0010167	0.0010287	0,0010432	0.0010602	0,0010796	0,0011019
	h	1.0	84.8	168.3	251,9	335.7	419.7	504,3	589,5	675.7
(179.9)	s	-0.0001	0.2961	0,5717	0,8305	1,0746	1.3062	1,5269	1.7383	1,9420
1500.0	v	0,0009995	0.0010010	0.0010071	0,0010165	0,0010285	0,0010430	0,0010599	0,0010793	0.0011016
	h	1.5	85.3	168.8	252.3	336.1	420.1	504,6	589,8	676.0
(198.3)	s	-0,0000	0.2960	0,5715	0,8302	1,0743	1.3058	1,5264	1.7378	1,9414
2000.0	v	0,0009992	0,0010008	0,0010069	0,0010162	0,0010282	0,0010427	0,0010596	0,0010790	0,0011012
	h	2,0	85.7	169,2	252,7	336.5	420,5	505,0	590.2	676,3
(212.4)	s	0,0000	0.2959	0,5713	0,8299	1.0740	1,3054	1,5260	1.7373	1,9408
3000.0	v	0,0009987	0,0010004	0,0010065	0,0010158	0,0010278	0,0010422	0,0010590	0,0010783	0.0011005
	h	3.0	86.7	170,1	253,6	337.3	421,2	505,7	590,8	676,9
(233.8)	s	0,0001	0.2957	0,5709	0,8294	1,0733	1,3046	1,5251	1,7362	1,9396
4000.0	v	0,0009982	0,0009999	0,0010060	0,0010153	0,0010273	0,0010417	0,0010584	0,0010777	0.0010997
	h	4,0	87.6	171,0	254,4	338.1	422,0	506,4	591,5	677,5
(250.3)	s	0,0002	0.2955	0,5706	0,8289	1.0726	1.3038	1,5242	1,7352	1,9385
5000.0	v	0,0009977	0,0009995	0.0010056	0,0010149	0,0010268	0,0010412	0,0010579	0,0010771	0,0010990
	h	5.1	88.6	171,9	255,3	338,8	422,7	507,1	592,1	678,1
(263.9)	s	0,0002	0.2952	0,5702	0,8283	1,0720	1,3030	1,5233	1,7342	1,9373
6000.0	v	0,0009972	0,0009990	0,0010052	0,0010144	0,0010263	0,0010406	0,0010573	0,0010764	0,0010983
	h	6.1	89.5	172,7	256,1	339.6	423,5	507,8	592,8	678,6
(275.5)	s	0,0003	0.2950	0,5698	0,8278	1,0713	1,3023	1,5224	1,7332	1,9361
8000.0	v	0,0009962	0,0009981	0,0010043	0,0010135	0,0010254	0,0010396	0,0010562	0,0010752	0,0010968
	h	8.1	91.4	174,5	257,8	341.2	425,0	509,2	594,1	679,8
(295.0)	s	0,0004	0.2946	0,5690	0.8267	1,0700	1.3007	1,5206	1,7311	1,9338
10000.0	v	0,0009953	0,0009972	0,0010034	0,0010127	0,0010245	0,0010386	0,0010551	0,0010739	0,0010954
	h	10.1	93.2	176,3	259,4	342.8	426,5	510,6	595,4	681,0
(311.0)	s	0,0005	0.2942	0,5682	0,8257	1,0687	1.2992	1,5188	1,7291	1,9315
15000.0	v	0,0009928	0,0009950	0,0010013	0,0010105	0,0010221	0,0010361	0,0010523	0,0010709	0,0010919
	h	15.1	97.9	180,7	263,6	346.8	430,3	514,2	598,7	684,0
(342.1)	s	0,0007	0.2931	0,5663	0.8230	1,0655	1,2954	1,5144	1,7241	1,9258
20000.0	v	0,0009904	0,0009929	0,0009992	0,0010083	0,0010199	0,0010337	0,0010497	0,0010679	0,0010886
	h	20.1	102.5	185,1	267,8	350.8	434,0	517,7	602,0	687,1
(365.7)	s	0,0008	0.2919	0,5643	0,8204	1,0623	1.2916	1,5101	1,7192	1,9203
30000.0	v	0,0009857	0,0009886	0,0009951	0,0010041	0,0010155	0,0010289	0,0010445	0,0010621	0,0010821
	h	30.0	111.7	193,8	276,1	358.7	441,6	524,9	608,7	693,3
	s	0,0008	0.2895	0,5604	0,8153	1,0560	1,2843	1,5017	1,7097	1,9095
40000.0	v	0.0009811	0,0009845	0,0009910	0,0010001	0,0010112	0,0010244	0,0010395	0,0010567	0,0010760
	h	39.7	120.8	202,5	284,5	366.7	449,2	532,1	615,5	699,6
	s	0,0004	0.2870	0,5565	0,8102	1,0498	1.2771	1,4935	1,7004	1,8991
50000.0	v	0.0009767	0,0009804	0,0009872	0,0009961	0,0010071	0,0010200	0,0010347	0,0010514	0,0010701
	h	49.3	129.9	211,2	292,8	374.7	456,8	539,4	622.4	705,9
	s	-0,0002	0.2843	0,5525	0,8052	1,0438	1,2701	1,4856	1,6915	1,8890
60000.0	v	0,0009723	0,0009765	0,0009834	0,0009923	0,0010031	0,0010157	0,0010301	0,0010464	0,0010645
	h	58.8	138.9	219,8	301,1	382,6	464,5	546,6	629,2	712,4
	s	-0,0012	0.2815	0,5486	0,8002	1,0379	1,2633	1,4778	1,6828	1,8793
80000.0	v	0,0009641	0,0009689	0,0009760	0,0009849	0,0009954	0,0010076	0,0010214	0,0010368	0,0010540
	h	77,5	156,6	236,9	317,6	398.5	479,7	561,3	643,2	725,5
	s	-0,0037	0.2756	0,5406	0,7904	1,0264	1,2501	1,4629	1,6661	1,8607
100000.0	v	0,0009565	0,0009616	0,0009690	0,0009779	0,0009882	0,0009999	0,0010132	0,0010279	0,0010443
	h	95.9	174,0	253,8	334,0	414.4	495,1	576,0	657,2	738,9
	s	-0,0067	0.2692	0,5325	0,7808	1,0152	1,2373	1,4486	1,6502	1,8431

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

Press. p, kPa		180.	200.	220.	240.	260.	280.	300.	320.	340.
500.0	v	0.4045	0.4250	0.4450	0.4647	0.4841	0.5034	0.5226	0.5416	0.5606
	h	2811.4	2855.1	2898.0	2940.1	2981.9	3023.4	3064.8	3106.1	3147.4
	s	6.9647	7.0592	7.1478	7.2317	7.3115	7.3879	7.4614	7.5322	7.6008
600.0	v	0.3346	0.3520	0.3690	0.3857	0.4021	0.4183	0.4344	0.4504	0.4663
	h	2804.8	2849.7	2893.5	2936.4	2978.7	3020.6	3062.3	3103.9	3145.4
	s	6.8691	6.9662	7.0567	7.1419	7.2228	7.3000	7.3740	7.4454	7.5143
800.0	v	0.2471	0.2608	0.2740	0.2869	0.2995	0.3119	0.3241	0.3363	0.3483
	h	2791.1	2838.6	2884.2	2928.6	2972.1	3014.9	3057.3	3099.4	3141.4
	s	6.7122	6.8148	6.9094	6.9976	7.0807	7.1595	7.2348	7.3070	7.3767
1000.0	v	0.1944	0.2059	0.2169	0.2276	0.2379	0.2480	0.2580	0.2678	0.2776
	h	2776.5	2826.8	2874.6	2920.6	2965.2	3009.0	3052.1	3094.9	3137.4
	s	6.5835	6.6922	6.7911	6.8825	6.9680	7.0485	7.1251	7.1984	7.2689
1500.0	v	0.0011271	0.1324	0.1406	0.1483	0.1556	0.1628	0.1697	0.1765	0.1832
	h	763.4	2794.7	2848.6	2899.2	2947.3	2993.7	3038.9	3083.3	3127.0
	s	2.1386	6.4508	6.5624	6.6630	6.7550	6.8405	6.9207	6.9967	7.0693
2000.0	v	0.0011267	0.0011560	0.1021	0.1084	0.1144	0.1200	0.1255	0.1308	0.1360
	h	763.6	852.6	2819.9	2875.9	2928.1	2977.5	3025.0	3071.2	3116.3
	s	2.1379	2.3300	6.3829	6.4943	6.5941	6.6852	6.7696	6.8487	6.9235
3000.0	v	0.0011258	0.0011550	0.0011891	0.06816	0.07283	0.07712	0.08116	0.08500	0.08871
	h	764.1	853.0	943.9	2822.9	2885.1	2942.0	2995.1	3045.4	3093.9
	s	2.1366	2.3284	2.5165	6.2241	6.3432	6.4479	6.5422	6.6285	6.7088
4000.0	v	0.0011249	0.0011540	0.0011878	0.0012280	0.05172	0.05544	0.05883	0.06200	0.06499
	h	764.6	853.4	944.1	1037.7	2835.6	2902.0	2962.0	3017.5	3069.8
	s	2.1352	2.3268	2.5147	2.7006	6.1353	6.2576	6.3642	6.4593	6.5461
5000.0	v	0.0011241	0.0011530	0.0011866	0.0012264	0.0012750	0.04222	0.04530	0.04810	0.05070
	h	765.2	853.8	944.4	1037.8	1134.9	2856.9	2925.5	2987.2	3044.1
	s	2.1339	2.3253	2.5129	2.6984	2.8840	6.0886	6.2105	6.3163	6.4106
6000.0	v	0.0011232	0.0011519	0.0011853	0.0012249	0.0012729	0.03317	0.03614	0.03874	0.04111
	h	765.7	854.2	944.7	1037.9	1134.7	2804.9	2885.0	2954.2	3016.5
	s	2.1325	2.3237	2.5110	2.6962	2.8813	5.9270	6.0692	6.1880	6.2913
8000.0	v	0.0011216	0.0011500	0.0011829	0.0012218	0.0012687	0.0013277	0.02426	0.02681	0.02896
	h	766.7	855.1	945.3	1038.1	1134.5	1236.0	2786.8	2878.7	2955.3
	s	2.1299	2.3206	2.5075	2.6919	2.8761	3.0629	5.7942	5.9519	6.0790
10000.0	v	0.0011199	0.0011480	0.0011805	0.0012188	0.0012648	0.0013221	0.0013979	0.01926	0.02147
	h	767.8	855.9	945.9	1038.4	1134.2	1235.0	1343.4	2783.5	2883.4
	s	2.1272	2.3176	2.5039	2.6877	2.8709	3.0563	3.2488	5.7145	5.8803
15000.0	v	0.0011159	0.0011433	0.0011748	0.0012115	0.0012553	0.0013090	0.0013779	0.0014736	0.0016324
	h	770.4	858.1	947.6	1039.2	1134.0	1232.9	1338.3	1454.3	1593.3
	s	2.1208	2.3102	2.4953	2.6775	2.8585	3.0407	3.2278	3.4267	3.6571
20000.0	v	0.0011120	0.0011387	0.0011693	0.0012047	0.0012466	0.0012971	0.0013606	0.0014451	0.0015704
	h	773.1	860.4	949.3	1040.3	1134.0	1231.4	1334.3	1445.6	1572.4
	s	2.1145	2.3030	2.4869	2.6677	2.8468	3.0262	3.2089	3.3998	3.6100
30000.0	v	0.0011046	0.0011301	0.0011590	0.0011922	0.0012307	0.0012763	0.0013316	0.0014012	0.0014939
	h	778.7	865.2	953.1	1042.8	1134.7	1229.7	1328.7	1433.6	1547.7
	s	2.1022	2.2891	2.4710	2.6492	2.8250	2.9998	3.1757	3.3556	3.5447
40000.0	v	0.0010976	0.0011220	0.0011495	0.0011808	0.0012166	0.0012583	0.0013077	0.0013677	0.0014434
	h	784.4	870.2	957.2	1045.8	1136.3	1229.2	1325.4	1425.9	1532.9
	s	2.0905	2.2758	2.4560	2.6320	2.8050	2.9761	3.1469	3.3193	3.4965
50000.0	v	0.0010910	0.0011144	0.0011407	0.0011703	0.0012040	0.0012426	0.0012874	0.0013406	0.0014055
	h	790.2	875.4	961.6	1049.2	1138.5	1229.8	1323.7	1421.0	1523.0
	s	2.0793	2.2632	2.4417	2.6158	2.7864	2.9545	3.1213	3.2882	3.4572
60000.0	v	0.0010847	0.0011073	0.0011325	0.0011607	0.0011924	0.0012285	0.0012698	0.0013179	0.0013751
	h	796.2	880.8	966.3	1053.0	1141.2	1231.1	1323.2	1418.0	1516.3
	s	2.0684	2.2511	2.4281	2.6005	2.7690	2.9345	3.0981	3.2606	3.4236
80000.0	v	0.0010731	0.0010941	0.0011174	0.0011433	0.0011720	0.0012041	0.0012401	0.0012809	0.0013280
	h	808.4	891.9	976.2	1061.4	1147.8	1235.4	1324.7	1415.7	1508.6
	s	2.0478	2.2281	2.4026	2.5720	2.7370	2.8985	3.0570	3.2130	3.3671
100000.0	v	0.0010623	0.0010821	0.0011039	0.0011279	0.0011543	0.0011833	0.0012155	0.0012514	0.0012921
	h	820.9	903.5	986.7	1070.7	1155.6	1241.5	1328.7	1416.9	1505.9
	s	2.0283	2.2067	2.3789	2.5458	2.7081	2.8663	3.0210	3.1723	3.3200

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Press. p, kPa (t_s)		Temperature, t, °C 360.	380.	400.	420.	440.	460.	480.	500.	520.
	v	0.5795	0.5984	0.6172	0.6359	0.6547	0.6734	0.6921	0.7108	0.7294
500.0	h	3188.8	3230.4	3272.1	3314.0	3356.1	3398.4	3441.0	3483.8	3526.8
(151.8)	s	7.6673	7.7319	7.7948	7.8561	7.9160	7.9745	8.0318	8.0879	8.1428
	v	0.4821	0.4979	0.5136	0.5293	0.5450	0.5606	0.5762	0.5918	0.6074
600.0	h	3187.0	3228.7	3270.6	3312.6	3354.8	3397.2	3439.8	3482.7	3525.8
(158.8)	s	7.5810	7.6459	7.7090	7.7705	7.8305	7.8891	7.9465	8.0027	8.0577
	v	0.3603	0.3723	0.3842	0.3960	0.4078	0.4196	0.4314	0.4432	0.4549
800.0	h	3183.4	3225.4	3267.5	3309.7	3352.1	3394.7	3437.5	3480.5	3523.7
(170.4)	s	7.4441	7.5094	7.5729	7.6347	7.6950	7.7539	7.8115	7.8678	7.9230
	v	0.2873	0.2969	0.3065	0.3160	0.3256	0.3350	0.3445	0.3540	0.3634
1000.0	h	3179.7	3222.0	3264.4	3306.9	3349.5	3392.2	3435.1	3478.3	3521.6
(179.9)	s	7.3368	7.4027	7.4665	7.5287	7.5893	7.6484	7.7062	7.7627	7.8181
	v	0.1898	0.1964	0.2029	0.2094	0.2158	0.2223	0.2287	0.2350	0.2414
1500.0	h	3170.4	3213.5	3256.6	3299.7	3342.8	3386.0	3429.3	3472.8	3516.5
(198.3)	s	7.1389	7.2060	7.2709	7.3340	7.3953	7.4550	7.5133	7.5703	7.6261
	v	0.1411	0.1461	0.1511	0.1561	0.1610	0.1659	0.1707	0.1756	0.1804
2000.0	h	3160.8	3204.9	3248.7	3292.4	3336.0	3379.7	3423.4	3467.3	3511.3
(212.4)	s	6.9950	7.0635	7.1296	7.1935	7.2555	7.3159	7.3748	7.4323	7.4885
	v	0.09232	0.09584	0.09931	0.1027	0.1061	0.1095	0.1128	0.1161	0.1194
3000.0	h	3140.9	3187.0	3232.5	3277.5	3322.3	3367.0	3411.6	3456.2	3500.9
(233.8)	s	6.7844	6.8561	6.9246	6.9906	7.0543	7.1160	7.1760	7.2345	7.2916
	v	0.06787	0.07066	0.07338	0.07604	0.07866	0.08125	0.08381	0.08634	0.08886
4000.0	h	3119.9	3168.4	3215.7	3262.3	3308.3	3354.0	3399.6	3445.0	3490.4
(250.3)	s	6.6265	6.7019	6.7733	6.8414	6.9069	6.9702	7.0314	7.0909	7.1489
	v	0.05316	0.05551	0.05779	0.06001	0.06218	0.06431	0.06642	0.06849	0.07055
5000.0	h	3097.6	3148.8	3198.3	3246.5	3294.0	3340.9	3387.4	3433.7	3479.8
(263.9)	s	6.4966	6.5762	6.6508	6.7215	6.7890	6.8538	6.9164	6.9770	7.0360
	v	0.04330	0.04539	0.04738	0.04931	0.05118	0.05302	0.05482	0.05659	0.05834
6000.0	h	3074.0	3128.3	3180.1	3230.3	3279.3	3327.4	3375.0	3422.2	3469.1
(275.5)	s	6.3836	6.4680	6.5462	6.6196	6.6893	6.7559	6.8199	6.8818	6.9417
	v	0.03088	0.03265	0.03431	0.03589	0.03740	0.03887	0.04030	0.04170	0.04308
8000.0	h	3022.7	3084.2	3141.6	3196.2	3248.7	3299.7	3349.6	3398.8	3447.4
(295.0)	s	6.1872	6.2828	6.3694	6.4493	6.5240	6.5945	6.6617	6.7262	6.7883
	v	0.02331	0.02493	0.02641	0.02779	0.02911	0.03036	0.03158	0.03276	0.03391
10000.0	h	2964.8	3035.7	3099.9	3159.7	3216.2	3270.5	3323.2	3374.6	3425.1
(311.0)	s	6.0110	6.1213	6.2182	6.3057	6.3861	6.4612	6.5321	6.5994	6.6640
	v	0.01256	0.01428	0.01566	0.01686	0.01794	0.01895	0.01989	0.02080	0.02166
15000.0	h	2770.8	2887.7	2979.1	3057.0	3126.9	3191.5	3252.4	3310.6	3366.8
(342.1)	s	5.5677	5.7497	5.8876	6.0016	6.1010	6.1904	6.2724	6.3487	6.4204
	v	0.0018269	0.008246	0.009947	0.01120	0.01224	0.01315	0.01399	0.01477	0.01551
20000.0	h	1742.9	2660.2	2820.5	2932.9	3023.7	3102.7	3174.4	3241.1	3304.2
(365.7)	s	3.8835	5.3165	5.5585	5.7232	5.8523	5.9616	6.0581	6.1456	6.2262
	v	0.0016285	0.001874	0.002831	0.004921	0.006227	0.007189	0.007985	0.008681	0.009310
30000.0	h	1678.0	1837.7	2161.8	2558.0	2754.0	2887.7	2993.9	3085.0	3166.6
	s	3.7541	4.0021	4.4896	5.0706	5.3499	5.5349	5.6779	5.7972	5.9014
	v	0.0015425	0.001682	0.001909	0.002371	0.003200	0.004137	0.004941	0.005616	0.006205
40000.0	h	1650.5	1776.4	1934.1	2145.7	2399.4	2617.1	2779.8	2906.8	3013.7
	s	3.6856	3.8814	4.1190	4.4285	4.7893	5.0906	5.3097	5.4762	5.6128
	v	0.0014862	0.001589	0.001729	0.001938	0.002269	0.002747	0.003308	0.003882	0.004408
50000.0	h	1633.9	1746.8	1877.7	2026.6	2199.7	2387.2	2564.9	2723.0	2854.9
	s	3.6355	3.8110	4.0083	4.2262	4.4723	4.7316	4.9709	5.1782	5.3466
	v	0.0014444	0.001528	0.001632	0.001771	0.001962	0.002226	0.002565	0.002952	0.003358
60000.0	h	1622.8	1728.4	1847.3	1975.0	2113.5	2263.2	2418.8	2570.6	2712.6
	s	3.5948	3.7589	3.9383	4.1252	4.3221	4.5291	4.7385	4.9374	5.1189
	v	0.0013833	0.001445	0.001518	0.001605	0.001710	0.001841	0.001999	0.002188	0.002405
80000.0	h	1609.7	1707.0	1814.2	1924.1	2036.6	2152.5	2272.8	2397.4	2524.0
	s	3.5296	3.6807	3.8425	4.0033	4.1633	4.3237	4.4855	4.6488	4.8104
	v	0.0013388	0.001390	0.001446	0.001511	0.001587	0.001675	0.001777	0.001893	0.002024
100000.0	h	1603.4	1696.3	1797.6	1899.0	2000.3	2102.7	2207.7	2316.1	2427.2
	s	3.4767	3.6211	3.7738	3.9223	4.0664	4.2079	4.3492	4.4913	4.6331

PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER (TEMPERATURE AND PRESSURE)

TABLE 2

Temperature, t, °C

Press. p, kPa		540.	560.	580.	600.	625.	650.	700.	750.	800.
500.0	v	0.7481	0.7667	0.7853	0.8039	0.8272	0.8504	0.8968	0.9432	0.9896
	h	3570.1	3613.6	3657.4	3701.5	3757.0	3812.8	3925.8	4040.3	4156.4
	s	8.1967	8.2496	8.3016	8.3526	8.4152	8.4766	8.5957	8.7105	8.8213
600.0	v	0.6230	0.6386	0.6541	0.6696	0.6890	0.7084	0.7471	0.7858	0.8245
	h	3569.1	3612.7	3656.6	3700.7	3756.2	3812.1	3925.1	4039.8	4155.9
	s	8.1117	8.1647	8.2167	8.2678	8.3305	8.3919	8.5111	8.6259	8.7368
800.0	v	0.4666	0.4783	0.4900	0.5017	0.5163	0.5309	0.5600	0.5891	0.6181
	h	3567.2	3610.9	3654.8	3699.1	3754.7	3810.7	3923.9	4038.7	4155.0
	s	7.9771	8.0302	8.0824	8.1336	8.1964	8.2579	8.3773	8.4923	8.6033
1000.0	v	0.3728	0.3822	0.3916	0.4010	0.4127	0.4244	0.4477	0.4710	0.4943
	h	3565.2	3609.0	3653.1	3697.4	3753.1	3809.3	3922.7	4037.6	4154.1
	s	7.8724	7.9256	7.9779	8.0292	8.0921	8.1537	8.2734	8.3885	8.4997
1500.0	v	0.2477	0.2540	0.2604	0.2667	0.2745	0.2824	0.2980	0.3136	0.3292
	h	3560.4	3604.5	3648.8	3693.3	3749.3	3805.7	3919.6	4034.9	4151.7
	s	7.6808	7.7343	7.7869	7.8385	7.9017	7.9636	8.0838	8.1993	8.3108
2000.0	v	0.1852	0.1900	0.1947	0.1995	0.2054	0.2114	0.2232	0.2349	0.2467
	h	3555.5	3599.9	3644.4	3689.2	3745.5	3802.1	3916.5	4032.2	4149.4
	s	7.5435	7.5974	7.6503	7.7022	7.7657	7.8279	7.9485	8.0645	8.1763
3000.0	v	0.1226	0.1259	0.1291	0.1323	0.1364	0.1404	0.1483	0.1562	0.1641
	h	3545.7	3590.6	3635.7	3681.0	3737.8	3795.0	3910.3	4026.8	4144.7
	s	7.3474	7.4020	7.4554	7.5079	7.5721	7.6349	7.7564	7.8733	7.9857
4000.0	v	0.09135	0.09384	0.09631	0.09876	0.1018	0.1049	0.1109	0.1169	0.1229
	h	3535.8	3581.4	3627.0	3672.8	3730.2	3787.9	3904.1	4021.4	4140.0
	s	7.2055	7.2608	7.3149	7.3680	7.4328	7.4961	7.6187	7.7363	7.8495
5000.0	v	0.07259	0.07461	0.07662	0.07862	0.08109	0.08356	0.08845	0.09329	0.09809
	h	3525.9	3572.0	3618.2	3664.5	3722.5	3780.7	3897.9	4016.1	4135.3
	s	7.0934	7.1494	7.2042	7.2578	7.3233	7.3872	7.5108	7.6292	7.7431
6000.0	v	0.06008	0.06179	0.06349	0.06518	0.06728	0.06936	0.07348	0.07755	0.08159
	h	3515.9	3562.7	3609.4	3656.2	3714.8	3773.5	3891.7	4010.7	4130.7
	s	7.0000	7.0568	7.1122	7.1664	7.2326	7.2971	7.4217	7.5409	7.6554
8000.0	v	0.04443	0.04577	0.04709	0.04839	0.05001	0.05161	0.05477	0.05788	0.06096
	h	3495.7	3543.8	3591.7	3639.5	3699.3	3759.2	3879.2	3999.9	4121.3
	s	6.8484	6.9068	6.9636	7.0191	7.0866	7.1523	7.2790	7.3999	7.5158
10000.0	v	0.03504	0.03615	0.03724	0.03832	0.03965	0.04096	0.04355	0.04609	0.04858
	h	3475.1	3524.5	3573.7	3622.7	3683.8	3744.7	3866.8	3989.1	4112.0
	s	6.7261	6.7863	6.8446	6.9013	6.9703	7.0373	7.1660	7.2886	7.4058
15000.0	v	0.02250	0.02331	0.02411	0.02488	0.02584	0.02677	0.02859	0.03036	0.03209
	h	3421.4	3475.0	3527.7	3579.8	3644.3	3708.3	3835.4	3962.1	4088.6
	s	6.4885	6.5535	6.6160	6.6764	6.7492	6.8195	6.9536	7.0806	7.2013
20000.0	v	0.01621	0.01688	0.01753	0.01816	0.01893	0.01967	0.02111	0.02250	0.02385
	h	3364.7	3423.0	3479.9	3535.5	3603.8	3671.1	3803.8	3935.0	4065.3
	s	6.3015	6.3724	6.4398	6.5043	6.5814	6.6554	6.7953	6.9267	7.0511
30000.0	v	0.009890	0.01043	0.01095	0.01144	0.01202	0.01258	0.01365	0.01465	0.01562
	h	3241.7	3312.1	3378.9	3443.0	3520.2	3595.0	3739.7	3880.3	4018.5
	s	5.9949	6.0805	6.1597	6.2340	6.3212	6.4033	6.5560	6.6970	6.8288
40000.0	v	0.006735	0.007219	0.007667	0.008088	0.008584	0.009053	0.009930	0.01075	0.01152
	h	3108.0	3193.4	3272.4	3346.4	3433.8	3517.0	3674.8	3825.5	3971.7
	s	5.7302	5.8340	5.9276	6.0135	6.1122	6.2035	6.3701	6.5210	6.6606
50000.0	v	0.004888	0.005328	0.005734	0.006111	0.006550	0.006960	0.007720	0.008429	0.009076
	h	2968.9	3070.7	3163.2	3248.3	3346.8	3438.9	3610.2	3770.9	3925.3
	s	5.4886	5.6124	5.7221	5.8207	5.9320	6.0331	6.2138	6.3749	6.5222
60000.0	v	0.003755	0.004135	0.004496	0.004835	0.005229	0.005596	0.006269	0.006885	0.007460
	h	2838.3	2951.7	3055.8	3151.6	3261.4	3362.4	3547.0	3717.4	3879.6
	s	5.2755	5.4132	5.5367	5.6477	5.7717	5.8827	6.0775	6.2483	6.4031
80000.0	v	0.002641	0.002886	0.003132	0.003379	0.003682	0.003974	0.004519	0.005017	0.005481
	h	2648.2	2765.1	2874.9	2980.3	3104.6	3220.3	3428.7	3616.7	3792.8
	s	4.9650	5.1072	5.2374	5.3595	5.4999	5.6270	5.8470	6.0354	6.2034
100000.0	v	0.002168	0.002326	0.002493	0.002668	0.002891	0.003106	0.003536	0.003952	0.004341
	h	2538.6	2648.2	2754.5	2857.5	2985.8	3105.3	3324.4	3526.3	3714.3
	s	4.7719	4.9050	5.0311	5.1505	5.2954	5.4267	5.6579	5.8600	6.0397

STEAM LOSS THROUGH ORIFICES DISCHARGING TO ATMOSPHERE

TABLE 3

Orifice Diameter, in.	Steam loss, lb/hr, when steam gauge pressure is:											
	2 psi	5 psi	10 psi	15 psi	25 psi	50 psi	75 psi	100 psi	125 psi	150 psi	200 psi	250 psi
1/32	0.31	0.49	0.70	0.85	1.14	1.86	2.58	3.3	4.02	4.74	6.17	7.61
1/16	1.25	1.97	2.8	3.4	4.6	7.4	10.3	13.2	16.1	18.9	24.7	30.4
3/32	2.81	4.44	6.3	7.7	10 3	16.7	15.4	29.7	36.2	42.6	55.6	68.5
1/8	4.5	7.9	11.2	13.7	18.3	29.8	41.3	52.8	64.3	75.8	99.0	122.0
5/32	7.8	12.3	17.4	21.3	28.5	46.5	64.5	82.5	100.0	118.0	154.0	190.0
3/16	11.2	17.7	25.1	30.7	41 1	67.0	93.0	119.0	145.0	170.0	222.0	274.0
7/32	15.3	24.2	34.2	41.9	55.9	91.2	126.0	162.0	197.0	232.0	303.0	373.0
1/4	20.0	31.6	44.6	54.7	73.1	119.0	165.0	211.0	257.0	303.0	395.0	487.0
9/32	25.2	39.9	56.5	69.2	92.5	151.0	209.0	267.0	325.0	384.0	500.0	617.0
5/16	31.2	49.3	69.7	85.4	114.0	186.0	258.0	330.0	402.0	474.0	617.0	761.0
11/32	37.7	59.6	84.4	103.0	138.0	225.0	312.0	399.0	486.0	573.0	747.0	921.0
3/8	44.9	71.0	100.0	123.0	164.0	268.0	371.0	475.0	578.0	682.0	889.0	1096.0
13/32	52.7	83.3	118.0	144.0	193.0	314.0	436.0	557.0	679.0	800.0	1043.0	1286.0
7/16	61.1	96.6	137.0	167.0	224.0	365.0	506.0	647.0	787.0	928.0	1210.0	1492.0
15/32	70.2	111.0	157.0	192.0	257.0	419.0	580.0	742.0	904.0	1065.0	1389.0	1713.0
1/2	79.8	126.0	179.0	219.0	292.0	476.0	660.0	844.0	1028.0	1212.0	1580.0	1949.0

Imperial - Metric Conversion
1 lb/hr = ·4536 kg/hr
1 inch = 25.4 mm
1 psi = 6.897 kPa

LOGARITHMIC MEAN TEMPERATURE DIFFERENCE CHART FOR HEATING OR COOLING APPLICATIONS

TABLE 4

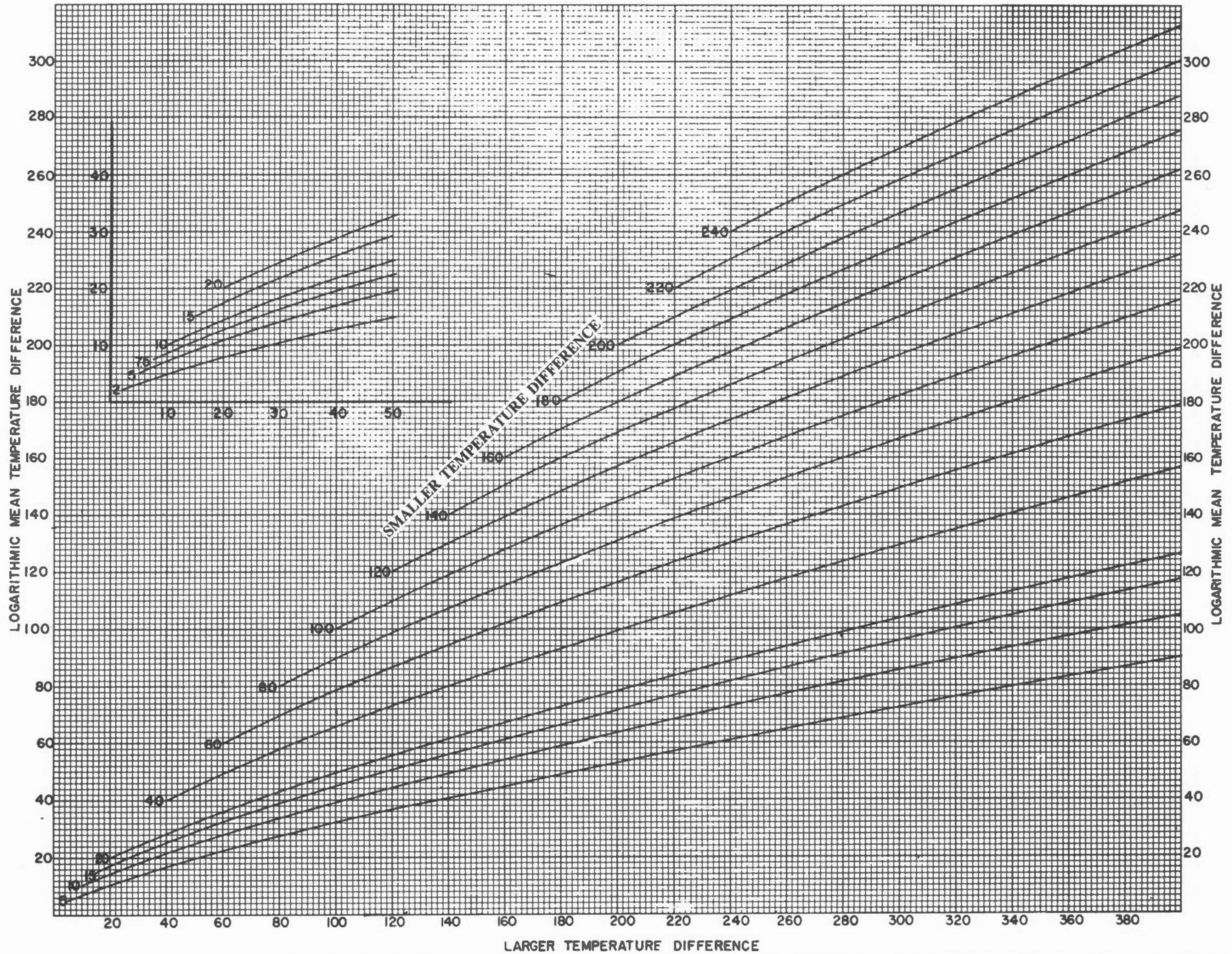


TABLE 5

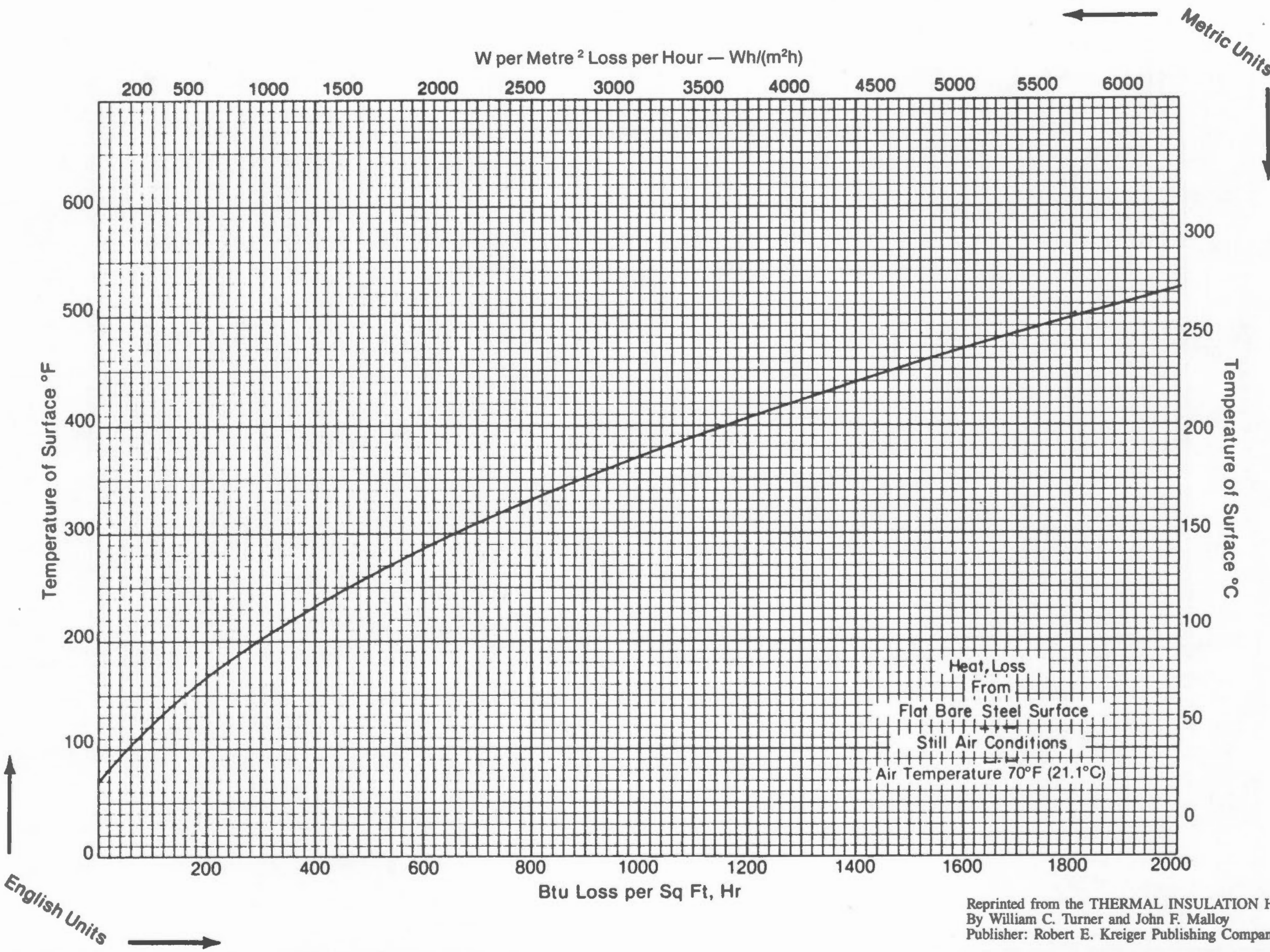


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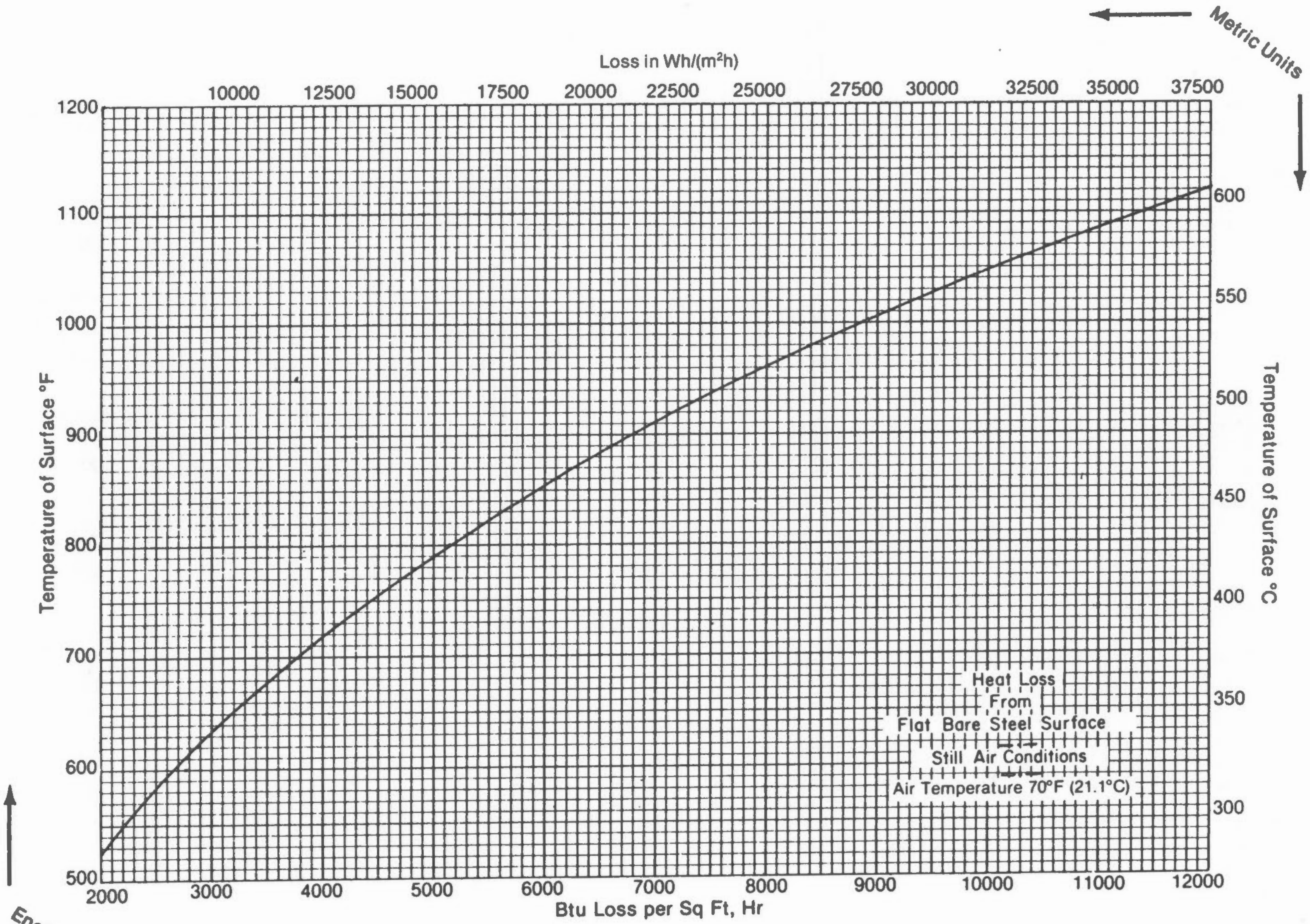
TABLE 5



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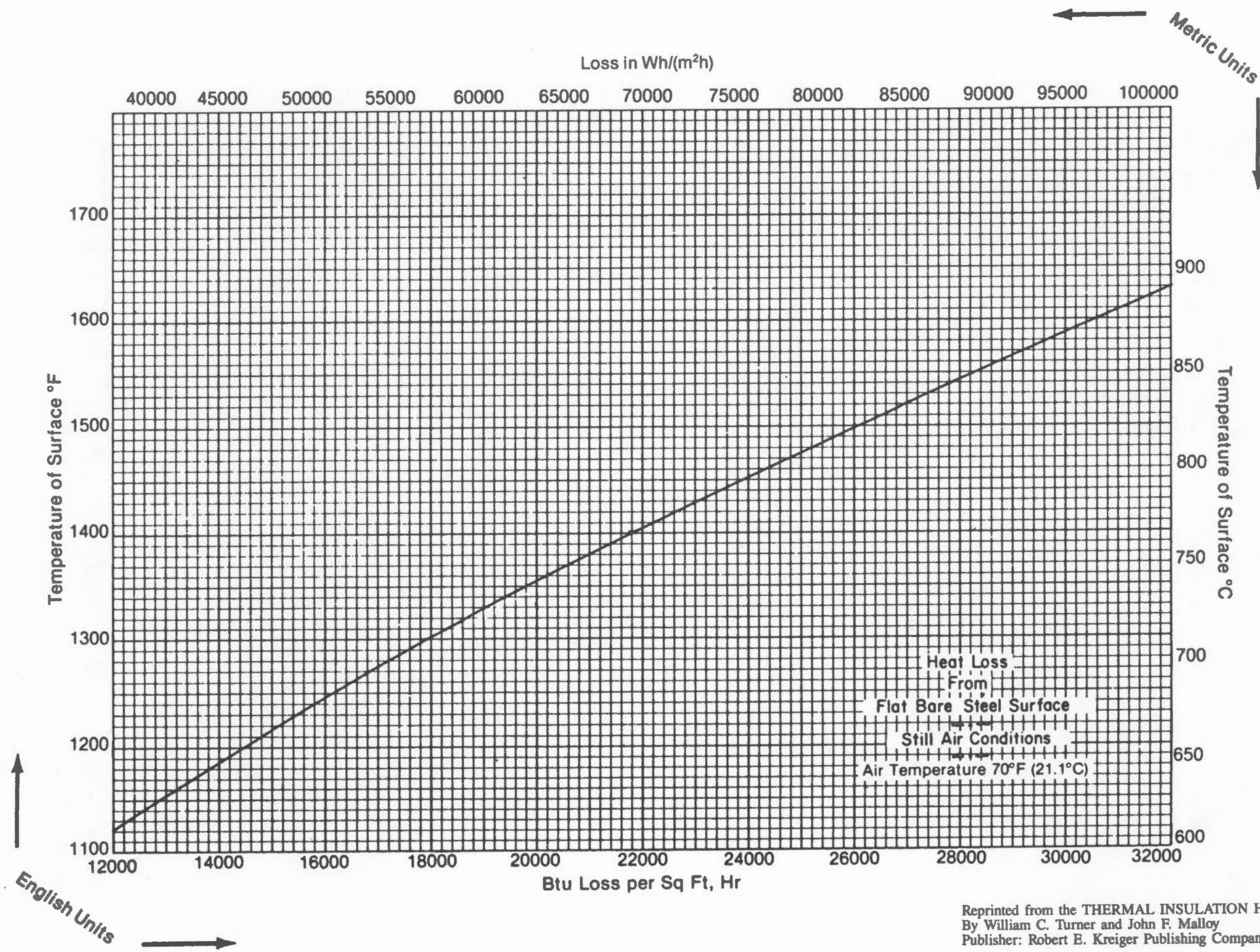

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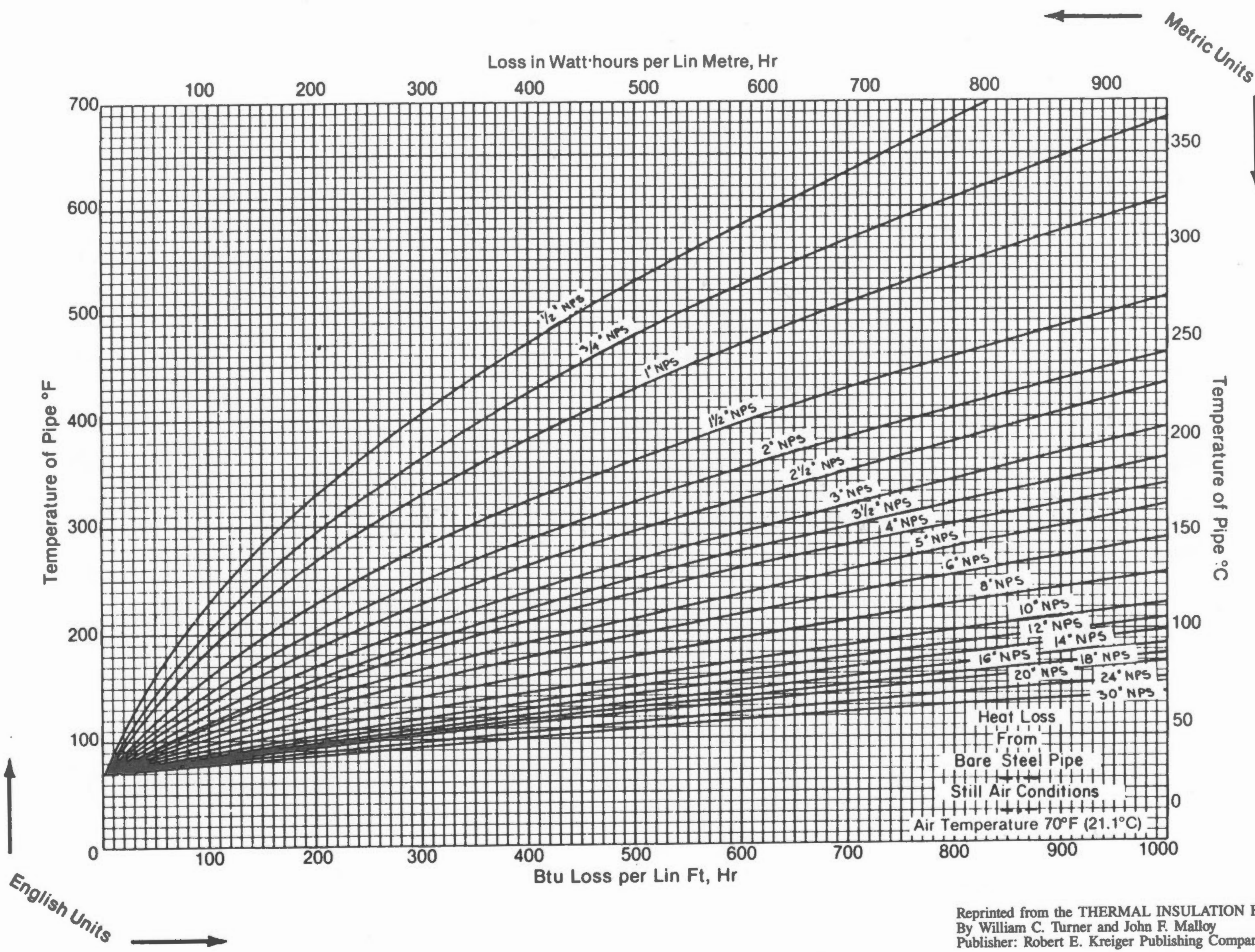
TABLE 6



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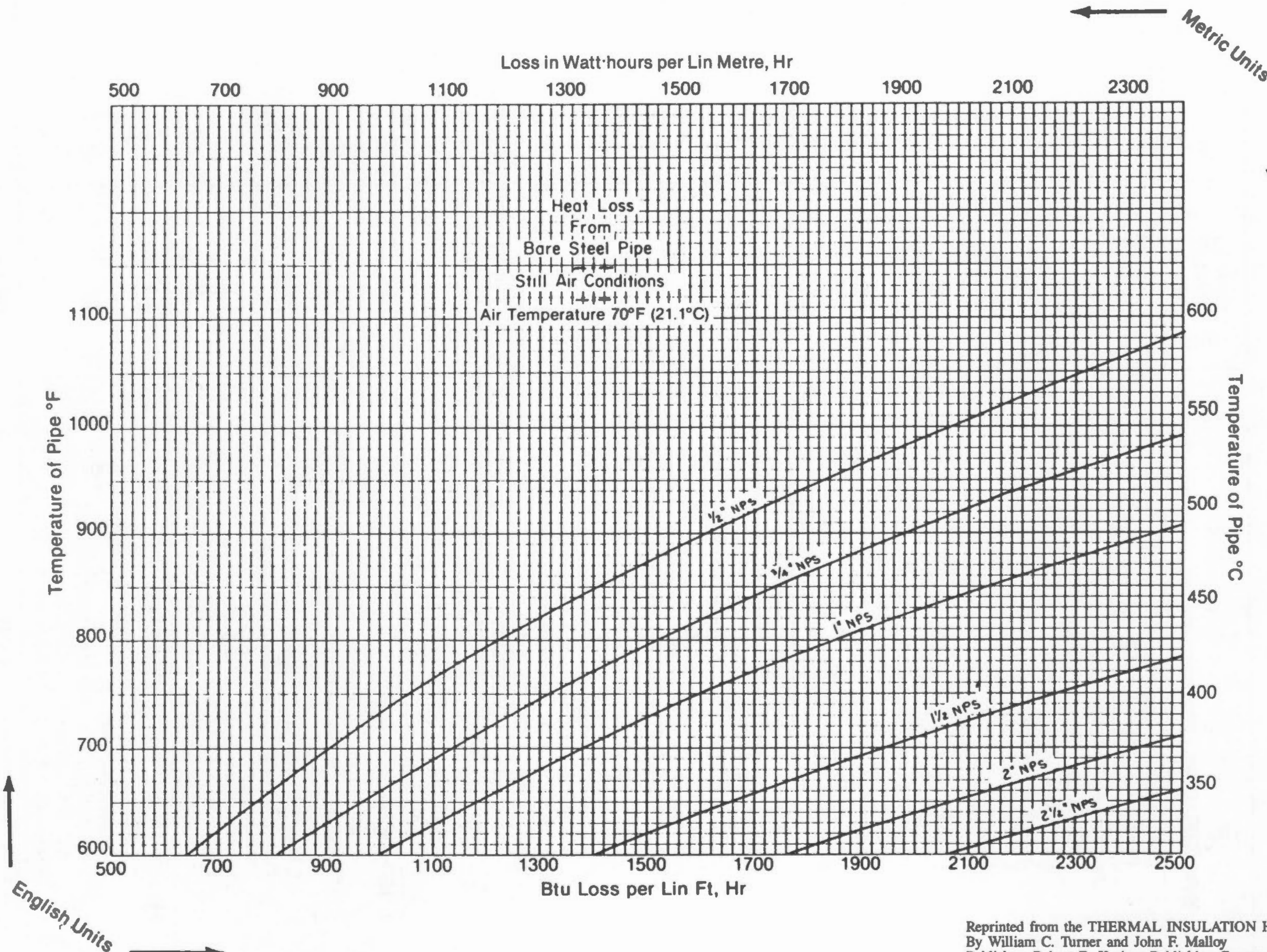

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TYPICAL STEAM CONSUMPTION RATES

TABLE 7

	Operating pressure PSIG	Lbs per hr	
		In use	Maximum
BAKERIES			
Dough room trough, 8 ft long	10	4	
Proof boxes, 500 cu ft capacity		7	
Ovens: Peel Or Dutch Type	10		
White bread, 120 sq ft surface		29	
Rye bread, 10 sq ft surface		58	
Master Baker Ovens		29	
Century Reel, w/pb per 100 lb bread		29	
Rotary ovens, per deck		29	
Bennett 400, single deck		44	
Hubbard (any size)		58	
Middleby-Marshall, w/pb		58	
Baker-Perkins travel ovens, long tray (per 100 lbs)		13	
Baker-Perkins travel ovens, short tray (per 100 lbs)		29	
General Electric		20	
Fish Duothermic Rotary, per deck		58	
Revolving ovens: 8-10 bun pan		29	
12-18 bun pan		58	
18-28 bun pan		87	
BOTTLE WASHING	5		
Soft drinks, beer, etc.: per 100 bottles/min		310	
Milk quarts, per 100 cases per hr		58	
CANDY and CHOCOLATE	70		
Candy cooking, 30-gal cooker, 1 hour,		46	
Chocolate melting, jacketed, 24″ dia		29	
Chocolate dip kettles, per 10 sq ft tank surface		29	
Chocolate tempering, tops mixing, each 20 sq ft active surface		29	
Candy kettle per sq ft of jacket	30		60
Candy kettle per sq ft of jacket	75		100
CREAMERIES and DAIRIES	15-75		
Creamery cans 3 per min			310
Pasteurizer, per 100 gal heated 20 min			232
DISH WASHERS	10-30		
2-Compartment tub type			58
Large conveyor or roller type			58
Autosan, colt, depending on size		29	117
Champion, depending on size		58	310
Hobart Crescent, depending on size		29	186
Fan Spray, depending on size		58	248
Crescent manual steam control	30		
Hobart model AM-5	10		
Dishwashing machine	15-20	60-70	
HOSPITAL EQUIPMENT	40-50		
Stills, per 100 gal distilled water		102	
Sterilizers, bed pan		3	
Sterilizers, dressing, per 10″ length, approx.		7	
Sterilizers, instrument, per 100 cu in approx.		3	
Sterilizers, water, per 10 gal, approx.		6	
Disinfecting Ovens, Double Door:	40-50		
Up to 50 cu ft, per 10 cu ft approx.		29	
50 to 100 cu ft, per 10 cu ft approx.		21	
100 and up, per 10 cu ft, approx.		16	

TYPICAL STEAM CONSUMPTION RATES

TABLE 7

HOSPITAL EQUIPMENT (Continued)	Operating pressure PSIG	Lbs per hr	
		In use	Maximum
Sterilizers, Non-Pressure Type			
For bottles or pasteurization	40		
Start with water at 70 F, maintained for 20 minutes at boiling at a depth of 3″		51	69
Instruments and Utensils:	40		
Start with water at 70F, boil vigorously for 20 min:			
Depth 3½″: Size 8 × 9 × 18″		27	27
Depth 3½″: Size 9 × 20 × 10″		30	30
Depth 4″: Size 10 × 12 × 22″		39	39
Depth 4″: Size 12 × 16 × 24″		60	60
Depth 4″: Size 10 × 12 × 36″		66	66
Depth 10″: Size 16 × 15 × 20″		92	92
Depth 10″: Size 20 × 20 × 24″		144	144
LAUNDRY EQUIPMENT	100		
Vacuum stills, per 10 gal		16	
Spotting board, trouser stretcher		29	
Dress finisher, overcoat shaper, each		58	
Jacket finisher, Susie Q, each		44	
Air vacuum finishing board, 18″ Mushroom Topper, ea.		20	
Steam irons, each		4	
Flat Iron Workers:	100		
48″ × 120″, 1 cylinder		248	
48″ × 120″, 2 cylinder		310	
4-Roll, 100 to 120″		217	
6-Roll, 100 to 120″		341	
8-Roll, 100 to 120″		465	
Shirt Equipment	100		
Single cuff, neckband, yoke No. 3, each		7	
Double sleeve		13	
Body		29	
Bosom		44	
Dry Rooms	100		
Blanket		20	
Conveyor, per loop, approx.		7	
Truck, per door, approx.		58	
Curtain, 50 × 114		29	
Curtain, 64 × 130		58	
Starch cooker, per 10 gal cap		7	
Starcher, per 10-in. length, approx.		5	
Laundry presses, per 10-in. length, approx.		7	
Handy irons, per 10-in. length, approx.		5	
Collar equipment: Collar and Cuff Ironer		21	
Deodorizer		87	
Wind Whip, Single		58	
Wind Whip, Double		87	
Tumblers, General Usage Other Source	100		
36″, per 10″ length, approx.		29	
40″, per 10″ length, approx.		38	
42″, per 10″ length, approx.		52	
Vorcone, 46″ × 120″		310	
Presses, central vacuum, 42″		20	
Presses, steam, 42″		29	

TYPICAL STEAM CONSUMPTION RATES

TABLE 7

	Operating pressure PSIG	Lbs per hr	
		In use	Maximum
PLASTIC MOLDING			
Each 12 to 15 sq ft platen surface	125	29	
PAPER MANUFACTURE			
Corrugators per 1,000 sq ft	175	29	
Wood pulp paper, per 100 lb paper	50	372	
RESTAURANT EQUIPMENT	5-20		
Standard steam tables, per ft length		36	
Standard steam tables, per 20 sq ft tank		29	
Bain Marie, per ft length, 30″ wide		13	
Bain Marie, per 10 sq ft tank		29	
Coffee urns, per 10 gal, cold make-up		13	
3-compartment egg boiler		13	
Oyster steamers		13	
Clam or lobster steamer		29	
Steam Jacketed Kettles	5-20		
10 gal capacity		13	
25 gal stock kettle		29	
40 gal stock kettle		44	
60 gal stock kettle		58	
Plate And Dish Warmers	5-20		
Per 100 sq ft shelf		58	
Per 20 cu ft shelf		29	
Warming ovens, per 20 cu ft		29	
Direct vegetable steamer, per compartment		29	
Potato steamer		29	
Morandi Proctor, 30 comp., no return		87	
Pot sink, steam jets, average use		29	
Silver burnishers, Tahara		58	
SILVER MIRRORING			
Average steam tables	5	102	
TIRE SHOPS	100		
Truck molds, large		87	
Truck molds, medium		58	
Passenger molds		29	
Sections, per section		7	
Puff Irons, each		7	

COMMON CONVERSIONS

1 barrel (35 Imp gal) (42 US gal)	= 159.1 litres	1 kilowatt	= 3600 kilojoules
1 gallon (Imp)	= 1.20094 gallon (US)	1 Newton	= 1 kg-m/s^2
1 horsepower (boiler)	= 9809.6 watts	1 therm	= 10^5 Btu
1 horsepower	= 2545 Btu/hour	1 ton (refrigerant)	= 12002.84 Btu/hour
1 horsepower	= 0.746 kilowatts	1 ton (refrigerant)	= 3516.8 watts
1 joule	= 1 N-m	1 watt	= 1 joule/second
Kelvin	= (°C + 273.15)	Rankine	= (°F + 459.67)

Cubes

1 yd^3	= 27 ft^3
1 ft^3	= 1728 in^3
1 cm^3	= 1000 mm^3
1 m^3	= 10^6 cm^3
1 m^3	= 1000 L

Squares

1 yd^2	= 9 ft^2
1 ft^2	= 144 in^2
1 cm^2	= 100 mm^2
1 m^2	= 10000 cm^2

SI PREFIXES

Prefix	Symbol	Magnitude	Factor
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^9
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deca	da	10	10^1
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pica	p	0.000 000 000 001	10^{-12}

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
amperes/square centimetre	A/cm^2	amperes/square inch	A/in^2	6.452
Celsius	°C	Fahrenheit	°F	(°C × 9/5) + 32
centimetres	cm	inches	in	0.3937
cubic centimetres	cm^3	cubic inches	in^3	0.06102
cubic metres	m^3	cubic foot	ft^3	35.314
grams	g	ounces	oz	0.03527
grams	g	pounds	lb	0.0022
grams/litre	g/L	pounds/cubic foot	lb/ft^3	0.06243
joules	J	Btu	Btu	9.480×10^{-4}
joules	J	foot-pounds	ft-lb	0.7376
joules	J	horsepower-hours	hp-h	3.73×10^{-7}
joules/metre, (Newtons)	J/m, N	pounds	lb	0.2248
kilograms	kg	pounds	lb	2.205
kilograms	kg	tons (long)	ton	9.842×10^{-4}
kilograms	kg	tons (short)	tn	1.102×10^{-3}
kilometres	km	miles (statute)	mi	0.6214
kilopascals	kPa	atmospheres	atm	9.87×10^{-3}
kilopascals	kPa	inches of mercury (@ 32°F)	in Hg	0.2953
kilopascals	kPa	inches of water (@ 4°C)	in H_2O	4.0147
kilopascals	kPa	pounds/square inch	psi	0.1450
kilowatts	kW	foot-pounds/second	ft-lb/s	737.6
kilowatts	kW	horsepower	hp	1.341
kilowatt-hours	kWh	Btu	Btu	3413
litres	L	cubic foot	ft^3	0.03531
litres	L	gallons (Imp)	gal (Imp)	0.21998
litres	L	gallons (US)	gal (US)	0.2642
litres/second	L/s	cubic foot/minute	cfm	2.1186
lumen/square metre	lm/m^2	lumen/square foot	lm/ft^2	0.09290
lux, lumen/square metre	lx, lm/m^2	footcandles	fc	0.09290
metres	m	foot	ft	3.281
metres	m	yard	yd	1.09361
parts per million	ppm	grains/gallon (Imp)	gr/gal (Imp)	0.07
parts per million	ppm	grains/gallon (US)	gr/gal (US)	0.05842
permeance (metric)	PERM	permeance (Imp)	perm	0.01748
square centimetres	cm^2	square inches	in^2	0.1550
square metres	m^2	square foot	ft^2	10.764
square metres	m^2	square yards	yd^2	1.196
tonne (metric)	t	pounds	lb	2204.6
watt	W	Btu/hour	Btu/h	3.413
watt	W	lumen	lm	668.45

4138T/T33(-4)

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in^2	A/in^2	ampere/cm^2	A/cm^2	0.1550
atmospheres	atm	kilopascals	kPa	101.325
British Thermal Unit	Btu	joules	J	1054.8
Btu	Btu	kilogram-metre	kg-m	107.56
Btu	Btu	kilowatt-hour	kWh	2.928×10^{-4}
Btu/hour	Btu/h	watt	W	0.2931
calorie, gram	cal or g-cal	joules	J	4.186
chain	chain	metre	m	20.11684
cubic foot	ft^3	cubic metre	m^3	0.02832
cubic foot	ft^3	litre	L	28.32
cubic foot/minute	cfm	litre/second	L/s	0.47195
cycle/second	c/s	Hertz	Hz	1.00
Fahrenheit	°F	Celsius	°C	(°F-32)/1.8
foot	ft	metre	m	0.3048
footcandle	fc	lux, lumen/ square metre	lx, lm/m^2	10.764
footlambert	fL	candela/square metre	cd/m^2	3.42626
foot-pounds	ft-lb	joule	J	1.356
foot-pounds	ft-lb	kilogram-metres	kg-m	0.1383
foot-pounds/second	ft-lb/s	kilowatt	kW	1.356×10^{-3}
gallons (Imp)	gal (Imp)	litres	L	4.546
gallons (US)	gal (US)	litres	L	3.785
grains/gallon (Imp)	gr/gal (Imp)	parts per million	ppm	14.286
grains/gallon (US)	gr/gal (US)	parts per million	ppm	17.118
horsepower	hp	watts	W	745.7
horsepower-hours	hp-h	joules	J	2.684×10^6
inches	in	centimetres	cm	2.540
inches of Mercury (@ 32°F)	in Hg	kilopascals	kPa	3.386
inches of water (@ 4°C)	in H_2O	kilopascals	kPa	0.2491

UNIT CONVERSION TABLES
IMPERIAL TO METRIC (cont'd)

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
lamberts	* L	candela/square metre	cd/m^2	3.183
lumen/square foot	lm/ft^2	lumen/square metre	lm/m^2	10.76
lumen	lm	watt	W	0.001496
miles (statute)	mi	kilometres	km	1.6093
ounces	oz	grams	g	28.35
perm (at 0°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.721×10^{-11}
perm (at 23°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.745×10^{-11}
perm-inch (at 0°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4532×10^{-12}
perm-inch (at 23°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4593×10^{-12}
pint (Imp)	pt	litre	L	0.56826
pounds	lb	grams	g	453.5924
pounds	lb	joules/metre, (Newtons)	J/m, N	4.448
pounds	lb	kilograms	kg	0.4536
pounds	lb	tonne (metric)	t	4.536×10^{-4}
pounds/cubic foot	lb/ft^3	grams/litre	g/L	16.02
pounds/square inch	psi	kilopascals	kPa	6.89476
quarts	qt	litres	L	1.1365
slug	slug	kilograms	kg	14.5939
square foot	ft^2	square metre	m^2	0.09290
square inches	in^2	square centimetres	cm^2	6.452
square yards	yd^2	square metres	m^2	0.83613
tons (long)	ton	kilograms	kg	1016
tons (short)	tn	kilograms	kg	907.185
yards	yd	metres	m	0.9144

* "L" as used in Lighting

4138T/T33(-2)

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

Consistent factors must be used when calculating Base Year and Current Year energy usage.

ENERGY TYPE	METRIC	IMPERIAL
COAL		
— metallurgical	29,000 megajoules/tonne	25.0 × 10^6 Btu/ton
— anthracite	30,000 megajoules/tonne	25.8 × 10^6 Btu/ton
— bituminous	32,100 megajoules/tonne	27.6 × 10^6 Btu/ton
— sub-bituminous	22,100 megajoules/tonne	19.0 × 10^6 Btu/ton
— lignite	16,700 megajoules/tonne	14.4 × 10^6 Btu/ton
COKE		
— metallurgical	30,200 megajoules/tonne	26.0 × 10^6 Btu/ton
— petroleum		
— raw	23,300 megajoules/tonne	20.0 × 10^6 Btu/ton
— calcined	32,600 megajoules/tonne	28.0 × 10^6 Btu/ton
PITCH	37,200 megajoules/tonne	32.0 × 10^6 Btu/ton
CRUDE OIL	38,5 megajoules/litre	5.8 × 10^6 Btu/bbl
No. 2 OIL	38.68 megajoules/litre	5.88 × 10^6 Btu/bbl .168 × 10^6 Btu/IG
No. 4 OIL	40.1 megajoules/litre	6.04 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
No. 6 OIL (RESID. BUNKER C)		
@ 2.5% sulphur	42.3 megajoules/litre	6.38 × 10^6 Btu/bbl .182 × 10^6 Btu/IG
@ 1.0% sulphur	40.5 megajoules/litre	6.11 × 10^6 Btu/bbl .174 × 10^6 Btu/IG
@ .5% sulphur	40.2 megajoules/litre	6.05 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
KEROSENE	37.68 megajoules/litre	.167 × 10^6 Btu/IG
DIESEL FUEL	38.68 megajoules/litre	.172 × 10^6 Btu/IG
GASOLINE	36.2 megajoules/litre	.156 × 10^6 Btu/IG
NATURAL GAS	37.2 megajoules/m^3	1.00 × 10^6 Btu/MCF
PROPANE	50.3 megajoules/kg 26.6 megajoules/litre	.02165 × 10^6 Btu/lb .1145 × 10^6 Btu/IG
ELECTRICITY	3.6 megajoules/kWh	.003413 × 10^6 Btu/kWh

Steam Velocity Calculation

Worksheet 9-1

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Steam pipe internal diameter ______________________ m

Steam flow (w) ______________________ kg/h

Specific volume of steam (v_g) ______________________ m^3/kg

Cross sectional area of pipe (A) $= \frac{3.142 \times (\text{internal dia})^2}{4}$

$= \frac{3.142 \times (\qquad\qquad)^2}{4}$

$=$ ______________________ m^2

Velocity (V) $= \frac{w \times v_g}{A \times 3600}$

$= \frac{\qquad \times \qquad}{\qquad \times 3600}$

$=$ ______________________ m/s

For steam mains, velocity should fall between 40 m/s and 60 m/s. If velocity exceeds 75 m/s flow should be reduced or pipe should be increased in size.

Steam Loss To Atmosphere

Worksheet 9-2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Equipment ______________________________

Estimated leak diameter ______________________ mm

Steam pressure ______________________ kPa(gauge)

Steam loss ______________________ kg/h (Table 3)

Operation: Hours per day ______________

Days per week ______________

Weeks per year ______________

Steam cost: $________/1000 kg (obtain from steam generator operator)

Steam lost = ________kg/h x ________h/day x ________day/week x ________week/yr

= __________kg/yr

Potential dollar savings

= ______________________kg/yr x $______________________/1000 kg

= $______________________ per year

Calculation Of LMTD

Worksheet 9-3

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

<u>Heating Application</u>

Original temperature of liquid (T_2) ____________________ °C

Final temperature of liquid (T_3) ____________________ °C

Steam temperature (T_1) ____________________ °C

Greater temperature difference (DT_1) $= T_1 - T_2$

= ________ – ________

= ____________________ °C (DT_1)

Lesser temperature difference (DT_2) $= T_1 - T_3$

= ________ – ________

= ____________________ °C (DT_2)

LMTD $= \dfrac{DT_1 - DT_2}{\ln\left(\dfrac{DT_1}{DT_2}\right)}$

$= \dfrac{\rule{5cm}{0.4pt}}{\ln \rule{1cm}{0.4pt}}$

$= \dfrac{\rule{5cm}{0.4pt}}{2.306 \log \rule{1cm}{0.4pt}}$

= ____________________

= ____________________ °C

Heat Loss From Piping

Worksheet 9-4

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

Pipe diameter (NPS) ____________________ Pipe length ____________________ m

Pipe temperature ____________________ °C Operating hours per year ____________________ h

Proposed insulation type ____________________ Proposed insulation thickness ____________________ mm

	Uninsulated	Insulated
Heater loss per metre	____________ Wh/(m·h)(Table 6)	____________ Wh/(m·h)(Module 1)
Total heat loss/h =	Heat loss/metre x length	Heat loss/metre x length
	____________ x ________	____________ x ________
	____________________ Wh/h	____________________ Wh/h
Annual heat loss =	Heat loss/h x h/yr	Heat loss/h x h/yr
	____________ x ________	____________ x ________
	____________________ Wh/yr (1)	____________________ Wh/yr (2)

Reduction in heat loss due to addition of insulation

= (1) – (2)

= ____________ – ________

= ____________________ Wh/yr

or ____________ Wh/yr x 3.6 kJ/Wh

= ____________________ kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Heat Loss From Equipment

Worksheet 9-5

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Equipment ______________________ Operating hours per year __________ h

Surface area __________________ m^2 Proposed insulation type __________

Product temperature ______________ °C Proposed insulation thickness ______ mm

Uninsulated	Insulated
Heat loss = __________ Wh/(m^2h)(Table 5)	__________ Wh/(m^2h)(Module 1)
Total heat loss/h = Surface area x Heat loss	Surface area x Heat loss
__________ x __________	__________ x __________
____________________ Wh/h	____________________ Wh/h
Annual heat loss = Heat loss/h x h/yr	Heat loss/h x h/yr
__________ x __________	__________ x __________
____________________ Wh/yr (1)	____________________ Wh/yr (2)

Reduction in heat loss due to addition of insulation

= (1) − (2)

= __________ − __________

= ____________________ Wh/yr

or ______________ Wh/yr x 3.6 kJ/Wh

= ____________________ kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

Heat Energy Available From Water Stream

(Approximate Method)
Worksheet 9-6

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Water stream ______________________________

Water flow (f_W) ______________________________ L/s

Water entering temperature T_1 ______________________ °C

Water leaving temperature T_2 ______________________ °C

Total heat transmitted Q (MJ/h)

$$Q = f_W \times (T_1 - T_2) \times 15$$

= ____ x (____ – ____) x 15

= __________ MJ/h

Heat Energy Available From Waste Water Stream To preheat A Water Stream

(Approximate Method)
Worksheet 9-7
Page 1 of 2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Waste Water Stream ____

- Water flow (f_W) ____________ L/s
- Present water temperature (T_1) ____________ °C
- Proposed water leaving temperature (T_2) (Discussions must be held with heat exchanger manufacturer to establish this figure) ____________ °C
- Heat available Q (MJ/h)

$$Q = f_W \times (T_1 - T_2) \times 15$$

= ____ x (____ – ____) x 15

= ____________ MJ/h

or $\dfrac{\rule{2cm}{0.4pt}}{3600}$

= ____________ MJ/s

Proposed heat exchanger efficiency (from heat exchanger manufacturer) ____________ %

Heat available = ________ MJ/s x ____________ %

= ________ MJ/s (1)

Heat Energy Available From Waste Water Stream To Preheat A Water Stream

(Approximate Method)
Worksheet 9-7
Page 2 of 2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Process Stream

Water flow (f_W) ______________ L/s

Entering water temperature (T_1) ______________ °C

Required water temperature (T_2) ______________ °C

Heat required Q (MJ/h)

$$Q = f_W \times (T_1 - T_2) \times 15$$

= ____ x (____ – ____) x 15

= –________ MJ/h

or $\frac{\_\_\_\_\_\_\_\_}{3600}$ (drop negative sign)

= ________ MJ/s (2)

Reduction of heat energy required for final heating of process water stream

= (2) – (1)

= _____ – _____

= _____ MJ/s (3)

Steam Requirements To Heat Water In Steam To Water Heat Exchanger

(Approximate Method)
Worksheet 9-8
Page 1 of 2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Steam

Pressure	______________	kPa(gauge)	
Temperature	______________	°C	
Enthalpy	______________	kJ/kg	(1)

Condensate

Pressure	______________	kPa(gauge)	
Temperature	______________	°C	
Enthalpy	______________	kJ/kg	(2)

Heat available from Steam = (1) − (2)

= __________ − __________

= ______________ kJ/kg (3)

Heat exchanger efficiency (obtain from heat exchanger manufacturer) __________ % (4)

Heat available to process water = (3) x (4)

= __________ x __________

= ______________ kJ/kg

or $\frac{\text{\_\_\_\_\_\_\_\_\_\_ kJ/kg}}{1000 \text{ kJ/MJ}}$

= ______________ MJ/kg (5)

Steam required by process steam (no heat recovery) = $\frac{\text{worksheet 9-7 (2)}}{\text{worksheet 9-8 (5)}}$

= $\frac{\text{\_\_\_\_\_\_\_\_\_\_ MJ/s}}{\text{MJ/kg}}$

= ______________ kg/s (6)

Steam Requirements To Heat Water in Steam To Water Heat Exchanger

(Approximate Method)
Worksheet 9-8
Page 2 of 2

Company ________________ Date: ________________

Location: ________________ By: ________________

Steam required by process stream (with heat recovery)	=	worksheet 9-7 (3) / worksheet 9-8 (5)		
	=	________________	MJ/s / MJ/kg	
		________________	kg/s	(7)
Steam savings due to waste heat recovery	=	(6) − (7)		
	=	________ − ________		
	=	________________	kg/s	(8)
Hours of operation per year	=	________________	h	(9)
Annual steam savings due to heat recovery	=	(8) x (9) x 3600		
	=	________________		
	=	________________	kg/yr	(10)
Steam cost	=	$________________/1000 kg		(11)
Annual dollar savings	=	(10) x (11)		
	=	________ x ________		
	=	$________________ per year		(12)
Installed cost of heat recovery equipment	=	$________________		(13)
Simple payback	=	(13) / (12)		
	=	________________		
	=	________________	years	