ENERGY
MANAGEMENT
SERIES

8

FOR INDUSTRY
COMMERCE
AND INSTITUTIONS

Steam and Condensate Systems

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 on how to save energy.

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

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INTRODUCTION

Prior to the invention of the steam engine, water and wind were the major sources of power. With the technology advances of the Industrial Revolution, steam engines began to replace water and wind powered equipment. The development of pressure vessels and improved piping materials allowed the generation and use of higher steam pressures and temperatures. These improvements also allowed steam to be transported over progressively greater distances.

With the availability of low cost, widely distributed electrical energy and low cost fossil fuels, greater versatility became possible for the design of steam and condensate systems. Higher pressure systems allowed the use of smaller pipes and heating devices, and permitted the use of more sophisticated control devices. However, the lack of proper maintenance on these systems created the potential for greater energy losses.

The dramatic increase of recent years in the cost of all energy sources provides renewed incentive to examine the efficiency of existing steam and condensate systems, to seek opportunities to minimize the required energy, and save money.

Purpose

The following summarizes the purpose of this module.

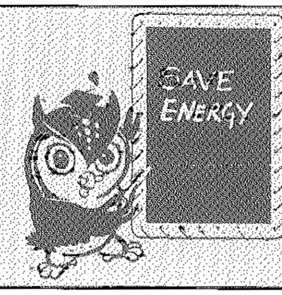
- Introduce the subject of steam and condensate distribution systems as used in the Industrial, Commercial and Institutional sectors.
- Provide an awareness of energy and cost savings available through implementation of Energy Management Opportunities.
- Provide, with the aid of worked examples, methods of determining energy and cost saving opportunities.
- Provide a set of worksheets to establish a standard method of calculating energy and cost savings for the noted Energy Management Opportunities.

Contents

The module is subdivided into the following sections.

- *Fundamentals* describes the basic theory and uses of steam and condensate systems. Basic energy calculations are presented and further explained with worked examples.
- *Equipment/Systems* describes the basic equipment used in steam and condensate distribution systems.
- A series of *Energy Management Opportunities* supported by estimated energy and cost savings where applicable.
- *Appendices*, including a glossary of terms, tables, common conversions and worksheets.

FUNDAMENTALS



Steam is probably one of the most commonly used sources of heat or thermal energy found in Industrial, Commercial and Institutional establishments. This module focuses on the distribution of steam energy and the return of condensate. It represents the link between Module 6, Boiler Plant Systems, and Module 9, Heating and Cooling Equipment, (Steam and Water).

Safety Considerations

The generation, distribution and utilization of steam and condensate fall under regulations issued by the various provincial governments. Prior to making any changes to a system, it is the responsibility of the owner to ensure that all codes and standards have been met.

Steam and Condensate Systems Terminology

Certain steam and condensate terms and concepts are required to understand how the transfer of heat energy is performed within the system, and where improvements can be made.

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 heat energy an object will possess. 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.

Change of State

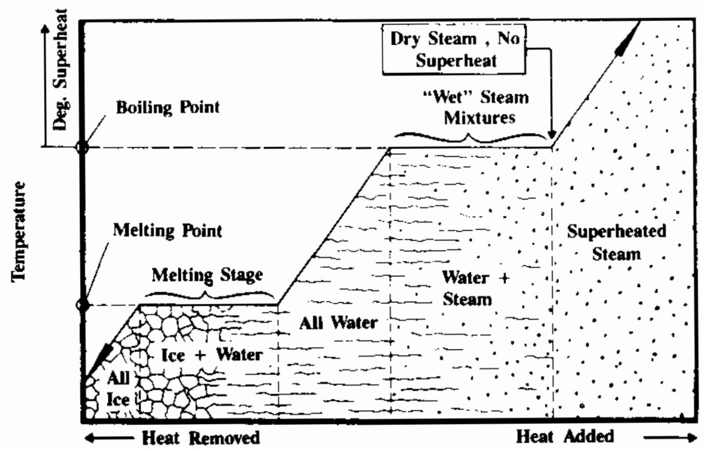
Temperature is a measure of the heat energy stored in an object. As heat energy is added, the temperature will increase until a *change of state* takes place. Typical examples are ice melting, or water boiling. Figure 1 illustrates the change of state process.

Most pure substances have a specific melting and freezing 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.

Evaporation is a 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.

Steam Forms

As heat is added to water, the temperature of the water increases until its boiling point is reached (Figure 1). This heat, which increases the water temperature, is called *sensible heat.* Once the boiling point is reached, any further addition of heat causes some of the water to change to steam, but the mixture of steam and water remains at the boiling temperature. The heat which converts the water to steam at the constant boiling temperature is called *latent heat.* When the water has been fully vaporized at the boiling temperature it is called *dry saturated steam.* This means that there are no droplets of moisture within the steam.



Example Of Change Of State
Figure 1

If water is heated at a pressure above atmospheric, its boiling point will be higher than 100°C and the sensible heat required will be greater. Thus, 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.

Water can also be evaporated or boiled 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 flavor of the concentrate.

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 metho of desuperheating is by spraying water into the steam.

Quality of Steam

As stated, when steam leaves the surface of boiling water, it is called saturated steam. Removal of heat from this steam will cause it to condense into water and appear in the form of droplets over the water surface. The ratio of the mass of pure vapor to the total mass of vapor and water droplets is called the *quality of steam* or *dryness fraction*.

Quality of steam can be expressed by the following equation.

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

If the quality of steam is 1.0, then there is no free moisture in the steam. This is referred to as dry 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,

$$\text{Per cent water} = 100 - (0.98 \times 100)$$

$$= 100 - 98$$

$$= 2\%$$

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

Steam Tables

Steam tables for saturated steam (Table 1) and superheated steam (Table 2) are used to express the quantity of energy available in water or steam. 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.

- The *pressure* used in steam tables is the saturation pressure expressed as kPa (absolute) and is equal to gauge pressure plus standard atmospheric pressure (101.325 kPa).
- *Saturation temperature*, expressed in °C, 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) [476 kPa (absolute)] it will operate at a temperature of 150°C.
- *Specific volume of saturated liquid*, v_f, is expressed in units of m^3/kg. This value does not change significantly over a wide range of temperatures. The specific volume of a liquid is the reciprocal of its density at any given temperature. The density of water is 1000 kg/m^3 at room temperature.
- The *specific volume of saturated steam*, v_g, expressed in units of m^3/kg, is the volume (m^3) occupied by one kilogram of dry saturated steam at a given pressure.

When steam tables were formulated, water at 0°C was selected as the condition representing zero 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 (kJ/kg). Under the enthalpy heading in Table 1, there are three columns that identify the enthalpy of the liquid (h_f), the enthalpy of evaporation (h_{fg}), and the enthalphy of steam (h_g).

1. The *enthalpy of liquid* (h_f) is a measure of the amount of heat energy contained in the water (sensible heat) at a specific temperature.
2. 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.
3. The *enthalpy of steam* (h_g) is the total heat energy (latent heat) 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 for a specific temperature (h_{fg}) and can be expressed in the following equation.

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

Steam Conditioning

Although the chemical treatment of water is usually performed within the boiler plant, it is important to know the effects of improper treatment of water and steam within a steam and condensate distribution system.

The rate of heat transfer from a steam distribution system is directly affected by the steam temperature and by the presence of air and carbon dioxide (CO_2) within the system.

Air, with its excellent insulation property, is undesirable in the steam supply because of the effect on the rate of heat transfer from the steam to the steam heated equipment. Under certain conditions, as little as one per cent by volume of air in steam can reduce the heat transfer efficiency by up to 50 per cent. When air is present in a steam space the steam cannot be maintained at saturation temperature. The following 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

Air and CO_2 are both contributors of excessive corrosion which can occur in the steam and condensate piping, on heat transfer surfaces and other system components. Corrosion can occur in the form of *grooving* where the metal is dissolved away or by *pitting* which occurs where dissimilar metals are in contact or at points where stresses occur in the piping system.

Dealkalizers and deaerators are used to remove O_2 and CO_2 from boiler water. In addition, there are chemicals such as amines and oxygen scavenging agents, which can be added to the boiler feed water to improve the steam purity.

Condensate

The steam, leaving the surface of boiling water is at saturation conditions and contains no free water. Removal of heat from this steam will cause it to condense into water and appear in the form of droplets over the water surface. Some of these droplets escape with the steam into the steam distribution piping, where, with the further loss of heat they form into larger drops which eventually fall to the bottom of the pipe to form condensate. To ensure satisfactory operation of the steam distribution system this condensate must be removed.

This same phenomenon occurs in steam using equipment. As heat is given up by the steam, condensate forms, and again for proper operation of the equipment must be removed.

The condensate contains usable heat energy in the form of sensible heat and every effort possible should be made to recapture this heat energy. This may consist of items of the following type.

- Return the condensate to the boiler plant where it is reused as boiler feed water. As well as saving energy this has the added advantage of reducing boiler make-up water treatment costs.
- If the condensate is to be discharged as a waste product because of possible contamination, its heat content can be transferred to other process streams prior to disposal.
- Use *flash steam* as a heat source in low pressure steam systems.

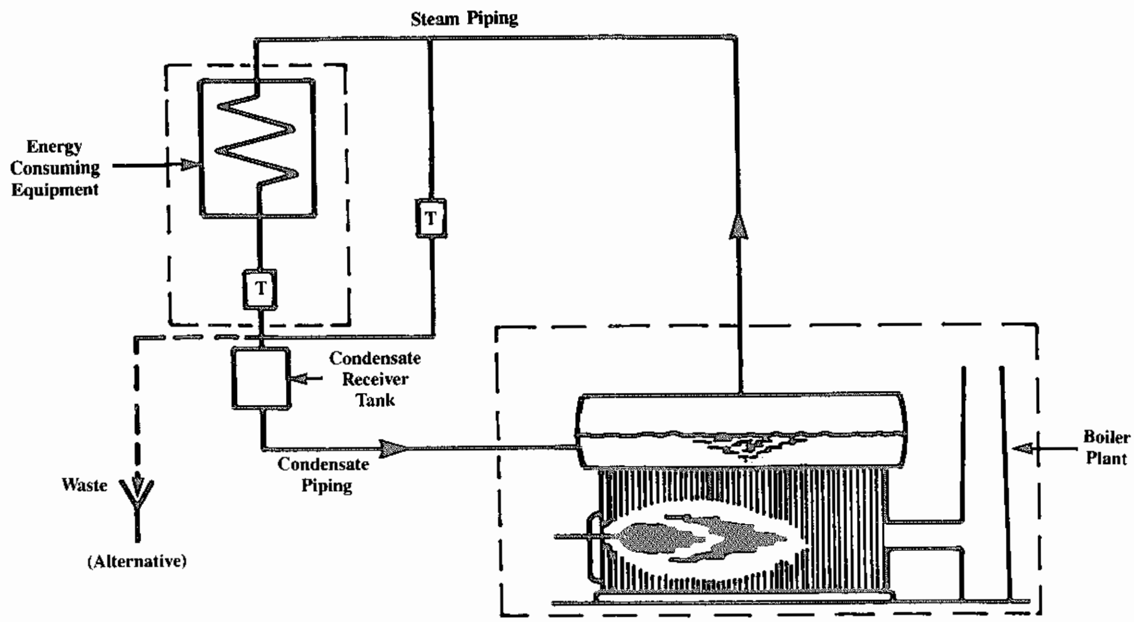
Piping Systems

In any steam system, steam is generated in a boiler, distributed to the energy consuming equipment, and the unused portion (condensate) is returned to the boiler or discharged as waste (Figure 2). In normal terminology the piping carrying the steam from the boiler to the energy consuming equipment is called the *Steam Distribution System* and the piping returning the condensate is called the *Condensate Return System*.

Piping systems vary in size, but the basic concepts are the same. Steam can be used for space heating, or as a heat source for process equipment, where it is put to use through heat exchangers, steam coils, jacketed vessels, and laundry and kitchen equipment. Steam can also be used as an energy source in certain cooling systems.

Steam and condensate piping systems are classified under three separate categories.

- Piping arrangement.
- Pressure ranges.
- Method of condensate return.



Steam And Condensate Cycle
Figure 2

Piping Arrangement

Under this classification, the systems are further subdivided as follows.

- *One-pipe systems* in which a single main is used to deliver the steam to, and return the condensate from, the terminal unit.
- *Two-pipe systems* in which the steam and condensate flow in separate pipes.

Piping arrangements can be further classified as dry or wet return and up or down feed. In a dry return system the condensate enters the boiler above the boiler water line. Condensate enters below the boiler water line in a wet return system. Up or down feed depends on the direction steam flows in the riser.

Pressure Ranges

Under this classification, the systems are further subdivided as follows.

- *High pressure system* with operating pressures of 690 to 2400 kPa(gauge).
- *Medium pressure system* with operating pressures of 103 to 690 kPa(gauge).
- *Low pressure systems* with operating pressures of 0 to 103 kPa(gauge).
- A *vacuum system* operates under a vacuum below 0 kPa(gauge).
- A *vapor system* operates under the same conditions as a vacuum system but without the use of a vacuum pump.

Method of Condensate Return

Under this classification, the systems are further subdivided as follows.

- *Gravity return systems* where condensate is returned to the boiler or condensate receiver by gravity.
- *Mechanical return systems* where steam traps, condensate pumps or vacuum pumps are used to return condensate.

Pipe

In piping systems, the term schedule is used to assign a number that relates to the pressure and stress capability of the pipe. The heavier the schedule the stronger the pipe. The Nominal Pipe Size (NPS) is designated in inches. Table 3 provides dimensional data for pipe sizes up to NPS 12 for standard schedule 40 and heavier schedule 80 pipe.

Velocity

It is recommended that in sizing steam distribution piping, the velocity of 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 higher pipeline noise caused by velocity, as well as pressure loss and lower capacity. Worksheet 8-1 is provided to allow calculations of steam velocity to be performed and an example of the use of this worksheet follows at the end of this section.

Condensate flow rates should also be kept within practical limits. Good practice suggests that the velocity should be held between 1.5 and 4.0 metres per second. Table 4 is a nomograph which may be used to establish flow rate, velocity, nominal schedule 40 pipe size and pipe internal diameter, as long as two of the items are known.

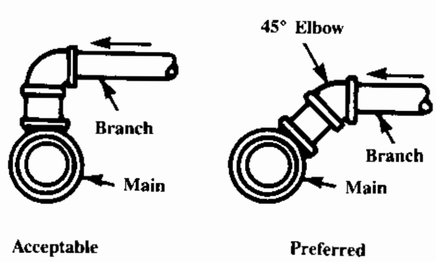
When steam condenses, the quantity of condensate generated in kg/h is equal to the steam flow rate in kg/h. This means that if end use equipment uses steam for indirect heating at the rate of 1000 kg/h, the quantity of condensate produced will also be 1000 kg/h.

Branch Connections

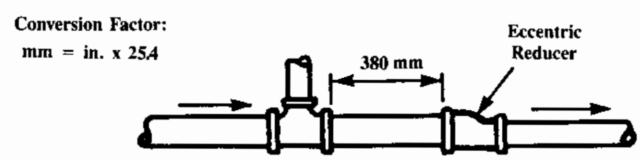
Branch connections to steam mains should preferably be at 45° from the top, but 90° connections are acceptable (Figure 3). This is done to allow condensate to collect in the bottom of the steam main and not flow into the branch main, as well as to minimize the friction losses of the steam flowing through the piping. There is an exception to this rule in a one-pipe gravity system. For a one-pipe gravity system which requires dripping, the connection is made at 45° from the bottom. Steam traps must not be installed in this connection.

Reducers

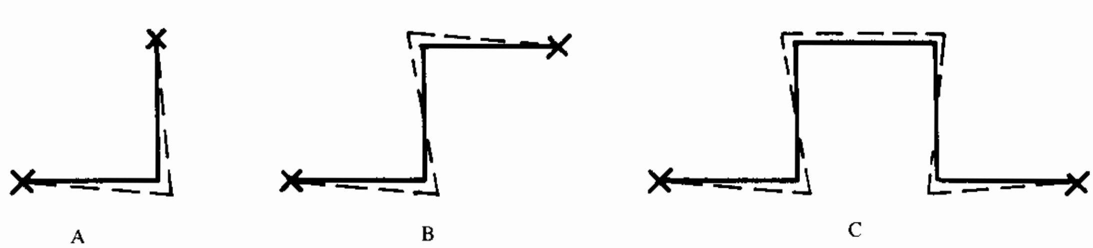
When steam mains are reduced, the connections must always be made to avoid water pockets so that the condensate drains freely. Eccentric reducers (Figure 4) are installed to eliminate water pockets at reduction points in horizontal steam mains. Concentric reducers are normally used for size reduction in vertical steam and condensate mains.



Steam Main Branch Connections
Figure 3



Typical Size Reduction for a Horizontal Line
Figure 4



Expansion Pipe Bends
Figure 5

Thermal Expansion

Thermal expansion and contraction cause piping systems to move. Similar movement can also occur in attached machinery and structures. This movement must be accommodated to prevent damage to structures and system elements. This can be accomplished using the inherent flexibility of the piping system, by designing loops into the system where needed, by expansion joints or by special couplings. The method or devices selected depend on force limitations, available space, installed cost, serviceability, maintenance cost, length of life and the type of system selected. Stresses on the pipe, and available expansion space dictate acceptable design.

In the simplest case, axial movement in each of two pipe segments connected through a 90° elbow is accommodated by bending in each segment (Figure 5A). The addition of pipe segments results in a Z-bend (Figure 5B), or loop (Figure 5C).

Cold springing of the pipe is a technique which is also used to accomodate expansion and contraction. Cold springing of loops and Z-bends is relatively easy in the field, however single elbows are very difficult to cold spring.

Using the inherent flexibility of the piping system is the preferred method of accommodating pipe movement. However, if there is a lack of space for expansion loops or changes of direction, expansion joints can be used. These should be installed where they are accessible for maintenance or replacement. They must be insulated to prevent heat loss.

Accessories

As well as the pipe, certain other items are used to make up the system. Their basic functions will be described in the following text with detailed information being found in the Equipment/Systems section.

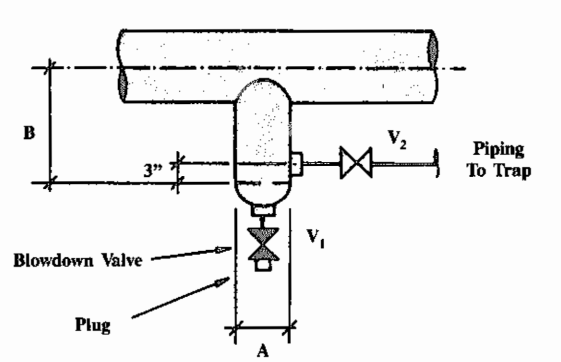
Drip Legs

Condensation occurs as steam flows through a pipe because of heat loss to the surroundings. Unless this condensate is removed it can cause water hammer and degrade steam quality. Drip legs (Figure 6) should be provided at all natural drainage points in the system. Normally, on straight "horizontal" runs, drip legs are provided every 90 m where the pipe is sloped down in the direction of flow. When the pipe is sloped upwards, so that direction of condensate flow is opposite the steam flow, drip legs should be provided every 45 m. Eccentric reducers are used in "horizontal" piping to avoid water pockets.

	Dimensions & Sizes (Nominal) In Inches											
Line Size	*	3	4	6	8	10	12	14	16	18	20	24
Dimension 'A'		3	4	6	6	8	8	10	12	12	12	12
Dimension 'B'		12	12	14	14	16	16	18	20	21	22	24
Size Of V_1		¾	¾	¾	¾	¾	¾	1	1	1	1	1
Size Of V_2		¾	¾	¾	¾	¾	1	1	1	1	1	1

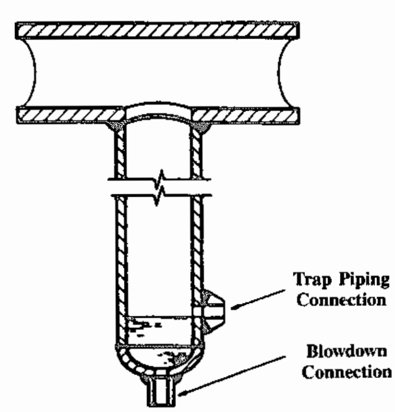
To 2"

*For lines 2-inch and smaller, use 3/4 inch pipe, valves and fittings, reducing line size at the trap as necessary.

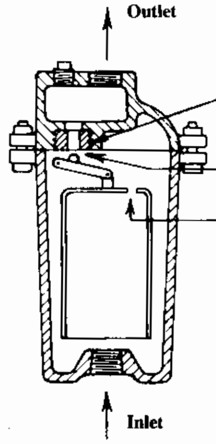


1 inch = 25.4 mm

Dripleg Construction



Drip Legs
Figure 6



Inverted Bucket Trap
Figure 7

Steam Traps

Steam traps are installed to obtain fast heating of product and equipment by keeping the steam lines and equipment free of condensate, air and noncondensible gases. A steam trap (Figure 7) 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.

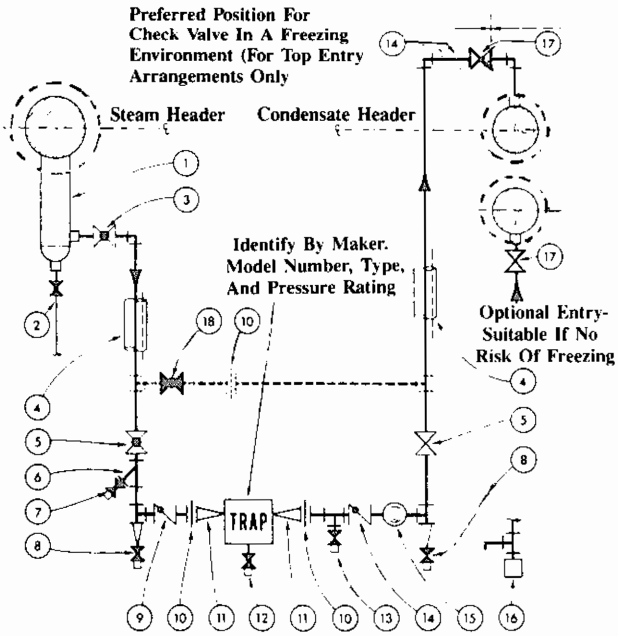
Two methods are used to discharge condensate from steam mains. In systems operating at a steam pressure below 103 kPa(gauge), condensate discharged from steam traps may flow by gravity return to an atmospheric pressure receiver, a flash tank, or to drain. Condensate from the receiver is then pumped to its intended point of use, usually the boiler plant. In systems over 103 kPa(gauge), the pressure in the steam main may be used to force the condensate to an overhead condensate return main.

Figure 8 illustrates recommended steam trap piping arrangements. The following should be considered wherever steam traps are installed.

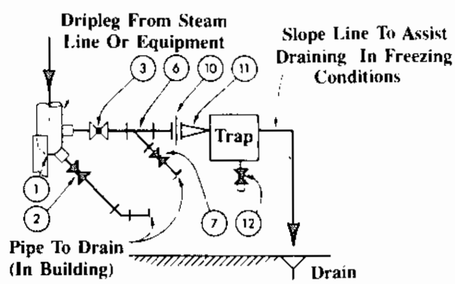
- Traps should be grouped in an orderly arrangement for ease of maintenance and servicing.
- Pipe, valves and fittings used with the steam trap should never be smaller than NPS 3/4.
- Drip legs and traps should be installed below the piping or device.
- Traps should be provided where there are low points in steam mains. Condensate, which collects during start-up can then be discharged from the mains.
- For installations in freezing conditions where condensate is not collected, thermostatic traps should be selected. They should be installed vertically to allow continuous drainage by gravity. Otherwise, a trap that is fitted with an automatic draining device by the manufacturer should be used.
- When freezing conditions exist, long horizontal discharge lines should be avoided since ice can form in the line downstream of the trap. Discharge lines should be kept short, and in the event that the condensate is not collected, they should be sloped downward to allow self drainage. Even if condensate is being collected, condensate lines should be kept as short as practical.

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 then 200 kg/h or the pressure differential could drop. In either case, the coil would flood with condensate and 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.



For Collected Condensate



For Drained Condensate

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 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 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.

Steam Trap Piping Arrangements
Figure 8

Strainers

Strainers are used to remove dirt and scale which may have been picked up by the steam as it is transported through the system. These devices are normally installed to protect other system components such as control valves, traps, and steam using equipment. In condensate return systems, strainers are used to protect control devices and pumps.

Condensate Receivers and Flash Tanks

Condensate receivers are tanks or similar devices used as a central collection point for condensate which is generated from steam mains or steam using equipment. The condensate is normally pumped from the receiver to its final destination. Condensate receivers are normally vented to atmosphere. *Even though steam can normally be seen escaping from the vent, valves should never be added into a condensate receiver vent.* The resulting pressure generated in the receiver could exceed the design rating of the unit or other devices in the condensate system.

Flash tanks are a specific type of condensate receiver where the condensate is allowed to *flash*. Details on flash steam are located in the section labeled "Flash Steam".

Insulation

Insulation is an extremely important accessory in any steam or condensate system. It is installed externally on pipes to minimize heat loss to the surroundings. An additional benefit is the protection of personnel from hot pipes. Bare or improperly insulated steam pipes are a constant source of wasted energy, and reduce the steam pressure at the terminal equipment. Insulating steam piping can reduce the energy loss by as much as 90 per cent.

Additional information on insulation may be found in Process Insulation, Module 1.

Metering and Monitoring

Metering and monitoring of steam and condensate flows is critical in determining the efficiency of boiler plants, steam and condensate systems, a single piece of equipment or the complete process which uses steam.

Under normal circumstances it is easier and more accurate to measure liquid flow (i.e. condensate) than steam. This should be considered when selecting the location of metering points.

There are several flow metering devices which can be used for measuring steam and condensate. These include orifice plates, flow nozzles, flow tubes, and displacement meters. Refer to Measuring, Metering and Monitoring, Module 15, for flow metering devices.

Energy Loss Areas

The ultimate goal of a steam system is to provide heat for buildings and processes. However, a percentage is wasted through system losses. The most significant of these is steam trap loss. Other losses include piping heat loss, leaks and flash losses, condensate loss to drain and overall system losses.

Steam Trap Losses

Steam trap losses are difficult to detect. These losses are normally from trap failure (leaking), incorrect trap selection or sizing, and incorrect trap location. Trap failures can average 25 per cent per year in a steam distribution system and steam leakage through a defective trap can vary from 5 to 50 per cent of the rated trap capacity.

Steam trap misapplication is a common source of energy loss. Oversizing is probably the most common fault. Steam traps are often selected for heavy condensate loads and then placed in service where the condensate load is very light. This keeps steam adjacent to a loosely fitting internal trap valve, resulting in live steam loss.

The material from which a steam trap is constructed has a dramatic effect on steam loss. Flashing condensate is erosive and in most cases corrosive. Trap construction must be carefully considered since condensate can bypass the steam trap valve by eroding the threaded portion of the carbon steel cap. This erosion will eventually lead to trap failure and wasted energy. Eroded traps should be replaced as soon as they are identified.

Table 5 illustrates steam loss through various sized orifices at different steam pressures discharging to atmosphere.

The annual energy wasted by a leaking trap can be calculated by the following equation.

$$Q = f_S \times h_{fg} \times h$$

Where, Q = Energy loss (kJ/yr)

f_S = Steam leak flow rate (kg/h) (Table 5)

h_{fg} = Latent heat of steam at system pressure (kJ/kg) (Table 1)

h = Operation hours (h/yr)

The cost of the energy loss can also be calculated.

$$\text{Cost} = f_S \times h \times Cs$$

Where, Cost = Total cost of energy ($/yr)

Cs = Unit cost of steam ($/kg)

The following calculation example shows the approximate energy wasted by one leaky trap.

Cost of steam (Cs)	\$22/1000 kg
Trap orifice size	3.2 mm
Steam pressure	690 kPa(gauge)
Latent heat of steam at 690 kPa(gauge) (h_{fg})	2047.9 kJ/kg (Table 1)
Hours of operation	8760 hours per year

From Table 5 the estimated steam loss from the leaky trap is 24 kg/h. The total energy loss can be calculated.

$$Q = f_S \times h_{fg} \times h$$

$$= 24 \text{ kg/h} \times 2047.9 \text{ kJ/kg} \times 8760 \text{ h/yr}$$

$$= 430.6 \times 10^6 \text{ kJ/yr}$$

The dollar value or cost of the lost energy can also be calculated.

Cost = 24 kg/h x 8760 h/yr x \$0.022/kg

= \$4,625/yr

This illustrates that the energy loss though one leaking trap is significant. Several faulty traps can represent a substantial energy loss within a steam distribution system.

Uninsulated Pipe & Fitting Losses

Uninsulated pipes, tanks, vessels, fittings, flanges or other system components are also major sources of heat loss.

The greater the temperature difference between the pipe and the surroundings the greater the heat loss. As the thickness of insulation is increased, the heat loss decreases. However, there is a point when adding more insulation is no longer economical. Additional information on recommended insulation thickness can be found in Process Insulation, Module 1.

Heat loss from uninsulated piping can be established by the use of Table 6, and Worksheet 8-2. Table 6 illustrates the amount of energy that is lost from uninsulated steel pipe at an ambient air temperature of 21.1°C. If the ambient temperature differs from this figure, the heat loss will also vary, however, this table can be used for most indoor applications.

Energy loss is not restricted to the piping system. Process equipment and terminal heating units can also represent major sources of energy loss. At a normal process steam pressure of 200 kPa (gauge), every 30 m^2 of uninsulated steam heated surface can result in a loss of 1 kg of steam per hour.

Some areas that are easily overlooked when considering insulation are valves, flanges and fittings. A rule of thumb is that every uncovered pair of flanges represents the equivalent of 610 mm of uninsulated piping. For valves and fittings, equivalent lengths will have to be obtained from the specific manufacturer of the item in question.

As an example, consider an NPS 6 steam distribution system which contains 10 pairs of uninsulated flanges. The equivalent length of bare NPS 6 pipe is calculated.

Equivalent Length = 10 pairs of flanges x 610 mm per pair

= 6100 mm equivalent

or 6.1 metres equivalent

For this example consider the pipe surface temperature was measured at 121°C and the system was in operation 8760 hours per year. Table 6 can be used to establish the bare pipe heat loss in Watt-hours per meter (Wh/m) of length for every hour of operation.

From Table 6 the bare pipe heat loss per metre per hour is approximately 600 Wh/(m·h)

Annual heat loss = Heat loss/metre/hour x Length x Hours of operation per year.

= 600 x 6.1 x 8760

= 32 061 600 Wh/yr

If the cost of steam is $22/1000 kg, the value of the annual heat loss can be calculated.

From Table 1, the enthalpy of steam at 121°C is 2707 kJ/kg. This is equivalent to 752 Wh/kg.

$$\text{Annual heat loss cost} = \frac{32\ 061\ 600}{752} \times \$0.022$$

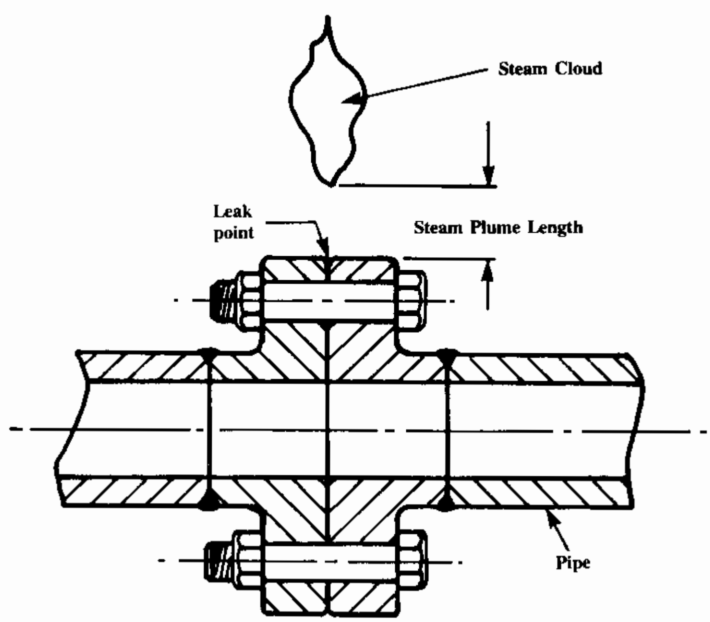
= $938 per year

This is a significant energy loss for only 10 pairs of uninsulated NPS 6 flanges.

Leaks

Steam leaks in distribution systems found at points such as pipe joints, valves and fittings, represent dollars lost through wasted energy. Table 7 can be used to approximate the hourly steam loss from steam leaks. The loss can be determined by measuring the length of the steam plume, which is the approximate distance from the leak opening to a point at which water condenses out of the steam (Figure 9). Using Table 7, and starting with the plume length, move vertically up the graph to the curve. The hourly steam loss can be read from the vertical axis of the graph.

As an example, for a plume length of 600 mm, Table 7 identifies a loss of steam as 7.5 kg/h. With this information, and knowing the cost of steam, the hourly or annual cost of the lost energy may be calculated.



Steam Plume Length
Figure 9

Flash Steam

Condensate is generated, at the saturation temperature of the steam. As the condensate is discharged into a lower pressure area, its temperature drops to the saturation temperature at the lower pressure. The heat released by the drop in temperature evaporates a percentage of the condensate producing *flash steam*. The condensate and flash steam are separated before the condensate is pumped to the boiler or to waste. This is normally accomplished in a *flash tank*. The flash steam may be vented to atmosphere or may be recovered for use in low pressure steam applications.

Flash steam can occur at discharges from traps, at boiler water blowdown discharge, or within the piping. In a high pressure system this steam could be recovered for uses such as space heating and low temperature process heating.

The percentage of condensate that will flash to steam can be calculated from the following equation.

$$\%\ \text{Flash Steam} = \frac{(h_{f1} - h_{f2})}{h_{fg2}} \times 100$$

Where, h_{f1} = Enthalpy of condensate at the higher pressure before discharge (kJ/kg)

h_{f2} = Enthalpy of the condensate at the lower pressure where discharge takes place (kJ/kg)

h_{fg2} = Latent heat of evaporation of flash steam at the lower pressure (kJ/kg)

The total flash steam available is given by the following equation.

$$f_{fs} = fc \times \%\ \text{Flash steam}$$

Where, f_{fs} = Flash steam flow rate (kg/h)

fc = Condensate flow rate (kg/h) (actual measured quantity)

The energy in flash steam can also be calculated.

$$Q_f = f_{fs} \times (h_{f1} - h_{f2})$$

Where, Q_f = Energy in flash steam (kJ/h)

Condensate Loss To Drain

Except where there is a possibility of the condensate being contaminated, it should all be returned to the steam generation point for use as boiler water make-up. This is done for the following reasons.

- The condensate contains heat energy. For example, if the temperature of the condensate is 90°C it will contain 376.94 kJ/kg of heat energy. If this is reused as boiler feedwater rather than city water at 10°C which has a heat energy content of 41.99 kJ/kg, then an additional 334.95 kJ of heat energy per kg of city water will be required to raise the temperature of the water to the return condensate temperature of 90°C.
- The condensate contains water treatment chemicals which will be returned to the boiler, thereby reducing boiler water treatment cost.

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.

System Losses

In any steam distribution and condensate return system one paramount question that must be asked is, "*Is the layout of the system as good as it should be?*"

Often system modifications, equipment removals or installations, reduced steam use or other similar factors have been implemented as required without any consideration being given to the system as a whole. The following points should be reviewed from a system standpoint to ensure that the system is operating efficiently.

- Is there unused steam or condensate piping in the system which has not been disconnected or at least isolated? If the end use equipment was removed, the piping should also be removed since it is a source of heat loss.
- Is the piping as short as possible between the point of generation and the point of use? In many cases pipes have been run around the perimeter of a facility to reach a piece of equipment instead of feeding directly to the equipment. Additional piping means additional surface areas and thus additional heat loss.
- Are pipelines oversized? The surface area of NPS 6 pipe is approximately 50 per cent greater than the surface area of NPS 4 pipe and the heat loss is greater for the same steam temperature. In many facilities there may be a possibility to reduce pipe sizing because of reduced steam utilization.
- Are steam traps oversized? In many facilities where steam reduction programs are in effect, steam utilization and therefore condensate quantities have reduced, however steam traps have not been downsized to match the reduced flows.
- Have steam utilization characteristics changed? In many instances steam mains servicing building heating equipment are not shut off when the heating equipment is not required.
- If meters are installed, are they being read and recorded on a daily or weekly basis? Is this data being reviewed? This data can often identify developing problems.
- Is condensate being recovered?

Boiler Plant Pressure

The boiler plant steam generating pressure should be held to the minimum value that is practical to accomplish the required task. Generally, when the boiler plant is located close to the loads, the generation pressure need only be high enough to provide the end use requirements and overcome minor friction and control valve losses. If the steam generator is located remotely from the loads, an assessment should be made of the economic advantage in distributing the steam at higher pressures in order to reduce pipe sizes. However, it should be realized that, at higher pressures, there could be increases in investment costs for the steam generation and terminal equipment, as well as greater heat loss from the distribution piping.

Techniques For Identifying Steam Trap Losses

Many system losses can be detected by a visual inspection. Missing insulation from a steam pipe or item of process equipment is a good example. Other equally recognizable indicators include visible flash steam plumes issuing from vent pipes of condensate receivers or other parts of the distribution system.

Probably the most overlooked system losses are faulty steam traps. Simple tests can be carried out to identify a faulty trap.

- The visual test method requires a shut-off valve to isolate the trap from the main condensate return line, as well as a test valve located between the shut-off valve and the trap (Figure 8). With the shut-off valve closed and the test valve open the condensate can be examined as it discharges. Inverted bucket, and float and thermostatic traps should discharge condensate continuously while thermodynamic traps can, depending on the load, be either continuous or intermittent. If steam blows out continuously in a "blue stream", the trap is leaking. If steam "floats" out intermittently in a whitish cloud, it is normal 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. This method requires experience, and it may not work well in areas with high background noise. A stethoscope is a typical listening device.
- Wet test the trap by squirting a few drops of water on it. The water should immediately start to vaporize. If it does not, a cold trap is indicated. This means that it may be failing to discharge condensate.

- Conduct sound tests using an ultrasonic detector. When flow passes through a trap, an inaudible ultrasonic vibration is generated and the detector magnifies this frequency to an audible level. A bucket trap should be relatively quiet, and cycle on and off at regular intervals depending upon condensate load and steam pressure. A ringing sound made by the bucket hitting the trap wall indicates that the trap is blowing steam. Disk traps are checked by touching the detector directly to the top of the trap. A good trap cycles every 6 to 10 seconds. If the frequency is greater than this steam is being lost, and the trap should be replaced.
- Conduct temperature tests using a pyrometer, which is a highly sensitive and accurate instrument for measuring temperature. It is used to measure the surface temperature of the trap inlet and discharge lines. If the discharge temperature is as high as the inlet temperature, the trap may be passing steam. Intermittent discharges can be detected by a rise and fall of the discharge line temperature. A hot disk trap that does not cycle at all may have failed in the open position. Bellows traps are checked at the outlet piping where the temperature cycles with variation in the condensate load. If there is no discernible variation in flow, the trap could be passing steam.
- 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.*

Pressure Reduction Effects

Steam is normally generated at the pressure required for the highest pressure steam using equipment in the system. Pressure reducing valves or other devices must be used to reduce the steam pressure for other medium to low pressure applications.

The pressure reduction in a pressure reducing valve takes place without loss of heat. Thus, for saturated steam, a reduction in pressure will result in superheated steam leaving the pressure reducing valve. This can be demonstrated by considering the following example.

A steam system is designed to distribute saturated steam at 300 kPa(absolute). A piece of equipment is installed which requires saturated steam at 150 kPa(absolute). The reduction in pressure is accomplished by using a pressure reducing valve.

Since there is no loss of heat, the heat content of the steam at 300 and 150 kPa(absolute) is the same.

For saturated conditions the following values are obtained from Table 1.

h_g at 300 kPa(absolute) 2724.7 kJ/kg

h_g at 150 kPa(absolute) 2693.4 kJ/kg

Since there is no change in the total heat content of the steam, the difference in enthalpy is the amount of superheat in the reduced pressure steam caused by the pressure reduction. The difference in enthalpy which is 2724.7 − 2693.4 or 31.3 kJ/kg is the amount of superheat in the reduced pressure steam.

Most medium to low pressure systems contain significant amounts of condensate in the steam. This condensate will absorb the superheat energy and return the steam to the saturated condition within a short distance downstream of the pressure reducing station.

As stated, heat transfer properties of superheated steam are not as good as that of saturated steam, and heating with superheated steam should be avoided if possible. In some cases, however, superheated steam is used to deliver dry saturated steam for applications such as live steam sterilizers or turbines.

Vapor Phase Compression

On some large, low pressure systems there may be a small local requirement for higher pressure steam. For these systems, the installation of a local high pressure steam boiler is usually the most economical way to avoid generating the entire steam supply at the higher pressure. However, it is also possible to compress low pressure steam. Vapor phase compression consists of physically compressing the steam in a motor driven compressor to achieve the higher pressure. By compressing the steam the enthalpy is increased and superheated steam is produced at the higher pressure. The energy imparted to the steam from the compressor may be recovered by desuperheating the steam with the controlled injection of treated water.

The advanced engineering principles and sophisticated equipment required for vapor compression are not covered by this module.

Steam System Utilization

The effective utilization of steam is dependent upon the temperature at which the condensate leaves the terminal equipment, i.e., the efficiency with which the terminal equipment extracts energy from the steam. A closed system, one in which the terminal equipment returns the condensate through a steam trap, may use only the latent heat of vaporization, or the latent heat and some of the sensible heat from the hot condensate. The more sensible heat that is removed, the greater the utilization of the energy delivered by the steam system. Steam is also used in direct injection processes where nearly all the sensible heat is utilized, but the consumed condensate must be made up with cold water at the boiler.

Consider a process heat exchanger which is heated with 600 kg/h of saturated steam at 1600 kPa(absolute). The measured temperature of the condensate from the exchanger to the steam trap is 190°C. The energy used by the heat exchanger is determined by the following procedure.

Obtaining enthalpy values from Table 1 for steam at 1600 kPa(absolute) and condensate at 190°C, the following calculations are performed.

The energy supplied to the heat exchanger is calculated.

$$\text{Energy supplied } (Q_T) = fs \times h_g$$

$$= 600 \times 2791.7$$

$$= 1.675 \times 10^6 \text{ kJ/h}$$

The energy leaving the heat exchanger in the condensate is calculated.

$$\text{Energy leaving} = fc \times h_f$$

$$= 600 \times 807.52$$

$$= 0.485 \times 10^6 \text{ kJ/h}$$

The energy used by the heat exchanger can now be calculated.

$$\text{Energy utilized } (Q_u) = \text{Energy supplied} - \text{Energy leaving}$$

$$= (1.675 \times 10^6) - (0.485 \times 10^6)$$

$$= 1.19 \times 10^6 \text{ kJ/h}$$

This can be converted to per cent energy utilization as follows.

$$\text{Per cent energy utilization} = \frac{Q_u}{Q_T} \times 100$$

$$= \frac{1.19 \times 10^6}{1.675 \times 10^6} \times 100$$

$$= 71.04\%$$

Flash Steam Utilization

The previous example demonstrated that 71.04 per cent of the energy supplied by the steam system was used by the heat exchanger. There is potential for the steam system to enhance its energy utilization through creative use of the flash steam.

The latent heat content of flash steam could be used for space heating, preheating of water, oil or other liquids, or for low pressure process heating. The flash steam recovered may be used directly, or as a supplement in a low pressure system.

The previously determined heat exchanger energy use was 1.19 x 10^6 kJ/h. Consider piping the trap to a flash tank maintained at 169 kPa(absolute) for reclaim of the flash steam. The flash steam is used to supplement the steam supply to air heating coils using saturated steam at 169 kPa(absolute). These units deliver condensate at 82°C to the steam trap.

Per cent flash steam from condensate at 190°C [1255 kPa(absolute)] discharged to 169 kPa(absolute) is calculated from the following equation.

$$\text{Per cent flash steam} = \frac{(h_{f1} - h_{f2})}{h_{fg2}} \times 100$$

The following values are obtained from Table 1.

Enthalpy of condensate (h_{f1}) at 190°C [1255 kPa(absolute)]	807.52 kJ/kg
Enthalpy of condensate (h_{f2}) at 169 kPa(absolute)	482.5 kJ/kg
Latent heat of evaporation in steam (h_{fg2}) at 169 kPa(absolute)	2216.2 kJ/kg

$$\text{Per cent flash} = \frac{807.52 - 482.5}{2216.2} \times 100$$

$$= 14.7\%$$

$$\text{Flash steam quantity } (f_S) = 600 \text{ kg/h} \times \frac{14.7}{100}$$

$$= 88.2 \text{ kg/h at 169 kPa(absolute)}$$

Energy from the flash steam available (Q_a) for use in the air heating coils can now be calculated.

Enthalpy of saturated steam (h_g) at 169 kPa(absolute)	2698.7 kJ/kg (Table 1)
Enthalpy of condensate (h_f) at 82°C	343.31 kJ/kg (Table 1)

$$Q_a = f_S \times (h_g - h_f)$$

$$Q_a = 88.2 \times (2698.7 - 343.31)$$

$$= 0.21 \times 10^6 \text{ kJ/h}$$

Total energy supplied (Q_t)	1.675 x 10^6 kJ/h	(Previously calculated)
Energy used by heat exchanger	1.19 x 10^6 kJ/h	(Previously calculated)
Energy in flash steam (Q_a)	0.21 x 10^6 kJ/h	(Previously calculated)

The total energy used by the heat exchanger and available in the flash steam can now be calculated.

$$\text{Total energy used} = (1.19 \times 10^6) + (0.21 \times 10^6)$$

$$= 1.4 \times 10^6 \text{ kJ/h}$$

$$\text{Per cent utilization} = \frac{1.4 \times 10^6}{1.675 \times 10^6} \times 100$$

$$= 83.58\%$$

Energy in condensate = Total energy supplied (Q_t) − Total energy used

$$= (1.675 \times 10^6) - (1.4 \times 10^6)$$

$$= 0.275 \times 10^6 \text{ kJ/h}$$

By integrating the steam supplies operated at two different pressures, steam utilization was increased from 1.19×10^6 kJ/h to 1.4×10^6 kJ/h.

The following summary provides a comparison of the two previous examples showing the differences with and without flash steam recovery.

Item	No Flash Steam Recovered	Flash Steam Recovered
Steam flow rate	600 kg/h	600 kg/h
Steam temperature	201.37 °C	201.37 °C
Steam pressure	1600 kPa(absolute)	1600 kPa(absolute)
Flash tank pressure	No flash tank, i.e. 101.325 kPa (absolute)	169 kPa(absolute)
Flash steam	–	14.7%
Flash steam recovered	–	88.2 kg/h @ 169 kPa(absolute)
Heat content of flash steam		0.21×10^6 kJ/h
Total energy supplied	1.675×10^6 kJ/h	1.675×10^6 kJ/h
Total energy used	1.19×10^6 kJ/h	1.40×10^6 kJ/h
Heat energy utilization	71.04%	83.58%

Energy Audit Methods

Energy Management Opportunities exist in steam and condensate systems 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. The following typical energy saving opportunities may be noted during a walk through audit.

- Steam traps not properly installed.
- Leaking or malfunctioning steam traps.
- Condition, thickness and type of pipe insulation on steam and condensate lines, condensate receivers and other equipment.
- Leaks in the piping, and around flanges and valves.
- Condensate discharged to sewer.
- Steam pressure or temperature higher than actually required.
- Piping runs which could be shortened by relocating equipment.
- Steam used where hot process fluids could be substituted as a heat source.
- Flash steam plumes visible from condensate collection tank vents.
- Control system setpoints not adjusted for the optimum conditions.
- Meters not operational or obviously out of calibration.
- Unused piping system not shut off and equipment operating when not required.

Alert management, operating staff and good maintenance procedures can reduce energy waste, improve energy use efficiency, and save money. Checklist 8-1 is provided to organize steam trap data collection during the walk through audit.

Not all items noted during the walk through audit are as easy to analyze as those described. For example, it may be noted that a steam or condensate line is uninsulated and losing heat to the surrounding areas. While the immediate reaction may be that the line should be insulated to reduce the loss, the following questions should be considered before any action is taken.

- How much insulation?
- What type of insulation?
- Will the energy and associated cost savings pay for the insulation?

A diagnostic audit is required to mathematically determine how much heat is being lost and how much this loss can be reduced by the installation of insulation. The reduction in energy loss establishes the dollar savings. With this, plus the estimated cost to supply and install the insulation, 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

Alert design, operations and maintenance personnel, with an awareness of energy management, can reduce steam and condensate system energy losses and save dollars.

Steam leaks from traps and other piping components account for the largest energy losses within a system. Substandard pipe insulation and flash steam losses also represent significant energy waste. It is important that good methods be developed to identify and quantify system losses to ensure that proper corrective measures are carried out. For example, a properly executed steam trap maintenance program will reduce energy consumption and provide a quick financial return on the capital investment.

Energy recovery cannot be overstressed. Where possible, effort must be made to recover and utilize flash steam, return all condensate to the point of steam generation, and recover heat energy from waste streams.

The subject of energy management must be approached with an open mind. The opportunities listed in the Energy Management Opportunities section of this module may suggest similar or additional items specific to a facility. An added awareness on the part of the staff managing, operating or maintaining a facility may see things, which, with some imagination and/or expert assistance, can reduce both energy and operating costs.

Steam Velocity Calculation

Worksheet 8-1

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

Location: ANYTOWN By: MBE

Steam pipe internal diameter 0.1541 m

Steam flow (f_s) 13 608 kg/h

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

Cross sectional area of pipe (A)

$$= \frac{3.142 \times (\text{internal dia})^2}{4}$$

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

$$= 0.0187 \text{ m}^2$$

Velocity (V)

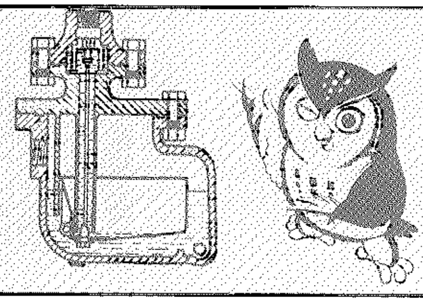
$$= \frac{f_s \times v_g}{A \times 3600}$$

$$= \frac{13\,608 \times 0.25888}{0.0187 \times 3600}$$

$$= 52.33 \text{ m/s}$$

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.

EQUIPMENT SYSTEMS



Steam is transferred from the point of generation to the point of use through a system consisting of pipes, valves and fittings. Similarly, condensate is collected throughout the system and returned to the boiler plant. Prior to discussing typical steam and condensate systems, the individual components most commonly encountered will be addressed.

Pipe and Fittings

A steam and condensate system is comprised of pipes and a variety of fittings as necessary.

Pipe

Steam and condensate pipes are normally made from carbon steel and are stocked from NPS 1/8 to NPS 36. Straight lengths of pipe are available from 3 m to 12 m and are joined by using fittings or by welding one to the other to form the piping system.

Pipe fittings can be flanged, welded or screwed. They are also identified by the NPS and schedule numbers and the material used is the same as pipe.

Drip Leg

A drip leg (Figure 6), fabricated from pipe and fittings, is used to collect condensate. Drip legs are normally provided at all low points in a steam system and wherever condensate can collect such as at the end of mains and at the bottoms of risers. Figure 6 also provides a list of pipe sizes and recommended drip leg sizes.

The drip leg should have adequate storage capacity to store some condensate to provide a hydraulic head at the trap.

Strainers

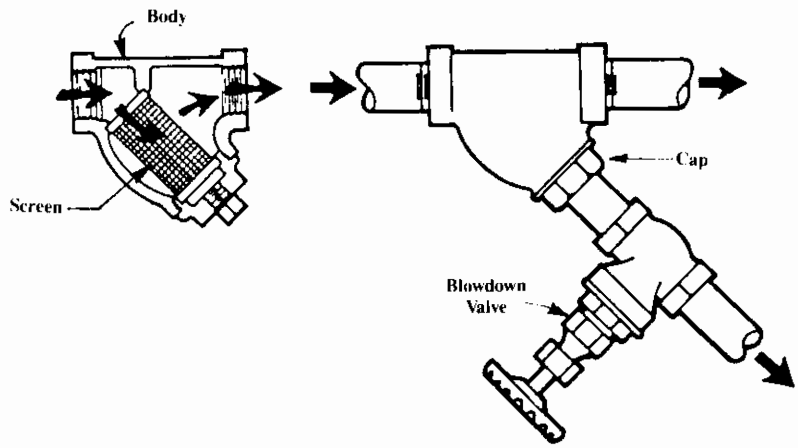
Strainers are devices which remove dirt, rust, scale and other impurities carried in steam and condensate lines. They are used to protect the equipment and prevent contamination of the steam. The basic strainer element is a screen, usually made of woven wire or perforated metal. The normally removable screen is contained in a housing or body which permits the incoming fluid to pass through it.

Some steam traps are susceptible to sticking or clogging. To overcome this problem, strainers containing a fine wire woven screen are used upstream of the trap. These strainers capture all but the finest of dirt particles.

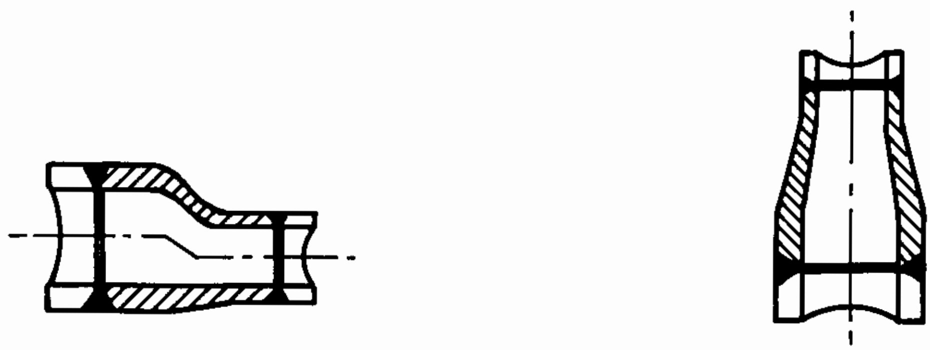
Perforated screens are commonly made of corrosion resistant brass, monel or stainless steel. The latter two are more expensive than brass. For any steam service, perforation sizes in screens range from 0.50 mm to 0.84 mm, with 0.25 mm openings common to dutch weave screens.

There are three types of strainers commonly used on steam and condensate systems.

- The Y-type is the most commonly used strainer (Figure 10). A valve is sometimes attached to the strainer cap to make cleaning easier. Dirt and scale are blown out when the valve is opened. This reduces the frequency of screen removal for cleaning.
- The T-type strainer is normally used in piping systems over NPS 12 where the physical size and space required for the Y-type makes them unwieldy.
- The Duplex strainer is used where excessive amounts of dirt and scale are encountered. Usually, it consists of two strainer baskets mounted side by side with flow directed to one or the other. In this configuration, one strainer may be removed for cleaning while the other unit is in use.



Y-Type Strainer
Figure 10



Eccentric
(A)

Concentric
(B)

Reducers
Figure 11

Reducers

Reducers are used to join a large pipe to a smaller one. Eccentric reducers (Figure 11A) in steam piping should be installed level with the bottom of the main as this will minimize water pocketing. Concentric reducers (Figure 11B) are normally used for pipe size reduction in vertical pipe runs, where water accumulation is not a factor.

Elbows

Standard 90 or 45° elbows are used to change the direction of the lines. Elbows are classified as either long radius (LR) or short radius (SR). The radius of the LR elbow is 1.5 times the Nominal Pipe Size and the SR elbow radius is equal to the Nominal Pipe Size. In some cases a 90° reducing elbow can be used. The radius will be the NPS of the larger pipe.

Tees

Tees are used to make branch connections from the main and are classified as straight, reducing or bullhead. For straight tees, the branch size is the same as the main. Reducing tees have branches which are smaller than the main. Bullhead tees have branches larger than the main.

Flanges

Flanges are one method used to join equipment, valves and piping. They provide easy removal of valves and equipment for servicing. Flanges can be welded or screwed to the pipe. A gasket is positioned between the mating flange faces to act as a seal.

Steam Traps

The many different types of steam traps manufactured operate by sensing the difference between steam and condensate using one or more of three basic physical properties. When classified according to these operating principles, each design has advantages and limitations which must be considered when selecting a steam trap for a specific application.

The three basic types of steam traps are as follows.

- Mechanical (Density operated)
- Thermostatic (Temperature operated)
- Disc and Orifice (Kinetic energy operated)

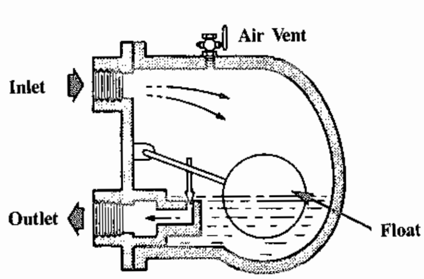
.1 *Mechanical traps* are operated by the density difference between steam and condensate. The traps are buoyancy operated and are available in several different types.

The float trap (Figure 12) is operated by the rise and fall of a float that follows the condensate level in the trap. This type can continuously discharge condensate by gravity, and is used mainly on steam separators, blast coils, sterilizers and other similar equipment.

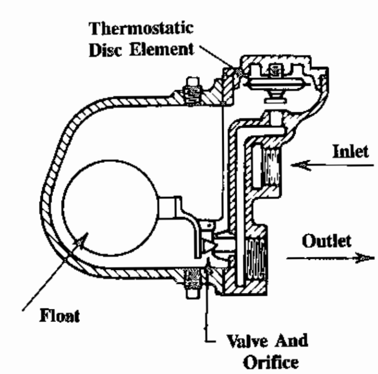
The float and thermostatic trap (Figure 13) is a combination of the ball float and the thermostatic trap, and is generally called the F & T trap. The float element handles the condensate, and the thermostatic bellows element permits the flow of air and gas. The trap can vent large volumes of air and gas, continuously discharge condensate, handle intermittent loads and operate at extremely low pressure differentials. Normally this trap operates from vacuum to pressures up to 1400 kPa(gauge). It is used on temperature regulated steam coils, unit heaters, and heating coils.

The open bucket trap (Figure 14) uses a bucket which is open on the top and is buoyancy operated. The bucket floats when condensate rises in the trap, closing the discharge port. Additional condensate flows into the bucket and causes it to sink, thereby opening the port. Steam pressure then forces the condensate in the bucket out the open port to refloat the bucket and the cycle repeats. Discharge of condensate is intermittent and a definite pressure differential is required between the inlet and outlet. Generally, this trap is used on steam mains, blast coils, unit heaters, laundry equipment, sterilizers and similar equipment. It is not greatly influenced by pulsations or wide fluctuations of pressure. The trap can be used on pressures from vacuum conditions up to 8300 kPa(gauge). The use of this trap is decreasing because of the large physical size, lack of venting capability and maintenance requirements.

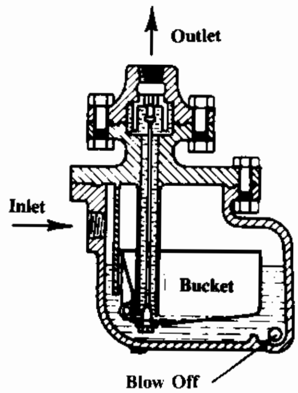
The inverted bucket trap (Figure 7) eliminates the size and venting problems associated with the open bucket trap by using an inverted bucket. The trap continuously vents air and noncondensible gases, while intermittently discharging condensate. It is made for pressures ranging from vacuum to 17 000 kPa(gauge), and is used on steam main drip legs and for most steam heating applications. Although this trap is not freezeproof, some units made of thin-wall stainless steel can withstand freeze/thaw cycles and continue to function.



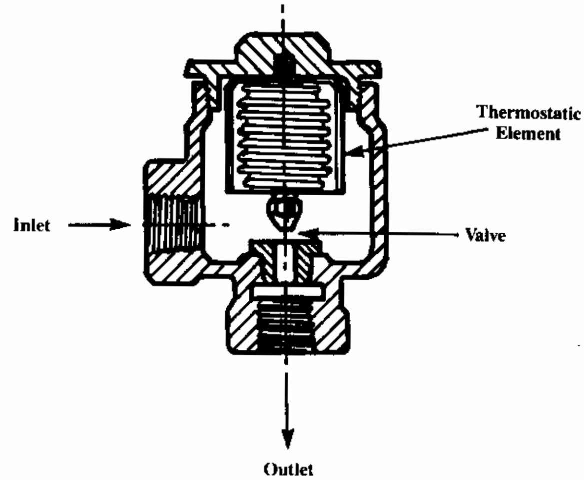
Float Trap
Figure 12



Float And Thermostatic Trap
Figure 13



Open Bucket Trap
Figure 14

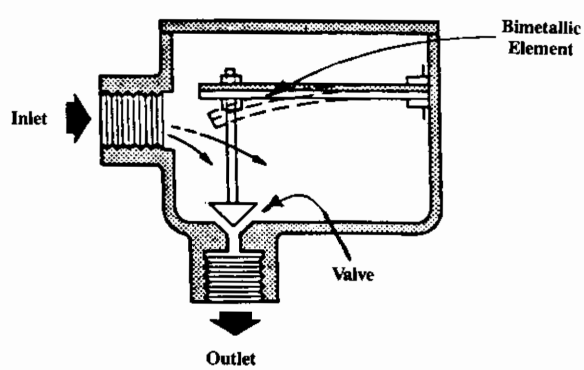


Bellows Thermostatic Trap
Figure 15

.2 *Thermostatic traps* are operated by the temperature difference between steam and condensate. They use a bellows, bimetallic element or liquid filled cartridge to operate a valve that opens in the presence of condensate, and closes in the presence of steam. They are made in pipe connection sizes from NPS 1/2 to NPS 2, for pressures ranging from vacuum conditions to 2070 kPa (gauge).

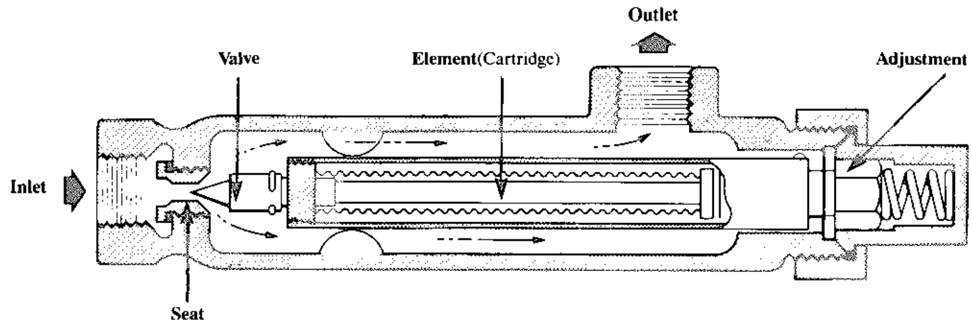
The bellows thermostatic trap (Figure 15) uses a bellows element containing a liquid that has a lower boiling point than water. When steam surrounds the bellows the liquid boils and closes the valve to stop condensate flow. It is a balanced pressure device that can be used at any pressure within the operating range of the trap. This trap is used mainly for low pressure saturated steam service such as radiators and convectors in building heating systems, where steady light loads are found.

The bimetallic thermostatic trap (Figure 16) uses an element made from metals with different expansion coefficients. This element changes shape in response to the steam and condensate temperatures to open or close the valve port. Used mainly in high pressure applications such as steam tracing, jacketed piping and high temperature heat transfer equipment, they respond only to temperature and their operation is not affected by superheated steam or water hammer. However, these disturbances will shorten the trap life.



Bimetallic Thermostatic Trap
Figure 16

The liquid expansion thermostatic trap (Figure 17) contains a cartridge filled with a hydrocarbon oil that expands and contracts in response to temperature. It operates only at temperatures of 100°C or less. Its use is limited to equipment where partial flooding can be tolerated. With an open discharge, this type of trap is freeze proof.

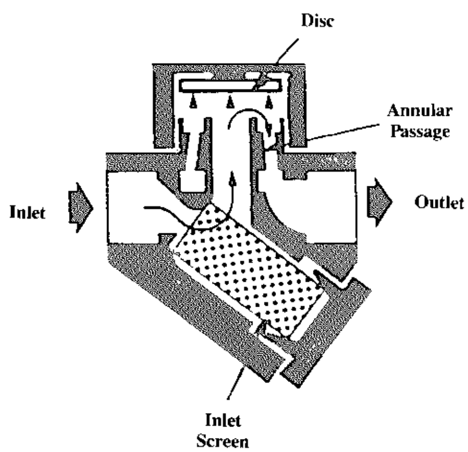


Liquid Expansion Thermostatic Trap
Figure 17

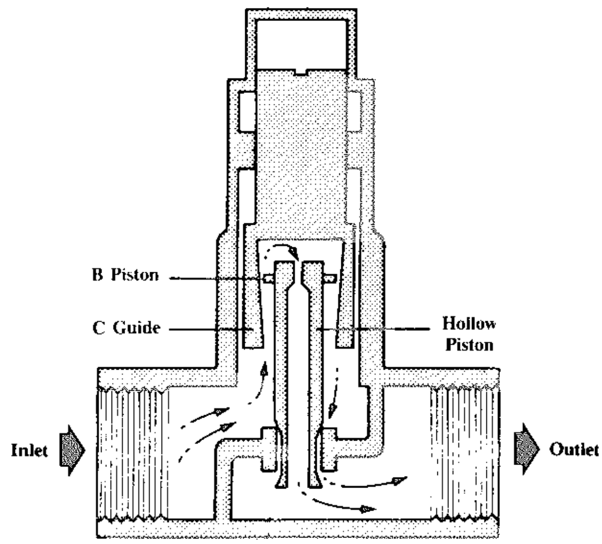
.3 *Kinetic traps* operate on the principle that there is a difference between the flow characteristics of steam and condensate.

The thermodynamic or disc trap (Figure 18) contains only one moving part. Upon start-up, pressure forces the disc up and air and condensate are discharged. As steam enters the trap, the disc is forced down by the increased velocity which decreases the pressure on the underside of the disc. The disc is again lifted when the trap receives a fresh charge of condensate. The trap opens and closes at fixed intervals for a given pressure. A pressure differential is required to operate the trap properly, restricting its use to systems which operate above 70 kPa(gauge), such as steam main drip legs and steam tracing.

The impulse or piston trap (Figure 19) operates like a disc trap, except that a piston is used instead of a disc and a continuous amount of steam or condensate is discharged. Because of the close tolerances of the piston it is more susceptible to clogging or sticking from dirt in the system.



Thermodynamic Or Disc Trap
Figure 18



Impulse Or Piston Trap
Figure 19

The orifice trap (Figure 20) has no moving parts and the flow of steam and condensate is controlled by two phase flow through an orifice. The orifice has a much greater capacity for condensate than for steam because of the density differences of these two materials. Therefore, it continuously passes all condensate, air, noncondensible gases and a small amount of steam. For properly sized orifice traps, steam losses are comparable to those of most cycling type traps. Because of the small orifice, this trap, like an impulse trap, requires an effective strainer upstream of the trap. An orifice trap can operate against any back pressure and is suitable for all system pressures. It is used where there are steady pressure and load conditions, such as on steam main drip legs.

Table 8 provides a typical steam trap selection guide and lists first and second choices for various applications.

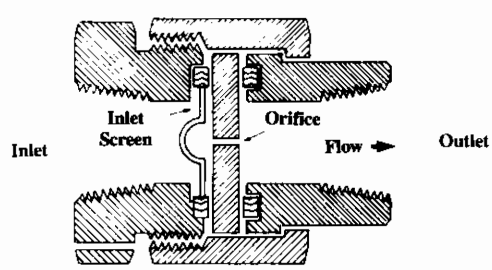
Air Vents

Air vents allow air to pass out of a system but close when steam starts to escape. Two types of air vents are applicable to steam systems.

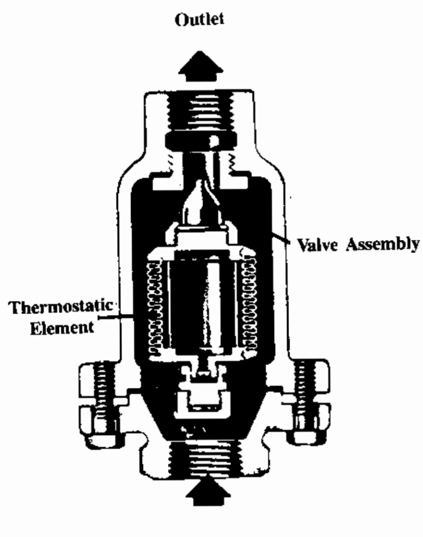
- Thermostatic Air Vents
- Combination Float and Thermostatic Air Vents

A thermostatic air vent (Figure 21) contains a bellows attached to the valve head. The vent is sensitive to temperature changes and opens the discharge valve upon a decrease in temperature which indicates air is present. When the air has been discharged the temperature rises and the vent closes. These units are small in size but have large capacities.

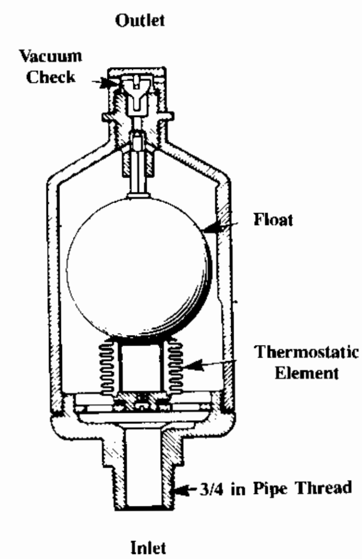
A combination float and thermostatic air vent (Figure 22) contains a thermostatic bellows and a float assembly to remove air or gases. They are used where condensate, steam and gas are present, and will discharge air and gases but not steam or condensate. The unit contains a check valve in the discharge port which permits operation in a vacuum system without loss of vacuum.



Orifice Trap
Figure 20



Thermostatic Air Vent
Figure 21



Combination Float And Thermostatic Air Vent
Figure 22

Valves

The proper selection of valves for steam and condensate systems is important. Gate, globe, check and relief valves are commonly used. Valves perform the following functions.

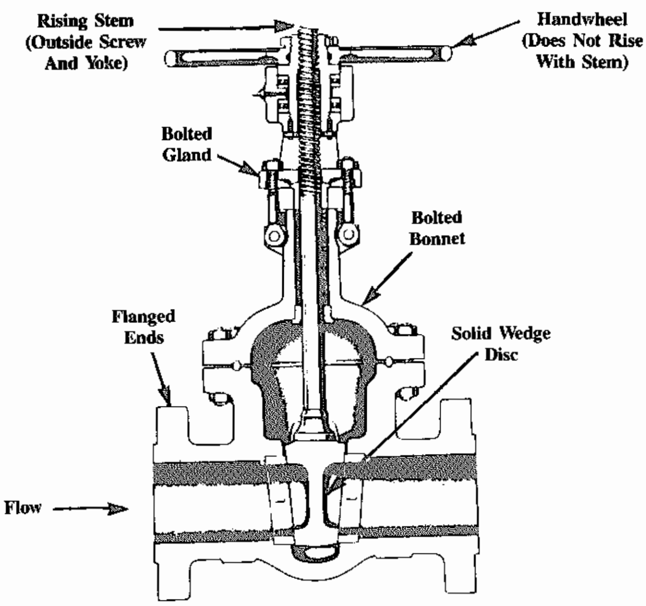
- Flow isolation.
- Flow regulation.
- Backflow prevention.
- Safety.

Some valves are capable of providing two of the stated functions.

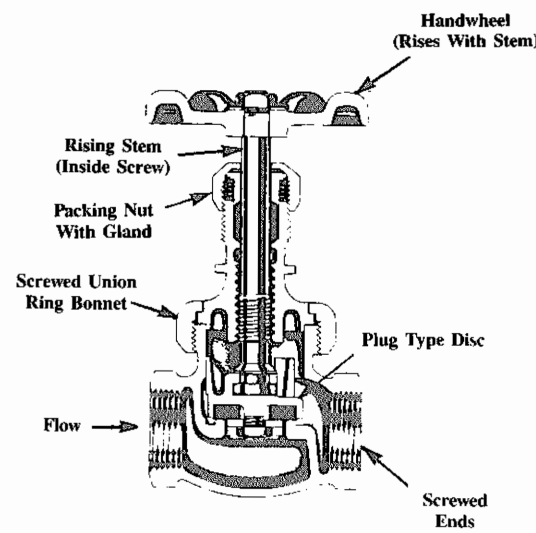
Gate valves (Figure 23) are used for isolation. They are most effective in the fully open or closed position. When the valve is fully open, flow is straight through and there is little obstruction and turbulence. The result is that it has a lower pressure drop than other valves. Gate valves should not be used for throttling flow.

Globe valves (Figure 24) have a high pressure drop when open. They are normally used for throttling and balancing flow, but, can be used in place of a gate valve. The percentage flow is proportional to the percentage opening. The disc and seats are more easily replaced than on gate valves.

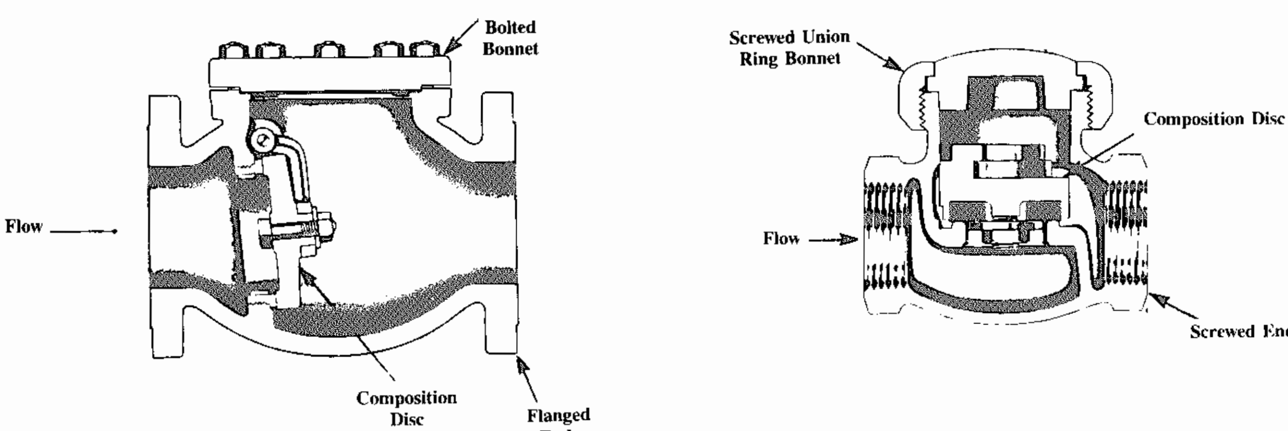
Check valves (Figure 25) are used in piping systems to prevent the reversal of flow. The swing check valve (Figure 25A) is used in a horizontal position or in a vertical line if the flow is upward. The lift check valve (Figure 25B) should only be installed in vertical lines if it is equipped with a closing spring.



Gate Valve
Figure 23



Globe Valve
Figure 24



Swing Check Valve
A

Lift Check Valve
B

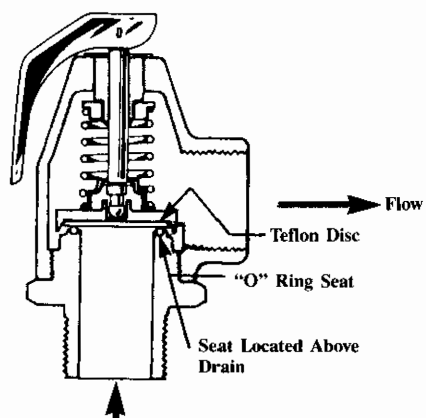
Check Valves
Figure 25

All pressurized steam and condensate systems must have a safety valve to relieve excess pressure which may be inadvertently placed on the system. *Pressure relief valves* (Figure 26) are designed to fully open at a set pressure, and to return to the closed position after a predetermined lower pressure is reached. The design and construction of the valve causes it to pop fully open at the set pressure. Once the pressure is reduced to a selected level below the set pressure, the valve must seat quickly. Failure to seat properly can result in significant steam or condensate leakage.

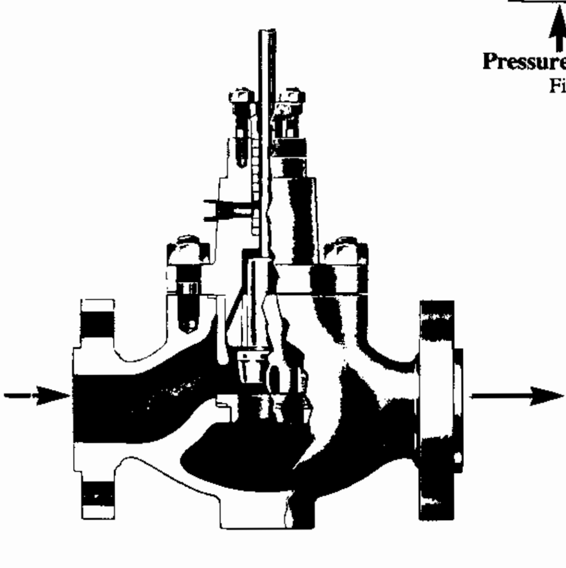
Pressure Reducing Stations

The function of a pressure reducing station is to provide a stable, controlled outlet steam pressure from a higher, often fluctuating, inlet steam pressure. For reduction from high pressure to very low pressure, reducing stations piped in stages may be required. Single seated (Figure 27A) and double seated (Figure 27B) valves are used in these stations. Single seated valves provide tighter shut-off to prevent the buildup of the outlet pressure under no-flow conditions.

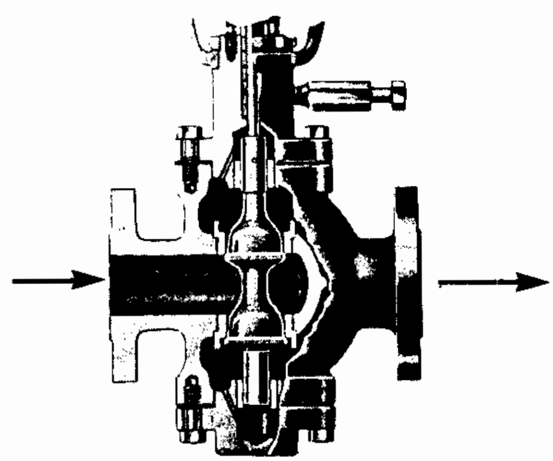
Piping arrangements for pressure reducing stations may include a bypass loop complete with a manually operated tight shut-off globe valve for servicing the reducing valve (Figure 28). A strainer is installed upstream of the pressure reducing valve. Isolation valves are also installed to allow removal of the reducing valve. Steam mains must have a pressure relief valve in the reduced pressure line. A drip leg and trap are installed immediately ahead of the pressure reducing station to minimize condensate erosion of the reducing valve seats.



Pressure Relief Valve
Figure 26

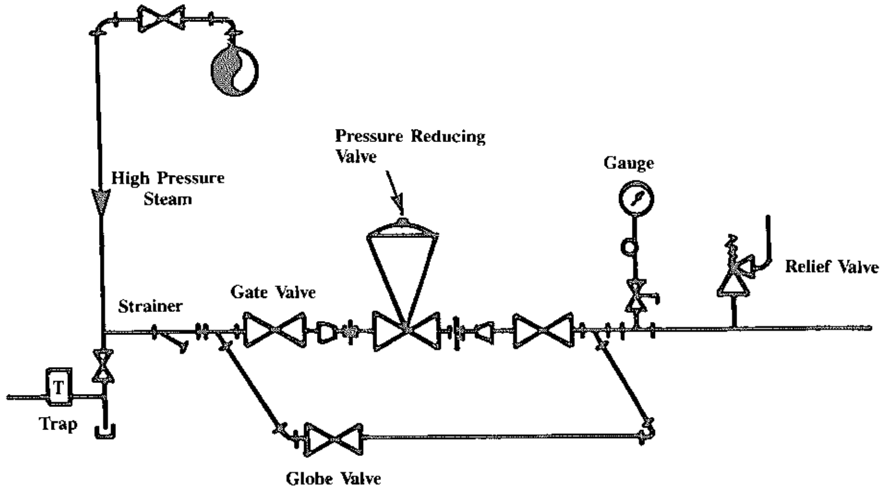


Single Seated Pressure Reducing Valve
A



Double Seated Pressure Reducing Valve
B

Pressure Reducing Valves
Figure 27

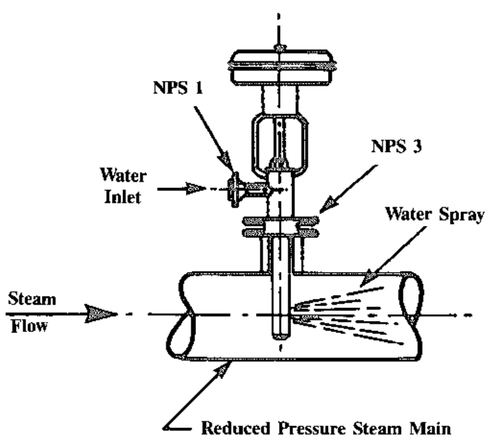


Pressure Reducing Station
Figure 28

Desuperheaters

There are two basic types of equipment used for desuperheating of superheated steam. The spray type unit (Figure 29) removes the superheat by the controlled injection of treated water. The surface type removes superheat through a heat exchanger in which the steam and water do not mix. Desuperheaters are used in many industrial facilities where the steam provided by a boiler is superheated, and saturated steam is required for certain process applications. Rather than use separate boilers, a desuperheater is a more economical method of providing saturated steam.

In many cases desuperheating of reduced pressure steam is required due to process conditions. Valves are available which reduce pressure and desuperheat in a single unit and greatly reduce the space required for the desuperheating function.



Spray Type Desuperheating Valve
Figure 29

Insulation

Insulation of steam and condensate piping systems serves two distinct functions.

- To reduce heat loss from the piping, valves and fittings.
- To provide safety from burn hazards for people and products which may come in contact with the hot piping.

Uninsulated steam mains have high radiant heat losses with a resulting drop in steam temperature. This in turn produces excess amounts of condensate which must be removed from steam systems. If steam mains and branches are not insulated steam must be generated at a higher temperature in the steam generating equipment than is required at the steam using equipment to account for the radiant heat loss from the piping.

Uninsulated steam and condensate systems are a definite safety hazard in the workplace. Even in low pressure steam systems used for building heating which operate in the vicinity of 200 kPa(absolute) the surface temperature of the steam main can approach 120°C. The National Building Code of Canada limits the surface temperature of piping in exposed areas to 70°C.

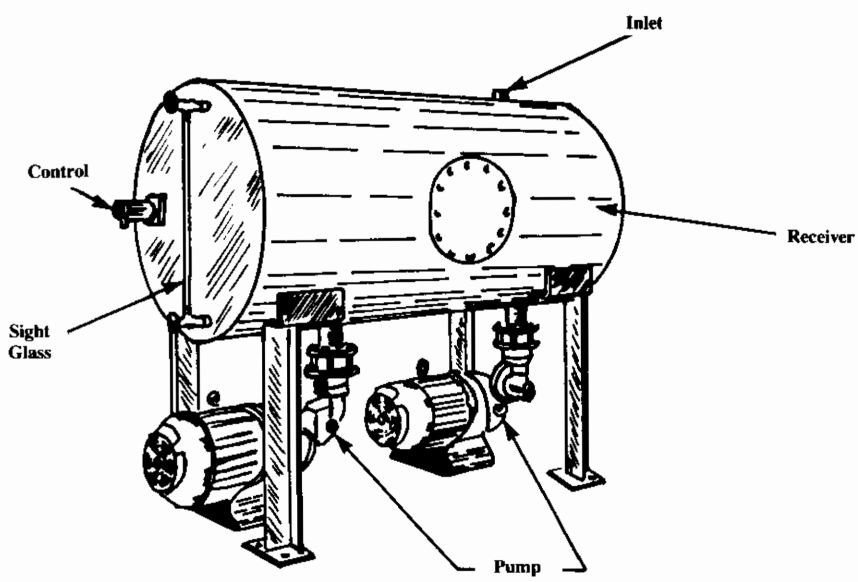
Additional details on insulation may be found in Process Insulation, Module 1.

Condensate Return Units

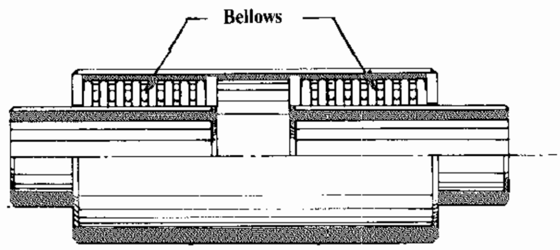
Condensate is hot distilled water which is ideal for use as boiler feedwater. Returning it to the boiler will save fuel, water and the cost of water treatment.

The usual method of collecting the condensate is by piping the various steam traps to a condensate return unit (Figure 30) which consists of a condensate receiver tank, one or two pumps for pumping the condensate, and controls. A float activated switch or similar device in the receiver operates the pump on a rise of liquid in the tank. The pump transfers the hot condensate to the boiler feed tank or flash tank where it is to be reused.

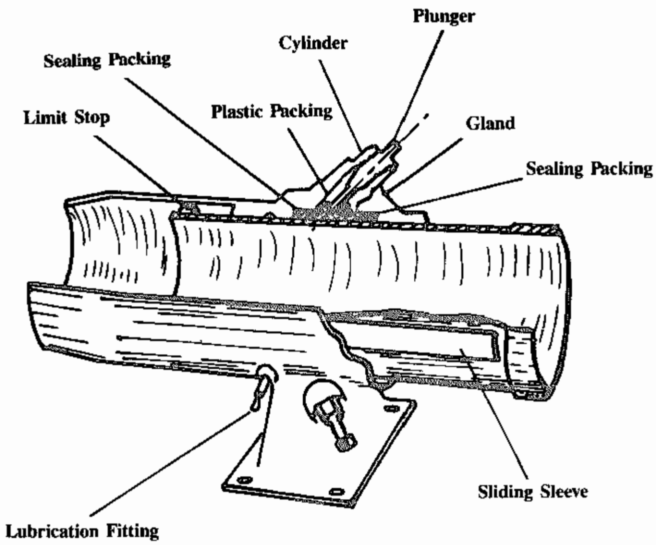
Packaged units such as that shown in Figure 30 can be purchased with receiver capacities from 6 to 220 L and with pump flow rates varying from 0.2 to 44 L/s depending on the overall steam system and condensate generation rates. Care must be taken in the selection of units and pumps to ensure that they are sized to handle the increased condensate loads generated on equipment or system start-up.



Condensate Return Unit
Figure 30



Bellows Type Expansion Compensator
Figure 31



Packed Type Expansion Compensator
Figure 32

Pipe Supports

Pipe supports come in three basic types, flexible, rigid and roller. Flexible pipe supports allow the pipe to move while still maintaining support. Rigid supports, on the other hand, maintain the pipe in a fixed position allowing no movement. Roller supports only support the pipe, allowing it to move along the pipe axis.

Insulation shields should be used when insulated pipe is laid on any piping support to allow a uniform insulation thickness to be maintained.

Expansion Compensators

Expansion compensators or expansion fittings are used in piping systems to allow for linear pipe expansion or contraction caused by temperature changes. The basic types of compensators are the bellows type expansion compensator (Figure 31) where the linear motion is absorbed by a metallic bellows, and the packed type expansion compensator (Figure 32) where the linear motion is absorbed by one section of the compensator moving inside the other section. It must be noted that these units will only accept linear expansion and the piping must be guided on either side of the compensator to ensure only linear movement takes place.

Expansion compensators are used where space limitations preclude the use of expansion loops.

Expansion Loops

Expansion loops are pipe loops designed into a piping system to allow the natural flexibility of steel piping to absorb expansion and contraction. Figure 5 shows typical expansion loops which may be encountered.

Steam and Condensate Flow Metering

The following flow measurement devices are commonly used for the metering of steam and condensate flows.

- Orifice plates, which are widely used because of the simplicity and broad range of application.
- Flow nozzles, which produce less restriction than orifice plates, and provide greater accuracy where the flow rate varies widely.
- Flow tubes and venturi tubes, which are used where the fluid contains some suspended solids.
- Elbow taps, which are easily installed and are less expensive. They are not as accurate as other types of flow elements.
- Displacement meters, which are used to measure condensate flow. They are normally limited to NPS 4 and smaller lines.

Metering of the steam and condensate flows is important in determining the efficiency of boiler plants, steam and condensate systems, and equipment and processes which use steam.

Miscellaneous Equipment

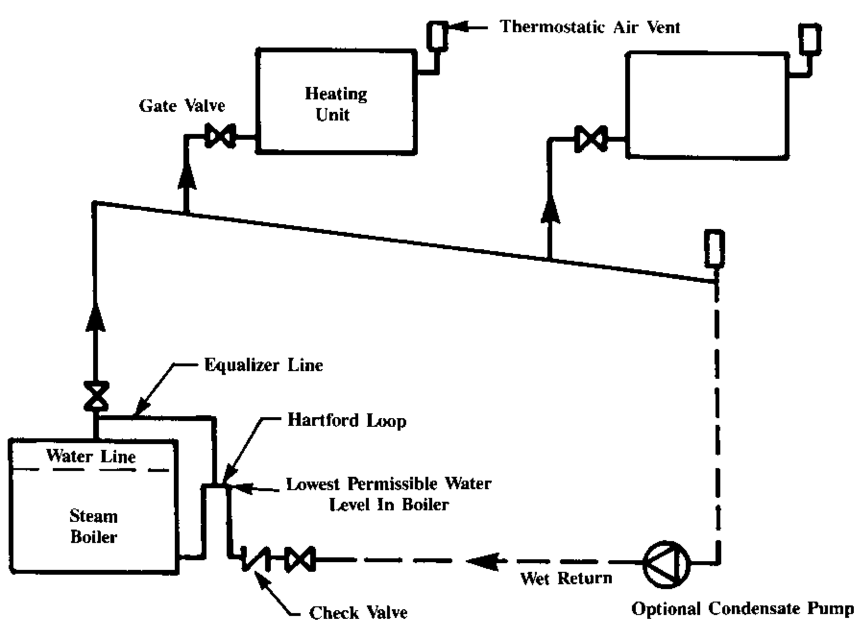
Normally steam and condensate systems include both thermometers and pressure gauges which are used to provide an indication of the system temperature and pressure conditions, and can be used for system trouble shooting.

Knowledge of the system operating conditions as confirmed by measuring instruments can easily show when system changes take place and when maintenance is required. Further, without certain basic measurements such as temperature and pressure, energy use or loss calculations cannot be performed with any degree of accuracy.

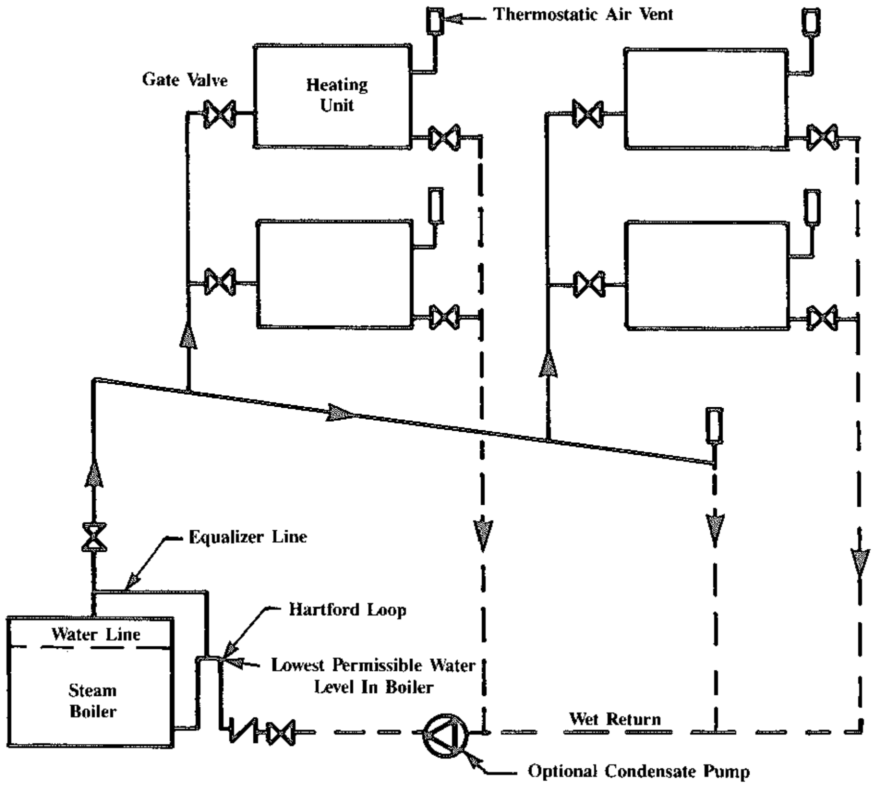
Steam Heating Systems

A combination of piping arrangement and method of condensate return is used in the identification of steam and condensate systems. The most common types of systems are:

- One-pipe gravity return systems.
- Two-pipe gravity return systems.
- Two-pipe trapped return systems.



One-Pipe Looped Return System
Figure 33



Two-Pipe Gravity Return System
Figure 34

One-Pipe Gravity Return System

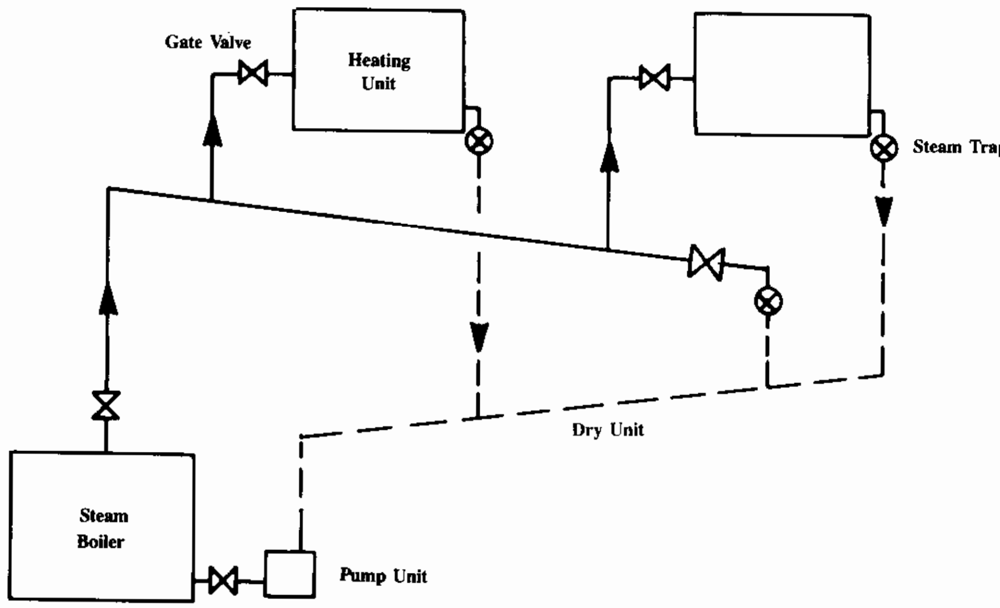
A one-pipe gravity return system does not require steam traps. This system uses thermostatic air vents to expel air during warmup, and admit air as it cools. All parts of the system are at the steam supply pressure, and all condensate is returned without flow loss within the steam supply piping. These systems are in limited use.

One-pipe looped return heating systems (Figure 33) are used on larger, horizontally distributed heating systems. Pipe sizes are smaller than those of a counterflow system, but water hammer can still occur in the runouts to individual heating units. On larger systems a condensate booster pump may be used. To reduce the risk of sudden loss of boiler water owing to return system leaks, the condensate piping is connected to the boiler in an arrangement known as a Hartford Loop. The Hartford Loop shown in Figure 33 consists of a line without valves connecting the steam outlet to the condensate return inlet. The condensate return line is connected to the steam-condensate line or loop at the same elevation as the lowest permissible level in the boiler.

Control is achieved by varying the pressure at the boiler and by starting and stopping the entire system. Normally, one-pipe steam heating systems are designed to operate at steam pressures below 35 kPa(gauge), and are difficult to control at higher pressures.

Two-Pipe Gravity Return System

Two-pipe gravity return systems (Figure 34) are used in small multistoried buildings to achieve vertical steam distribution to heating units. The system operates on the same principle as a one-pipe system except that counterflow of steam and condensate is avoided. Control of individual heating units requires shutting off valves in the supply and return connections to prevent counterflow of steam and condensate through the return connection. If air vents are not functioning properly, air and noncondensible gases can air lock the heat exchange equipment and return risers, and restrict condensate flow.



Two-Pipe Trapped Return System
Figure 35

Two-Pipe Trapped Return System

Two-pipe trapped return systems (Figure 35), use a steam trap at the outlet of each heating unit to retain the steam until it has given up its latent heat and condensed. Drip traps are provided at low points in the steam piping to remove condensate caused by heat loss from the pipes.

Trapped systems may operate over a wide range of pressures, but most heating systems operate at 15 to 200 kPa(gauge). Individual control of the heating units can be achieved by throttling the steam supply to each unit. Normally, trapped steam systems use a pumping unit to return the condensate to the boiler. The pumping unit may operate at atmospheric pressure with a vented condensate receiver, or under a partial vacuum by using a vacuum pump.

Condensate pumping systems with vented receivers are common for small, low pressure systems in which the condensate returns at a temperature near or below 100°C. When the condensate returns at a higher temperature, the vented system allows the steam to flash to atmosphere. Heating units on a vented system cannot discharge condensate at an internal pressure below atmospheric pressure. The combination of throttling the supply steam valve and the condensing of steam in the heating units can create a partial vacuum that would flood the unit.

Vacuum pumping of the condensate is used on many larger steam heating systems. There are two main advantages.

- The control of steam pressure below atmospheric pressure in heating units, allowing controlled operating temperatures below 100°C.
- Lower temperature in the condensate pipes resulting in lower heat losses.

Process Systems

There are five basic types of distribution systems used for process piping. They are classified as high pressure, medium pressure, low pressure, pressurized return, and vacuum systems.

The basic concepts are similar for high, medium and low pressure steam systems. Steam systems are more energy efficient at lower pressures due to lower heat losses, and should be operated at the minimum pressures required for operation of the end use equipment. However, when long piping runs are required, higher pressures are necessary to overcome friction losses and provide the proper pressures at the terminal equipment. Low pressure systems, on the other hand, require the use of larger pipe sizes and may require greater initial capital investment.

High Pressure Systems

High pressure systems, 690 to 2400 kPa(gauge) are used to provide steam for applications such as dryers, presses, molding dies, power drives, distribution in large commercial and institutional buildings or complexes, commercial and institutional cooking equipment, washers and sterilizers. Steam pressures greater than 2400 kPa(gauge) are found mainly in heavy industrial applications and are not addressed in detail in this module.

Medium Pressure Systems

Medium pressure systems, 103 to 690 kPa(gauge) are used in similar applications to high pressure systems.

Low Pressure Systems

Low pressure systems, 0 to 103 kPa(gauge) are used to supply steam for commercial cooking equipment, dishwashers, heating systems for commercial, institutional and small industrial buildings, domestic hot water heating, snow-melting heat exchangers and absorption cooling units.

Pressurized Return Systems

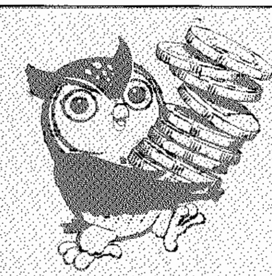
A pressurized return system is similar to the two-pipe trapped return system, except that the condensate is returned to a condensate receiver tank and then pumped directly to the boiler plant. Operation of the pump is controlled by a device which senses the liquid level in the condensate tank. A check valve, installed between the boiler and the condensate pump, prevents water from reentering the receiver tank. The tank must be vented to release the air which is returned from the system.

Vacuum Systems

The two-pipe vacuum steam system is also similar to the two-pipe trapped return system, except the condensate pump is replaced by a combination vacuum and condensate pump. The vacuum section of the pump withdraws the air and condensate from the system, separates the air from the condensate, and expels the air to atmosphere. The condensate pump returns the condensate to the boiler.

A vacuum steam system can operate at temperatures below 100°C at the process equipment.

ENERGY MANAGEMENT OPPORTUNITIES



Energy Management Opportunities is the term that represents all the ways that energy can be used wisely to save money. A number of Energy Management Opportunities, subdivided into Housekeeping, Low Cost, and Retrofit categories are outlined in this section, with worked examples, or written text, to illustrate the potential energy savings. This is not a complete listing of the opportunities available for steam and condensate systems. 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.

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. Steam trap maintenance program and procedures.
2. Check and maintain proper equipment operation.
3. Check and correct steam and condensate leaks.
4. Train operating personnel.
5. Maintain chemical treatment program.
6. Check control settings.
7. Shut down equipment when not required.
8. Shut down steam and condensate branch system when not required.

Housekeeping Worked Examples

1. Steam Trap Maintenance Program and Procedures

A malfunctioning steam trap can be a major source of energy loss. Often, one dollar spent on upgrading traps can return more than three dollars in energy savings. Many facilities can save 10 to 20 per cent of fuel costs by having a formal, active steam trap program.

The first step in the program is to select a steam trap energy coordinator. The coordinator should understand steam trap types, applications, causes of failures, and testing procedures. Steam trap manufacturers often provide schools or seminars on steam trap applications which the coordinator should be encouraged to attend.

The second step is to establish trap standards for all replacements and new installations. A minimum number of trap types, depending upon complexity of systems, should be selected according to the following guidelines.

- Steam loss over the life of the trap: Stainless steel fitted traps are less susceptible to erosion and corrosion than carbon steel traps.
- Trap life: Traps which have valve systems are susceptible to damage by scale and rust particles.
- Trap reliability or how well the trap responds when condensate loads or pressure changes occur.
- Physical size and weight of the trap.
- Ability to vent noncondensibles, such as air, that can cause corrosion problems.
- Trap cost.

The third step is to determine the effectiveness of the program by choosing a sample area of up to 100 traps that are not receiving routine steam trap maintenance. Establish the steam flow to this area and determine the total steam consumption over a period of one month under average plant conditions. Inspect each trap and record the percentage of cold traps, those that are blowing steam and those that are working properly. Checklist 8-2 for steam trap surveys is included.

Change all traps, good as well as bad, to the newly established trap standards. Again, measure the steam consumption over an equal period of time and calculate the average saving per steam trap. It is not uncommon for the average savings to be at least 4 to 5 kg/h per steam trap for systems where pressure is less than 3450 kPa(gauge).

The fifth step consists of establishing a routine checking procedure and maintaining proper records on each trap including identification, condition, operating pressure, and type of service. A minimum six month frequency check is recommended.

After the first year, a normal trap failure rate of less than 10 per cent can be expected.

It must be noted that prior to automatically replacing a defective steam trap with a unit of the same size and construction the application should be checked to ensure the sizing and trap selection was initially correct.

2. Check and Maintain Proper Equipment Operation

Check the complete steam and condensate system for proper operation of equipment. One important item often overlooked in a steam or condensate system is the pipeline strainer. It is necessary for the removal of dirt, rust, scale and other impurities, and proper application and maintenance is essential. The strainer helps to prevent scale and rust buildup on heat exchange surfaces by removing the foreign particles before they reach the steam heated equipment. This scale reduces heat exchange efficiency and increases energy losses.

Other items such as air vents, pressure relief valves, condensate receivers (pumps, controls, float valves), steam and condensate flow metering equipment, pressure reducing stations, expansion compensators, pipe supports, and vacuum pumps should also receive continuous attention to ensure efficient operation.

3. Check and Correct Steam and Condensate Leaks

The complete distribution system should be checked periodically for any visible steam or condensate leaks. On insulated lines, these are often identified by wet or soggy insulation. The plume length can be established once the insulation is removed.

As an example, consider a steam leak in a 790 kPa(absolute) steam system with a plume length of 500 mm. The system operates 8760 hours per year. The cost of steam is $22/1000 kg.

From Table 7 it is established that the steam loss under these conditions is 6 kg/h.

Annual steam loss from this leak is calculated as follows.

$$\text{Annual steam loss} = \text{loss/h} \times \text{h/yr}$$

$$= 6 \times 8760$$

$$= 52\,560 \text{ kg/yr}$$

The cost of this lost energy can also be calculated.

$$\text{Annual dollar loss} = \text{Annual steam loss} \times \text{Unit cost of steam}$$

$$= 52\,560 \times \frac{\$22}{1000}$$

$$= \$1{,}156.32 \text{ per year}$$

This leak should be noted and repaired as part of the normal facility maintenance procedures. As can be seen from this example a small leak can account for a large dollar loss.

4. Train Operating Personnel

Operating and maintenance personnel should be trained in energy management practices. They must be trained to spot Energy Management Opportunities and respond immediately with appropriate action. If possible, use the same maintenance crews for uniformity in checking.

5. Maintain Chemical Treatment Program

Maintain a controlled chemical treatment program for steam and condensate systems to improve system cleanliness and performance.

6. Check Control Settings

Check control system set points periodically to ensure optimum operation is maintained. For example, automatic steam valves serving space heating equipment or process equipment often operate above the set point or wide open, because of a malfunctioning control system. This leads to unnecessary overheating situations. It is difficult to quantify these situations but they can amount to significant energy losses.

7. Shut Down Equipment When Not Required

Equipment which is not used over extended periods of time should be equipped with automatic control systems, or planned manual shutdown procedures should be implemented. This action not only saves energy, but prevents unnecessary system component wear.

8. Shut Down Steam and Condensate Branch Systems When Not Required

Steam and condensate distribution systems lose heat to the surroundings even if insulated. If the distribution system is shut off when not in use this heat loss does not take place and both energy and dollars are saved.

Consider a 30 metre long NPS 4 insulated steam header at 950 kPa(absolute). Information from the insulation supplier indicates that the heat loss was 40 Watt-hours per metre of length for this pipe.

If the system is not required for 2000 hours per year, the annual heat loss can be calculated.

Annual heat loss = Heat loss/metre/hour x Hours per year x Length

= 40 x 2000 x 30

= 2 400 000 Wh/yr

or 2400 KWh/yr

Using the conversion 1 Wh = 3.6 kJ the heat loss can be restated

2 400 000 Wh/yr = 2 400 000 x 3.6

= 8 640 000 kJ/yr

From table 1 the heat content of steam at 950 kPa(absolute) is 2774 kJ/kg. If the cost of steam is $22/1000 kg the value of the lost energy can be calculated.

$$\text{Annual dollar loss} = \frac{8\,640\,000}{2774} \times \frac{\$22}{1000}$$

$$= \$68.52\ /\text{yr}$$

The savings in this example are small, however if this occurrence is happening in numerous areas throughout a facility the cumulative savings can become significant. It should also be noted that this is only heat loss from the pipe and does not include other possible sources of heat loss such as leaks, leaking traps, condensate being discharged to drain or other such items.

As well as the energy savings, reduced maintenance costs will result from shutting down branch mains and distribution piping when not in use.

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. Recover condensate.
2. Overhaul pressure reducing stations.
3. Operate equipment in efficient operating range.
4. Insulate uninsulated flanges and fittings.
5. Remove unused steam and condensate piping.
6. Reduce system pressure where possible.
7. Repipe system or relocate equipment to shorten pipe lengths.
8. Optimize location of control sensors.
9. Insulate uninsulated piping.
10. Add metering, measuring and monitoring equipment.
11. Replace or repair leaking traps.
12. Repair, replace or add air vents.
13. Repair damaged insulation.

Low Cost Worked Examples

1. Condensate Recovery

Encourage condensate recovery within the steam and condensate systems. Reduce the direct use of steam where possible by using a heat exchanger so that condensate is returned to the boiler plant. In areas where condensate from steam traps or other process equipment is being discharged to sewer and can be reclaimed, pipe the condensate into the nearest return system or install a separate pumping system. Condensate flowing directly to sewer is a loss of energy dollars and increases the cost of the chemical treatment system at the boiler plant. If the condensate is contaminated, investigate means of reclaiming the heat energy. In all cases where condensate is being discharged to atmospheric pressure, investigate the possible uses of the flash steam being generated. Flash steam contains valuable energy which should be recovered.

During a walk through audit of a facility, it was determined that a steam trap on a piece of process equipment was discharging directly to sewer. The average flow was measured to be 50 kg/h at 80°C. Make-up water was introduced to the feedwater tank at 5°C. The operating steam pressure was 860 kPa(gauge). The annual energy saving which could be achieved by returning the condensate to the boiler plant is determined with the aid of Worksheet No. 8-3.

The annual energy savings is equivalent to $1,481 and the capital investment to install the new piping is estimated to be $3,000.

$$\text{Simple Payback} = \frac{\$3{,}000}{\$1{,}481}$$

$$= 2 \text{ years.}$$

In the event that the condensate in this example was contaminated and could not be used as boiler feedwater it could still be used as heat source for space or process water heating, or in some instances, as a heat source for direct heating.

2. Overhaul Pressure Reducing Stations

Check all pressure reducing stations to ensure proper operation and maintenance. Rust, scale and other foreign particles found within a steam distribution system cause erosion of valve parts. When this occurs, the valve no longer operates under its original design tolerances. This could result in unwanted pressure fluctuations and require higher operating pressures.

If pressure reducing stations are not operating correctly and therefore allowing steam pressure at the terminal equipment to be lower than required for process operations, the system pressure may be raised. This results in higher piping operating temperatures with the associated greater heat loss and wasted dollars.

3. Operate Equipment In Efficient Operating Range

Improve equipment efficiency by operating condensate receivers, vacuum pumps, boiler feed units, heating units or process equipment at, or near capacity instead of running all units at reduced capacity. Part load performance is not as efficient as full load.

4. Insulate Uninsulated Flanges and Fittings

As indicated in Fundamentals, a pair of uninsulated flanges are equivalent to 610 mm of bare pipe. All flanges and fittings should be insulated to reduce heat loss and save energy.

During a walk through audit of a process facility it was noted that 40 flanges on an NPS 4 saturated steam distribution main operating at 700.8 kPa(absolute) were uninsulated. In this facility the steam main was in operation 8760 hours per year and the cost of steam was $22/1000 kg.

The equivalent length of bare pipe caused by one pair of uninsulated flanges is 610 mm.

Equivalent length of 40 uninsulated flanges $= \frac{40}{2} \times 610$

$= 12\ 200$ mm

or 12.2 m

Temperature of 700.8 kPa(absolute) steam 165°C (Table 1).

Hourly heat loss from NPS 4 bare piping at 165°C 790 Wh/(m·h) (Table 6)

Hourly heat loss from 12.2 m $= 790 \times 12.2$

$= 9638$ Wh/h

Annual heat loss from flanges $= 9638 \times 8760$

$= 84.43 \times 10^6$ Wh/yr

or $84.43 \times 10^6 \times 3.6$

$= 303.94 \times 10^6$ kJ/yr

Enthalpy of saturated steam at 700.8 kPa(absolute) 2762 kJ/kg (Table 1)

Equivalent steam loss per year $= \frac{303.94 \times 10^6}{2762}$

$= 110\ 043$ kg/yr

Annual cost of lost steam $= 110\ 043 \times \frac{\$22}{1000}$

= $2,421

Estimated cost to insulate the 40 flanges = $3,600

Simple payback $= \frac{\$3,600}{\$2,421}$

= 1.49 years

5. Remove Unused Steam and Condensate Piping

Steam and condensate piping which has become redundant because of process, equipment or facility changes should be removed. This piping is a source of heat losses. The removal of the redundant piping will also free up areas in the facility which could be used for other required services.

6. Reduce System Pressure Where Possible

Where saturated steam is the heating medium, the higher the system pressure the greater the heat loss from the piping system. Reducing the system pressure to the lowest possible level will reduce energy losses.

7. Repipe Systems or Relocate Equipment to Shorten Pipe Lengths

The shorter the pipe route from the generation source to the point of use, the lower the heat loss. It may be possible to either reroute piping or relocate equipment so that energy loss is reduced.

8. Optimize Location of Control Sensors

Assess the location of control components such as pressure, outdoor air and supply air sensors, and add or relocate components to improve system operation. Improper location of control point sensors often leads to incorrect settings of damper or valve operators, resulting in wasted energy.

9. Insulate Uninsulated Piping

Uninsulated piping is a major source of lost heat energy. Any uninsulated piping should be insulated to the recommended insulation thickness. See Process Insulation, Module 1 for additional details on insulation.

During a walk through audit of a facility it was noted that a NPS 2 saturated steam main operating at 600 kPa(absolute) was uninsulated for 60 metres of its length. Obviously heat energy was being wasted. This pipeline was in operation 8400 hours per year and the cost of steam was $22/1000 kg.

Temperature of 600 kPa(absolute) steam — 158.84°C (Table 1)

Heat loss per hour per metre of length for NPS 2 pipe at 158.84°C — 490 Wh/(m·h) (Table 6)

Annual heat loss for uninsulated piping $= 490 \times 60 \times 8400$

$= 246.96 \times 10^6$ Wh/yr.

From Module 1 it is found that if this pipe was insulated with 51 mm of glass fiber insulation, the hourly heat loss per metre would drop to 24 Wh/(m·h)

With insulation, annual heat loss $= 24 \times 60 \times 8400$

$= 12.096 \times 10^6$ Wh/yr

Reduction in heat loss with insulation $= (246.96 \times 10^6) - (12.096 \times 10^6)$

$= 234.864 \times 10^6$ Wh/yr

or 845.51×10^6 kJ/yr

Enthalpy of saturated steam at 600 kPa(absolute) — 2755.5 kJ/kg (Table 1)

$$\text{Equivalent steam loss} = \frac{845.51 \times 10^6}{2755.5}$$

$= 306\ 844$ kg/yr

Equivalent cost of steam loss $= 306\ 844 \times \frac{\$22}{1000}$

$= \$6{,}751/yr$

Estimated cost to insulate the pipeline is $4,200

Simple payback $= \frac{\$4{,}200}{\$6{,}751}$

$= 0.62$ years (7 months)

10. Add Measuring, Metering and Monitoring Equipment

Without measuring, metering and monitoring equipment it is almost impossible to establish if energy is being used wisely or is being wasted. Information on measuring, metering and monitoring may be found in Measuring, Metering and Monitoring, Module 15.

11. Replace or Repair Leaking Traps

During a steam trap survey in a commercial building it was noted that a steam trap with a 3.17 mm orifice on a 205 kPa(absolute) heating steam system did not appear to be operating correctly. Further investigation indicated that the trap was stuck in the open position allowing steam to flow into the condensate return system.

From Table 5 it was established that this condition would allow the trap to pass 6.2 kg of steam per hour. The heating system in this facility was used 3600 hours per year and the cost of steam was estimated to be $22/1000 kg.

Steam from leaking trap $= 6.2\ kg/h \times 3600\ h/yr$

$= 22\ 320\ kg/yr$

Cost of lost energy $= 22\ 320 \times \frac{\$22}{1000}$

$= \$491$ per year based on the 3600 hour heating season

Replacement cost of a new trap including labour is $90

Simple payback $= \frac{\$90}{\$491}$

$= 0.18$ years (2 months)

If the system pressure was higher, or the orifice larger, the quantity of lost steam would greatly increase as would the cost of the lost energy.

12. Repair, Replace or Add Air Vents

As indicated in the Fundamentals Section of this module small quantities of air or noncondensible gases in a steam system can reduce the heat transfer efficiency at the terminal equipment. Regardless of how the air or noncondensible gases enter the system (with the boiler feed water or through system leaks) it should be removed to improve system efficiency and energy use.

Consider a system operating at 138 kPa(gauge) [239.325 kPa(absolute)] using saturated steam containing 10 per cent air. Instead of the temperature being 126°C which is the saturation temperature at the system operating pressure, the temperature is only 122°C, a reduction of 4°C. If the temperature of 126°C is critical for the end use application it will be necessary to increase the overall system pressure to approximately 280 kPa(absolute) (131°C) to overcome this temperature reduction. This higher generation pressure will result in greater heat loss from the distribution system and therefore wasted dollars.

Removal of this air at system high points or before the terminal equipment by the use of thermostatic or float and thermostatic air vents will allow the system pressure to be dropped, saving both energy and dollars.

13. Repair Damaged Insulation

The insulating quality of damaged or water soaked insulation is greatly reduced, and this in turn increases the heat loss from the damaged or soaked area. Any damaged insulation should be replaced as soon as possible after the damage occurs and should be protected against further damage.

Consider an NPS 6 steam distribution main in use 8760 hours per year carrying saturated steam at 446 kPa(absolute). An investigation of the steam main indicated that there were 9 areas of damaged insulation providing an equivalent bare length of pipe of 4 metres.

From Table 6 it is established that the hourly heat loss per metre is 980 Wh/(m·h)

Annual heat loss = 980 x 4 x 8760

= 34.3×10^6 Wh/yr

or 123.6×10^6 kJ/yr

Enthalpy of saturated steam at 446 kPa(absolute) 2742 kJ/kg (Table 1)

$$\text{Annual steam loss} = \frac{123.6 \times 10^6}{2742}$$

= 45 077 kg/yr

Based on a cost of steam of $22/1000 kg the cost of the steam loss is calculated.

$$\text{Annual cost} = 45\ 077 \times \frac{\$22}{1000}$$

= $992/yr

The estimated cost to repair the insulation in the 9 damaged areas is $600.

$$\text{Simple payback} = \frac{\$600}{\$992}$$

= 0.605 years (7 months)

Retrofit Opportunities

Implemented retrofit opportunities are energy management actions that are done once and for which the cost is significant.

Many of the opportunities in this category will require detailed analysis by specialists, and all of these 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. Upgrade insulation on piping to recommended insulation thickness.
2. Institute a steam trap replacement program.
3. Optimize pipe sizes.
4. Recover flash steam.
5. Eliminate steam use where possible.
6. Stage the depressurization of condensate.
7. Recover heat from condensate.
8. Meter all steam and condensate flows.
9. Consider cogeneration of heat and electrical power.

Retrofit Worked Examples

1. Upgrade Insulation

During a walk through audit of a facility it was noted that a NPS 6 steam header carrying saturated steam at 450 kPa(absolute) was insulated over its entire length of 100 m with 25 mm of glass fiber insulation. The system operated 8760 hours per year.

From Module 1 it is established that the recommended insulation thickness for piping having the same size and temperature is 76 mm.

Manufacturer's data for glass fiber insulation was reviewed and it was found that the hourly Wh/(m·h) heat loss under these conditions with 25 mm of insulation was 136 Wh/(m·h) and with 76 mm of insulation was 57 Wh/(m·h). Adding an additional 51 mm of glass fiber insulation would therefore reduce the hourly heat loss per metre by 79 Wh/(m·h) (136-57).

$$\text{Annual reduction in heat loss} = \frac{79\text{Wh}}{\text{m·h}} \times 300 \text{ m} \times \frac{8760 \text{ h}}{\text{yr}}$$

$$= 207.612 \times 10^6 \text{ Wh/yr}$$

$$\text{or } 747.4 \times 10^6 \text{ kJ/yr}$$

Enthalpy of 450 kPa(absolute) steam   2742.9 kJ/kg (Table 1)

$$\text{Steam quantity equivalent of heat loss} = \frac{747.4 \times 10^6}{2742.9}$$

$$= 272\ 485 \text{ kg/yr}$$

The cost of steam in the facility was estimated to be $22/1000 kg.

$$\text{Dollar loss per year} = 272\ 485 \times \frac{\$22}{1000}$$

$$= \$5{,}995/\text{yr.}$$

Estimated cost to supply and install the additional 51 mm of insulation on the piping is $5,000.

$$\text{Simple payback} = \frac{\$5{,}000}{\$5{,}995}$$

$$= 0.83 \text{ years (10 months)}$$

2. Institute A Steam Trap Replacement Program

A steam distribution system operating at 860 kPa(gauge) contains a total of 300 steam traps. Following the steam trap maintenance program as discussed in Housekeeping Worked Example 1, a section of the distribution system containing 50 traps was selected as the test sample. Steam measuring equipment was installed for a 1 month period and total steam consumption was measured at 3.4 x 10^6 kg. After the development of a new steam trap standard, an exchange program was carried out and the steam consumption was recorded over a 1 month period. The total consumption was measured at 3.2 x 10^6 kg. The average steam trap loss per hour projected over the entire facility is estimated by the following equation:

$$W = \frac{(W_a - W_b) \times N_t}{N \times h}$$

Where, W = Average steam loss from all leaky traps in plant (kg/h)

W_a = Measured steam consumption before test (kg/month)

W_b = Measured steam consumption after test (kg/month)

N = Number of steam traps in test

N_t = Total number of traps in the plant

h = Number of hours in test period

Substituting into the equation the average steam trap loss for the total facility can be calculated.

$$W = \frac{[(3.4 \times 10^6) - (3.2 \times 10^6)] \times 300}{50 \times 720}$$

$$= 1667 \text{ kg/h}$$

If this facility operated 8760 hours per year the total annual steam loss is calculated as follows:

Annual steam loss = Steam loss per hour x Operating hours per year

= 1667 x 8760

= 14.6×10^6 kg/yr

With the cost of steam at $22/1000 kg the value of the steam loss can be calculated.

$$\text{Value of steam loss} = (14.6 \times 10^6) \times \frac{\$22}{1000}$$

= $321,200

The estimated cost to replace all 300 traps in the facility with the new standard trap selected as the plant standard is $60,000 and the cost of the steam metering equipment is $5,000, for a total expenditure of $65,000.

$$\text{Simple payback} = \frac{\$65{,}000}{\$321{,}200}$$

= 0.202 years (2.5 months)

The savings are a function of the number and condition of the steam traps in any facility, however the above calculations are representative for a 300 trap system.

3. Optimize Pipe Sizes

Optimize all steam and condensate piping sizes and length of runs. Oversized piping or excessive lengths mean greater surface areas than required and greater energy losses.

4. Recover Flash Steam

Determine the potential for flash steam recovery by first assessing the amount of flash steam available. To accomplish this, it is necessary to remember the following points.

- Establish if the flash steam can be utilized, and at what minimum pressure. Flash steam recovered from systems which operate year round should be used on systems which also operate year round. This helps to obtain maximum utilization of the flash steam being produced.
- Flash steam recovery for systems which are initially below 690 kPa(gauge) is not viable unless constant maximum loading is encountered.
- Where steam traps do not discharge condensate as it is formed, condensate is cooled and flash steam potential is reduced. A float or mechanical type of trap drains condensate quickly, and is considered to have greater potential for flash steam recovery than a thermostatic type which allows some waterlogging of heating surfaces and consequent condensate cooling.

A plant uses steam at 1000 kPa(gauge) and condenses 1000 kg/h to a condensate receiver vented to atmosphere. A flash steam recovery system is installed which will use the flash steam to heat process water. The flash steam is used at 70 kPa(gauge) on a year round basis. Cost of steam is $22/1000 kg. The annual energy savings which can be achieved by the installation of the flash steam recovery system is calculated using Worksheet 8-4.

The results show an annual saving of $24,200 and the simple payback on the capital investment of $10,000 is 0.41 years, or less than five months.

5. Eliminate Steam Use Where Possible

In some facilities it may be possible to eliminate the use of steam in certain operations and replace it with a different heat source such as electricity, hot water, or directly fired natural gas.

This option should be investigated.

Consider the following points.

- In steam generation only approximately 80 per cent of the heat available in the fuel is transferred to the steam. This figure is a function of the boiler type, operating conditions, fuel being used, boiler load and other factors.
- Direct fired heating unit such as natural gas fired space heaters operate at 100 per cent efficiency.
- Electric resistance heating operates at 100 per cent efficiency.
- Hot water distribution systems which normally operate at lower temperature than steam system lose less heat to the surroundings.

Investigations of this type should be carried out by engineers or specialists fully knowledgeable in this area.

6. Stage the Depressurization of Condensate

Where multipressure steam systems are employed, use the flash steam recovered from the higher pressure system in the next lowest pressure system. For example, in a building using 100 kPa(gauge), 500 kPa (gauge) and 1000 kPa(gauge) steam pressures, recover the flash steam from the 1000 kPa(gauge) system and use it in the 500 kPa(gauge) system. Similarly, recover the flash steam from the 500 kPa(gauge) system for use in the 100 kPa(gauge) system.

7. Recover Heat from Condensate

In areas where hot condensate is dumped to sewer, such as in boiler blowdown or a plant heating process application, heat recovery equipment should be installed. For example, where a flash tank has been installed on a boiler blowdown system, the condensate which discharges to sewer still contains valuable heat energy which could be used to heat cold water makeup to the boiler, or used in some other heating application.

The condensate discharge from a flash tank on a boiler blowdown system is measured at 50 kg/h and 90°C. The boiler plant pressure is 100 kPa(gauge). A water to water heat exchanger is installed to recover the available heat of the waste condensate before it goes to sewer. The heat exchanger has a 70 per cent efficiency and the condensate temperature is lowered from 90°C to 40°C as it passes through the heat exchanger. The cost of producing steam is $22/1000 kg and the raw makeup water is 10°C. The energy savings which can be achieved from the heat recovery system is calculated with the aid of Worksheet 8-5.

The results show an annual saving of $636 and the simple payback on the capital investment of $2,000 is 3.15 years.

8. Meter Steam and Condensate Flows

The metering of steam and condensate does not, in itself, conserve energy or reduce steam consumption. However, it does encourage effective energy management. Knowledge of the quantity of steam consumed and condensate returned allows the following values to be established.

- Quantity of energy used, and specifically where it is being used.
- Calculations of potential energy savings for proposed Energy Management Opportunities.
- Verification of energy savings for implemented Energy Management Opportunities.

Refer to Measuring, Metering & Monitoring, Module 15, for additional details.

9. Consider Cogeneration of Heat and Electrical Power

Where feasible, use cogeneration for the simultaneous production of heat energy and electrical or mechanical power.

The use of steam below the pressure at which it is generated requires a pressure reducing device between the two pressures. The device is normally a pressure reducing valve (PRV). When the low pressure demand is steady, it may be feasible to use a back pressure turbine in parallel with the PRV. The turbine will accept the high pressure steam at the inlet, discharge lower pressure steam and generate shaft power which may be used to drive a mechanical machine or an electrical generating device.

The cost saving advantage of the combined system is that the incremental increase in flow of high pressure steam usually costs less than purchasing the amount of power generated. Comparatively, a system of cogeneration can supply both the process steam load and electric energy with a higher efficiency use of the fuel resource than a system supplying only steam or electric energy.

The necessary calculations, the use of enthalpy charts, and the detailed information on equipment required for an evaluation are not covered by this module. Evaluation of a potential cogeneration application should be conducted by experienced personnel.

APPENDICES

Glossary

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

Atmospheric Pressure — Pressure of the earth's atmosphere at sea level. At sea level and 20°C this is 101.325 kPa.

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 being used or wasted.

Carbon Dioxide Gas (CO_2) — A heavy colorless gas. Dissolves in water to form carbonic acid.

Corrosive — Having a rusting or chemically destructive effect on metals (occasionally on other materials).

Density — The ratio of the mass of a specimen of a substance to the volume of the specimen.

Dry Saturated Steam — Steam containing no water in suspension.

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 — Potential energy saving 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 — Potential energy saving improvements that are done once and for which the cost is not considered great.

Energy Management Opportunities, retrofit — Potential energy saving improvements that are done once and for which the cost is considered significant.

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 energy in the form of steam, exhaust gases, discharge water or even refuse.

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

Erosive — Property of a substance that causes another substance to be diminished or destroyed by increments

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 of Saturated Liquid — The amount of heat required to raise the temperature of the kilogram of a liquid from O°C to the boiling point at any specific pressure (MJ/kg).

Latent Heat of Vaporization of water — The amount of heat required to change a kilogram of boiling water to one kilogram of steam at a constant pressure (MJ/kg).

Noncondensible Gas — A gas that will not condense (change from the vapor state to the liquid state) at the given conditions.

Psychrometric Properties — Properties of an air-water-vapor mixture that can be determined by the use of a psychrometric chart which illustrates methods of calculating relative humidity, specific (absolute) humidity, sensible heat, latent heat, total heat, and other properties.

Saturated Liquid — The liquid present in a mixture of vapor and liquid in a state of equilibrium.

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.

Specific Enthalphy — Enthalpy per unit mass of a substance.

SI Systems — The basic system of measurement adopted in Canada. The name, Système international d'unités (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.

Specific Volume — The ratio of the volume of a substance to the mass of the substance; the reciprocal of density.

Steam Quality — The measure of steam dryness expressed as the ratio of the mass of vapor to the total mass per unit volume of the mixture.

Steam Tracing — A method of protecting a fluid being piped from freezing. This is accomplished by installing a small steam pipe in contact with the pipe carrying the fluid being protected.

Superheated Vapor — Vapor at a temperature which is higher than the saturation temperature at a given pressure.

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

Water Hammer — Water hammer is a mechanical shock caused by pressure waves travelling in piping and meeting with obstructions. An example would be "slugs" of condensate hurled like a "battering ram" through steam or condensate systems and striking items such as valves or fittings.

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (TEMPERATURE)

TABLE 1

Temperature °C t	K T	Press. kPa p	Volume, m³/kg Water v_f	Evap. v_{fg}	Steam v_g	Enthalpy, kJ/kg Water h_f	Evap. h_{fg}	Steam h_g	Entropy, kJ/kg K Water s_f	Evap. s_{fg}	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	8,6694
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	142,38	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	0,7604	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	2267,9	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	K T	Press. kPa p	Volume, m³/kg Water v_f	Evap. v_{fg}	Steam v_g	Enthalpy, kJ/kg Water h_f	Evap. h_{fg}	Steam h_g	Entropy, kJ/kg K Water s_f	Evap. s_{fg}	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	2596.9	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 p	Temp. °C t	Volume, m³/kg Water v_f	Volume Evap. v_{fg}	Volume Steam v_g	Enthalpy, kJ/kg Water h_f	Enthalpy Evap. h_{fg}	Enthalpy Steam h_g	Entropy, kJ/kg K Water s_f	Entropy Evap. s_{fg}	Entropy Steam s_g	Energy, kJ/kg Water u_f	Energy Steam 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, 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
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.	167.78	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.	175.38	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	2113.8
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	9.4779
	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	8.7680	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	8.0370
	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	7.9989	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	3.3169
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	1.0792	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	1.0792	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	1.0792	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	1.0792	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	1.0791	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	1.0790	1.3066	1.5274	1.7389	6.9805

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

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.	920.
1.0	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
(6.983)	s	10.5457	10.6091	10.6711	10.7317	10.7909	10.8488	10.9056	10.9612	11.0157
1.5	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
(13.04)	s	10.3585	10.4220	10.4840	10.5445	10.6037	10.6617	10.7184	10.7741	10.8286
2.0	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
(17.51)	s	10.2257	10.2892	10.3512	10.4118	10.4710	10.5289	10.5857	10.6413	10.6958
3.0	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
(24.10)	s	10.0386	10.1021	10.1641	10.2246	10.2838	10.3418	10.3985	10.4541	10.5087
4.0	v	73.046	75.354	77.662	79.970	92.278	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
(28.98)	s	9.9058	9.9693	10.0313	10.0918	10.1510	10.2090	10.2657	10.3214	10.3759
5.0	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
(32.90)	s	9.8028	9.8663	9.9283	9.9888	10.0480	10.1060	10.1627	10.2184	10.2729
6.0	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
(36.18)	s	9.7186	9.7821	9.8441	9.9047	9.9639	10.0218	10.0786	10.1342	10.1888
8.0	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
(41.53)	s	9.5858	9.6493	9.7113	9.7719	9.8311	9.8890	9.9458	10.0014	10.0560
10.0	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
(45.83)	s	9.4828	9.5463	9.6083	9.6689	9.7281	9.7860	9.8428	9.8984	9.9530
15.0	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
(54.00)	s	9.2956	9.3591	9.4211	9.4817	9.5409	9.5988	9.6556	9.7112	9.7658
20.0	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
(60.09)	s	9.1627	9.2262	9.2882	9.3488	9.4081	9.4660	9.5228	9.5784	9.6330
30.0	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
(69.12)	s	8.9754	9.0389	9.1010	9.1615	9.2208	9.2788	9.3355	9.3912	9.4458
40.0	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
(75.89)	s	8.8424	8.9060	8.9680	9.0286	9.0879	9.1459	9.2027	9.2583	9.3129
50.0	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
(81.35)	s	8.7392	8.8028	8.8649	8.9255	8.9848	9.0428	9.0996	9.1552	9.2098
60.0	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
(85.95)	s	8.6549	8.7185	8.7806	8.8412	8.9005	8.9585	9.0153	9.0710	9.1256
80.0	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
(93.51)	s	8.5217	8.5854	8.6475	8.7081	8.7675	8.8255	8.8823	8.9380	8.9926
100.0	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
(99.63)	s	8.4183	8.4820	8.5442	8.6049	8.6642	8.7223	8.7791	8.8348	8.8894
150.0	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
(111.4)	s	8.2301	8.2940	8.3562	8.4170	8.4764	8.5345	8.5914	8.6472	8.7018
200.0	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
(120.2)	s	8.0964	8.1603	8.2226	8.2835	8.3429	8.4011	8.4581	8.5139	8.5686
300.0	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
(133.5)	s	7.9072	7.9713	8.0338	8.0949	8.1545	8.2128	8.2698	8.3257	8.3809
400.0	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
(143.6)	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

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

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.
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	0.31659
	h	0.6	84.4	168.0	251.6	335.4	419.4	504.0	589.3	2798.2
(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	725.9
	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	1429.9	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

Temperature, t, °C

Press. p, kPa (t_s)		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

	540.	560.	580.	600.	625.	650.	700.	750.	800.	Press. p, kPa
v	0.7481	0.7667	0.7853	0.8039	0.8272	0.8504	0.8968	0.9432	0.9896	500.0
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	
v	0.6230	0.6386	0.6541	0.6696	0.6890	0.7084	0.7471	0.7858	0.8245	600.0
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	
v	0.4666	0.4783	0.4900	0.5017	0.5163	0.5309	0.5600	0.5891	0.6181	800.0
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	
v	0.3728	0.3822	0.3916	0.4010	0.4127	0.4244	0.4477	0.4710	0.4943	1000.0
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	
v	0.2477	0.2540	0.2604	0.2667	0.2745	0.2824	0.2980	0.3136	0.3292	1500.0
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	
v	0.1852	0.1900	0.1947	0.1995	0.2054	0.2114	0.2232	0.2349	0.2467	2000.0
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	
v	0.1226	0.1259	0.1291	0.1323	0.1364	0.1404	0.1483	0.1562	0.1641	3000.0
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	
v	0.09135	0.09384	0.09631	0.09876	0.1018	0.1049	0.1109	0.1169	0.1229	4000.0
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	
v	0.07259	0.07461	0.07662	0.07862	0.08109	0.08356	0.08845	0.09329	0.09809	5000.0
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	
v	0.06008	0.06179	0.06349	0.06518	0.06728	0.06936	0.07348	0.07755	0.08159	6000.0
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	
v	0.04443	0.04577	0.04709	0.04839	0.05001	0.05161	0.05477	0.05788	0.06096	8000.0
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	
v	0.03504	0.03615	0.03724	0.03832	0.03965	0.04096	0.04355	0.04609	0.04858	10000.0
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	
v	0.02250	0.02331	0.02411	0.02488	0.02584	0.02677	0.02859	0.03036	0.03209	15000.0
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	
v	0.01621	0.01688	0.01753	0.01816	0.01893	0.01967	0.02111	0.02250	0.02385	20000.0
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	
v	0.009890	0.01043	0.01095	0.01144	0.01202	0.01258	0.01365	0.01465	0.01562	30000.0
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	
v	0.006735	0.007219	0.007667	0.008088	0.008584	0.009053	0.009930	0.01075	0.01152	40000.0
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	
v	0.004888	0.005328	0.005734	0.006111	0.006550	0.006960	0.007720	0.008420	0.009076	50000.0
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	
v	0.003755	0.004135	0.004496	0.004835	0.005229	0.005596	0.006269	0.006885	0.007460	60000.0
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	
v	0.002641	0.002886	0.003132	0.003379	0.003692	0.003974	0.004519	0.005017	0.005481	80000.0
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	
v	0.002168	0.002326	0.002493	0.002668	0.002891	0.003106	0.003536	0.003952	0.004341	100000.0
h	2538.6	2648.2	2754.5	2857.5	2985.8	3105.3	3324.4	3526.[illegible]	3714.3	
s	4.7719	4.9050	5.0311	5.1505	5.2954	5.4267	5.6579	5.8600	6.0397	

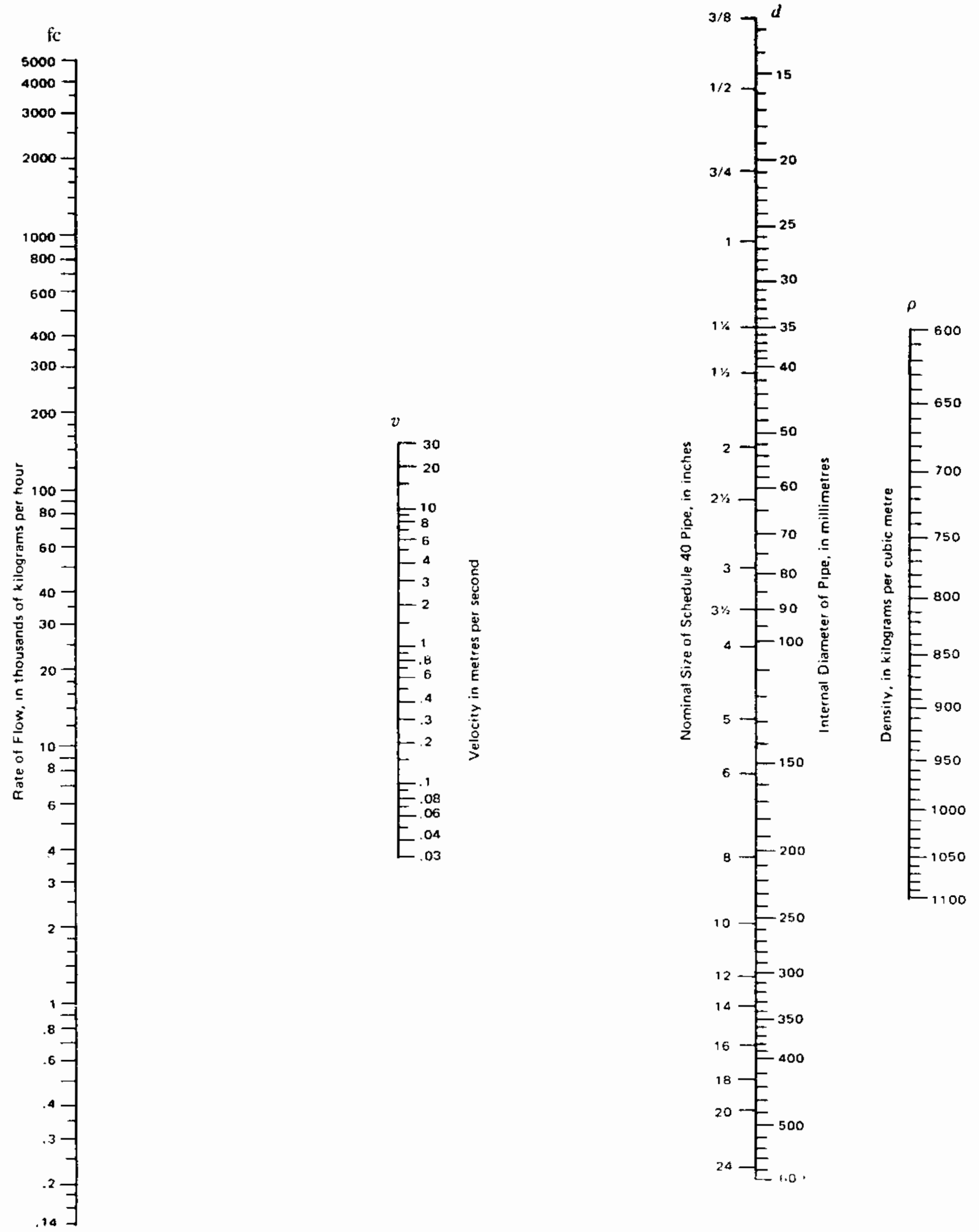
DIMENSIONAL DATA FOR PIPE SIZES UP TO NPS 12
TABLE 3

Pipe Size	O.D. In Inch.	40s & STD.	80s & E.H.
1/8	.405	068 2447	095 3145
1/4	.540	088 4248	119 5351
3/8	.675	091 5676	126 7388
1/2	.840	109 8510	147 1 088
3/4	1.050	113 1 131	154 1 474
1	1.315	133 1 679	179 2 172
1 1/4	1.660	140 2 273	191 2 997
1 1/2	1.900	145 2 718	200 3 631
2	2.375	154 3 653	218 5 022
2 1/2	2.875	203 5 793	276 7 661
3	3.500	216 7 576	300 10 25
3 1/2	4.000	226 9 109	318 12 51
4	4.500	237 10 79	337 14 98
4 1/2	5.000	247 12 53	355 17 61
5	5.563	258 14 62	375 20 78
6	6.625	780 18 97	432 28 57
7	7.625	301 23 57	500 38 05
8	8.625	322 28 55	500 43 39
9	9.625	342 33 90	500 48 72
10	10.750	365 40 48	500 54 74
11	11.750	375 45 55	500 60 07
12	12.750	375 49 56	500 65 42

Upper Figures
Wall Thickness
in Inches

Lower Figures
Weight Per Foot
in Pounds

VELOCITY OF LIQUIDS IN PIPE
TABLE 4

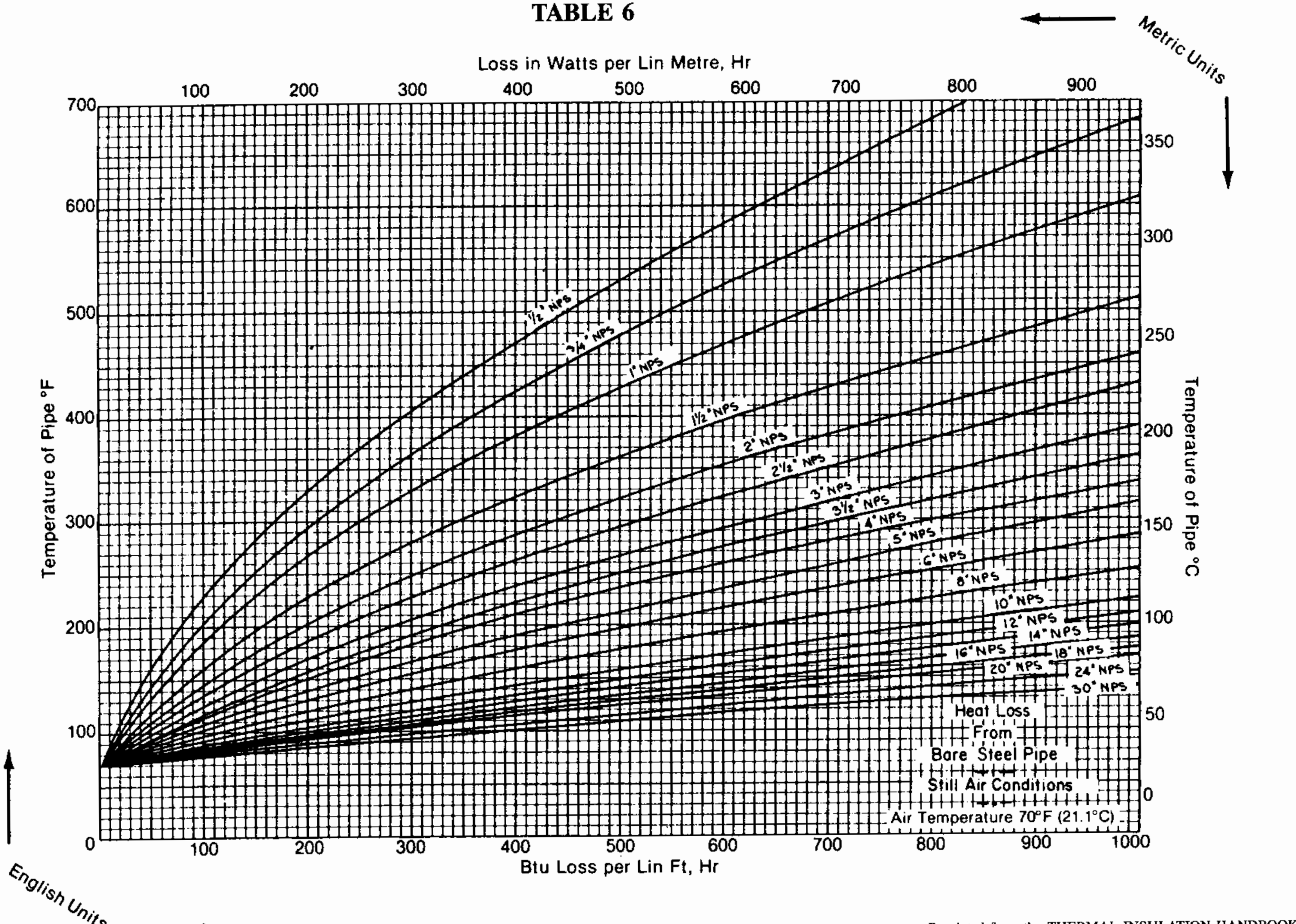


STEAM LOSS THROUGH ORIFICES DISCHARGING TO ATMOSPHERE
TABLE 5

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	300 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	4 05
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	36.2
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	81.5
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	145.0
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	226.0
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	326.0
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	443.0
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	579.0
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	733.0
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	905.0
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	1095.0
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	1303.0
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	1529.0
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	1774.0
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	2037.0
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	2317.0

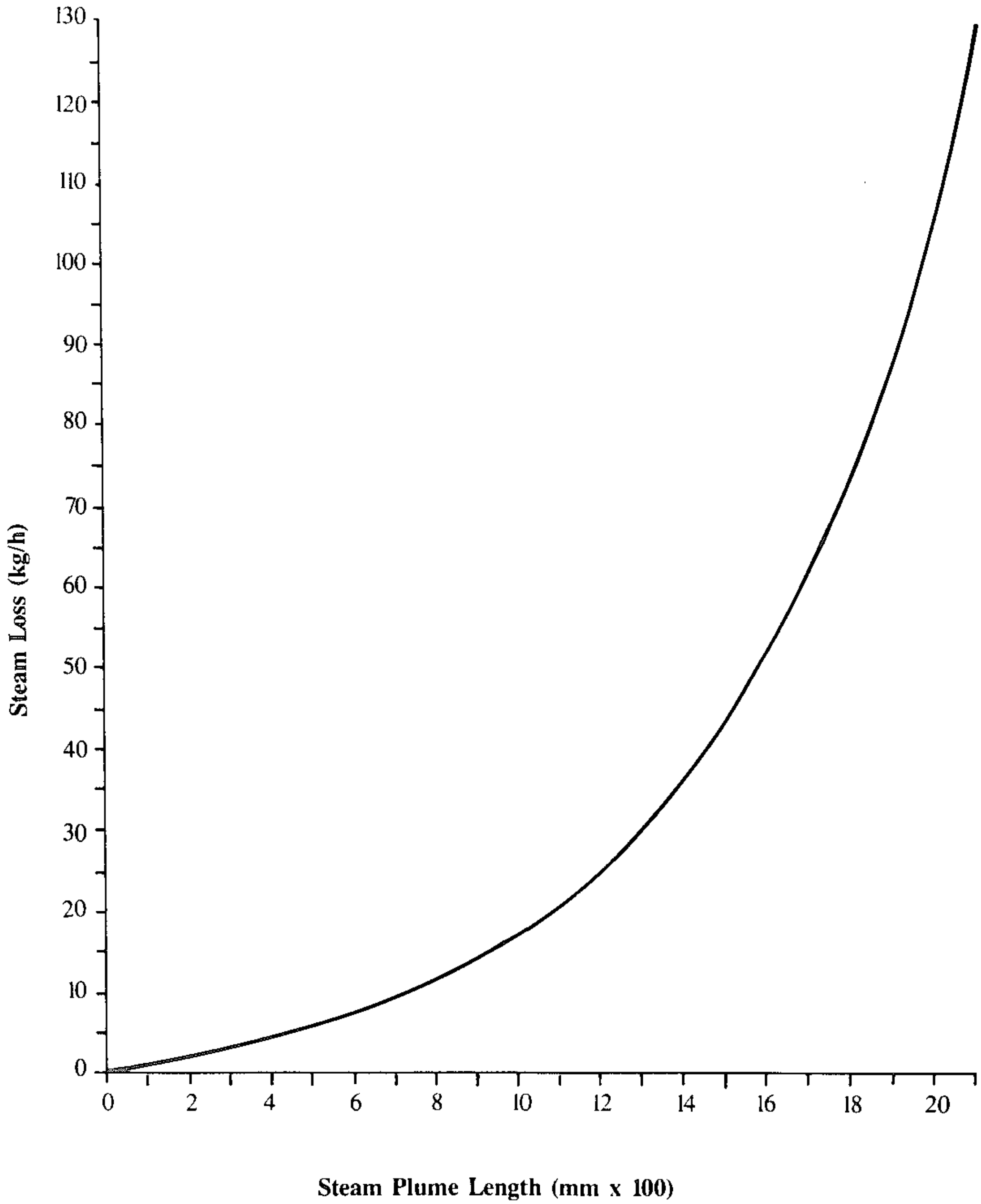
Metric — Imperial Conversion
1 kg/hr = 2.205 lb/hr
1 mm = 0.039 inch
1 kPa = 0.145 psi

HEAT LOSS FROM BARE STEEL PIPE
TABLE 6



Note:
Heat loss in SI units
shall be read as Wh/(m·h)

HOURLY STEAM LOSS FROM LEAKS AS A FUNCTION OF STEAM PLUME LENGTH
TABLE 7



STEAM TRAP SELECTION GUIDE
TABLE 8

APPLICATION	FIRST CHOICE	SECOND CHOICE
Air Heating Coils		
Low and Medium Pressure	Float-and-Thermostatic	....
High Pressure	Float-and-Thermostatic	....
Hot Water Heaters (Instantaneous)	Float-and-Thermostatic	....
Hot Water Heaters (Storage)	Float-and-Thermostatic	....
Shell-and-Tube Exchangers		
Small—High Pressure	Thermo-Matic Thermostatic	Float-and-Thermostatic
	Balanced-Pressure Thermostatic	....
Large—Low and Medium Pressure	Float-and-Thermostatic	....
Reboilers	Float-and-Thermostatic	....
	Thermo-Matic Thermostatic	....
Steam Humidifiers	Float-and-Thermostatic	Inverted Bucket
Steam-Jacketed Vessels		
High Pressure	Thermo-Matic Thermostatic	Float-and-Thermostatic
	Thermo-Dynamic	....
Low Pressure	Float-and-Thermostatic	Thermo-Dynamic
Steam Line Drip Traps		
0- 15 PSIG	Float-and-Thermostatic	....
16-125 PSIG	Thermo-Dynamic	Float-and-Thermostatic
126-600 PSIG	Thermo-Dynamic	Inverted Bucket
High Pressure—Superheat	Bimetallic	Thermo-Dynamic
Steam Pipe Coils (Air Heating)	Balanced Pressure Thermostatic	Thermo-Dynamic
	Thermo-Matic Thermostatic	....
Steam Radiators	Balanced-Pressure Thermostatic	Thermo-Dynamic
Steam Separators		
0- 15 PSIG	Float-and-Thermostatic	....
16-125 PSIG	Thermo-Dynamic	Float-and-Thermostatic
126-600 PSIG	Thermo-Dynamic	Inverted Bucket
Steam Tracer Lines	Thermo-Dynamic	Liquid Expansion
	Bimetallic	....
Storage Tank Coils	Liquid Expansion	Thermo-Dynamic
	Bimetallic	Thermo-Matic Thermostatic
Submerged Heating Coils		
High Pressure	Thermo-Matic Thermostatic	Inverted Bucket
	Thermo-Dynamic	Balanced-Pressure Thermostatic
Low and Medium Pressure	Float-and-Thermostatic	Balanced-Pressure Thermostatic
Unit Heaters	Float-and-Thermostatic	Balanced-Pressure Thermostatic
Sterilizers	Thermo-Dynamic	Balanced-Pressure Thermostatic
Autoclaves	Thermo-Dynamic	Inverted Bucket
Dryers	Thermo-Dynamic	Float-and-Thermostatic
Platen Presses	Thermo-Dynamic	Balanced-Pressure Thermostatic

NOTE: Unusual operating conditions, or severe corrosion may influence the choice of a steam trap for a particular application.

Metric — Imperial Conversion
1 kPa = 0.145 psi

COMMON CONVERSIONS

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

4138T/T33(-6)

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

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UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in²	A/in²	ampere/cm²	A/cm²	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	ft³	cubic metre	m³	0.02832
cubic foot	ft³	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/m²	10.764
footlambert	fL	candela/square metre	cd/m²	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

4138T/T33(-1)

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

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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.

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 8-1

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Steam pipe internal diameter ______________________ m

Steam flow (fs) ______________________ 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) $= \frac{fs \times v_g}{A \times 3600}$

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

= ______________________ 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.

Pipe Insulation

Worksheet 8-2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Steam pressure	____________	kPa(gauge)	(1)
Pipe size	____________		(2)
Heat loss from bare pipe (Table 6)	____________	Wh/(m·h)	(3)
Length of pipe	____________	m	(4)
Heat loss from insulated pipe (Insulation manufacturer's data)	____________	Wh/(m·h)	(5)
Total operating time	____________	h/yr	(6)
Latent heat of steam at pressure (1) (Table 1)	____________	kJ/kg	(7)
Cost of steam	____________	$/1000 kg	(8)

Energy loss from bare pipe

= (3) x (4) x (6) = x x = ____________ Wh/yr. (9)

Energy loss from insulated pipe

= (5) x (4) x (6) = x x = ____________ Wh/yr. (10)

Total energy savings = (9) − (10)

= −

= ________ Wh/yr. x 3.6 = ____________ kJ/yr. (11)

Total steam saved $= \frac{(11)}{(7)}$ = ________ = ____________ kg/yr (12)

Cost of energy saved $= \frac{(12) \times (8)}{1000}$

$= \frac{\quad \times \quad}{1000}$ = ____________ $/yr (13)

Capital investment required = ____________ $ (14)

Simple payback period $= \frac{(14)}{(13)}$ = ________ = ____________ years (15)

Condensate Recovery
Worksheet 8-3

Company: ______________		Date: ______________		
Location: ______________		By: ______________		
Measured condensate flow		______________	kg/h	(1)
Specific heat of condensate (use 4.14 at atmospheric pressure)		______________	kJ/(kg·°C)	(2)
Temperature of condensate		______________	°C	(3)
Temperature of makeup water		______________	°C	(4)
Total operating time		______________	h/yr	(5)
Steam pressure		______________	kPa(gauge)	(6)
Latent heat of steam at pressure (1) (Table 1)		______________	kJ/kg	(7)
Cost of steam		______________	$/1000 kg	(8)

Quantity of condensate to be recovered

= (1) x (2) x[(3) − (4)] x (5)

= x x [−] x = ______________ kJ/yr (9)

Total steam saved $= \frac{(9)}{(7)}$

= ______________ = ______________ kg/yr (10)

Cost of energy saved $= \frac{(10) \times (8)}{1000}$

$= \frac{\rule{4cm}{0.4pt}}{1000}$ = ______________ $/yr (11)

Capital investment = ______________ $ (12)

Simple payback period $= \frac{(12)}{(11)}$

= ______________ = ______________ years (13)

Flash Steam Recovery
Worksheet 8-4

Company: ______________		Date: ______________	
Location: ______________		By: ______________	
Steam pressure	______________	kPa(abs)	(1)
Pressure at which flash steam can be used	______________	kPa(abs)	(2)
Measured steam consumption	______________	kg/h	(3)
Total operating time	______________	h/yr	(4)
Enthalpy of condensate at pressure (1) (Table 1) (h_f)	______________	kJ/kg	(5)
Enthalpy of condensate at pressure (2) (Table 1) (h_f)	______________	kJ/kg	(6)
Latent heat of steam at pressure (2) (Table 1) (h_{fg})	______________	kJ/kg	(7)
Cost of steam	______________	\$/1000 kg	(8)

Total steam produced

$= (3) \times (4) = \quad\quad \times \quad\quad$ = ______________ kg/yr (9)

$\% \text{ flash steam} = \frac{(5) - (6)}{(7)} \times 100$

$= \frac{\quad - \quad}{\quad} \times 100$ = ______________ % (10)

Total flash steam available

$= \frac{(9) \times (10)}{100} = \frac{\quad \times \quad}{100}$ = ______________ kg/yr (11)

$\text{Cost of energy saved} = \frac{(11) \times (8)}{1000}$

$= \frac{\quad \times \quad}{1000}$ = ______________ \$/yr (12)

Capital investment required ______________ \$ (13)

$\text{Simple payback} = \frac{(13)}{(12)} =$ ______________ = ______________ years (14)

Condensate Heat Recovery

Worksheet 8-5

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Steam pressure	______________	kPa(gauge)	(1)
Flow of hot waste-water	______________	kg/h	(2)
Specific heat of condensate (Use 4.14 at atmospheric pressure)	______________	kJ/(kg·°C)	(3)
Temperature of condensate entering heat exchanger	______________	°C	(4)
Temperature of condensate leaving heat exchanger	______________	°C	(5)
Total operating time	______________	h/yr	(6)
Efficiency of heat exchanger	______________	%	(7)
Latent heat of steam at pressure (1) (Table1)	______________	kJ/kg	(8)
Cost of steam	______________	$/1000 kg	(9)

Quantity of waste heat recovered = (2) x (3) x [(4) − (5)] x (6) x $\frac{(7)}{100}$

= $\frac{\_\_\_\_ \text{ x } \_\_\_\_ \text{ x [} \_\_\_\_ - \_\_\_\_ \text{] x } \_\_\_\_ \text{ x } \_\_\_\_}{100}$

= ______________ kJ/yr (10)

Total steam saved year = $\frac{(10)}{(8)}$

= ______________ = ______________ kg/yr (11)

Cost of energy saved = $\frac{(11) \text{ x } (9)}{1000}$

= $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{1000}$ = ______________ $/yr (12)

Capital investment required ______________ $ (13)

Simple payback = $\frac{(13)}{(12)}$ = ______________ = ______________ years (14)

Steam Trap Survey
Checklist 8-1

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

ITEM	COMMENTS
Identification	
Trap Type	
Type of Service	
Line Size	
Trap Size	
Operating Pressure	
Condition of Trap	
Type of Test Used to Determine Condition	
Date Trap Installed (new)	
Date Trap Last Serviced	
Date Next Service Required	
Miscellaneous Comments	

Walk Through Survey
Checklist 8-2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

ITEM	LOCATION						
	AREA #1	AREA #2	AREA #3	AREA #4	AREA #5	AREA #6	AREA #7
Trap Malfunction							
Trap Leaking							
Missing Insulation From Flanges							
Missing Insulation From Pipe							
Missing Insulation From Equipment							
Pipe Leaking							
Equipment Leaking							
Condensate Dumped to Sewer							
Steam Pressure Higher Than Required							
Equipment Operating When Not Required							
Visible Steam Plumes From Vents							
Control Adjustments Required							
Piping Systems Operating but Not Required							
Miscellaneous Comments							