ENERGY MANAGEMENT SERIES

12

FOR INDUSTRY COMMERCE AND INSTITUTIONS

Water and Compressed Air 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 of how to save energy.

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

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Minister of Supply and
Services Canada 1985
Cat. No. M91-6/12E
ISBN 0-662-14164-4

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INTRODUCTION

Water systems are found in all sectors, for the distribution of water from a source to a point of use such as washrooms, kitchens, manufacturing processes, and water cooled equipment.

Compressed air systems may also be found in the same facilities. These distribute compressed air, which is used as a power source for air operated tools, control systems, and other air using devices.

In many facilities these distribution systems were not given adequate consideration in the original design, for retrofit expansions, or for the establishment of routine maintenance procedures. Thus, energy saving opportunities can often be found by a systematic analysis of these systems.

Purpose

The following summarizes the purpose of this module.

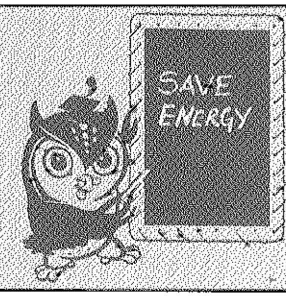
- Introduce the subject of water and compressed air systems as used in the Industrial, Commercial and Institutional sectors.
- Provide an awareness of potential energy and cost saving opportunities.
- Provide methods of establishing energy and cost saving potential.
- Provide a series of Worksheets that can be used to perform calculations for existing and proposed systems. These calculations are then used to determine the potential energy and cost savings.

Contents

The module is subdivided into the following sections.

- *Fundamentals* describes the uses of water and compressed air systems.
- *Equipment/Systems* describes the basic equipment used in water and compressed air distribution systems.
- *Energy Management Opportunities* are described and supported by estimated figures for energy and cost savings and simple payback calculations.
- Appendices which include a glossary of terms, tables, conversion factors and worksheets.

FUNDAMENTALS



The purpose of water and compressed air systems which are found in the Industrial, Commercial and Institutional sectors, is to deliver the necessary volume of water or air at the required pressure and temperature to the correct place. This is accomplished by a distribution system consisting of pipe, valves and fittings. A pump moves water within water systems and a compressor moves air within compressed air systems. Information dealing with pumps can be found in Fans and Pumps, Module 13, and with compressors in Compressors and Turbines, Module 14.

Careful evaluation of existing and proposed distribution systems can ensure against improper operation, and poor energy utilization. Alert design, operations, and maintenance personnel, with an awareness of energy management, can achieve significant savings in areas such as:

- Detection and elimination of leaks.
- Reduction of friction losses and the associated pressure drops.
- Reduction of heat loss from hot water systems and heat gain to chilled water systems.
- Application of new technology.

Water and compressed air systems are discussed separately to simplify the presentation.

Throughout this module these conventions have been used to differentiate between absolute and gauge pressures:

- *Absolute pressure is expressed kPa(absolute).*
- *Gauge pressure is expressed kPa(gauge).*

Water Systems

A variety of water systems exist within Industrial, Commercial and Industrial facilities, but generally, the same Energy Management Opportunities apply. Facilities contain some or all of the following systems.

- *Potable or Domestic Water.*
- *Process Water.*
- *Hot Water.*
- *Cooling Water.*
- *Chilled Water.*
- *Condenser Water.*
- *Discharge Water Collection.*
- *Glycol* (Used as a substitute for water where freezing may occur).

This module does not discuss municipal water supply, storm or sanitary sewage systems, fire protection systems, or specialized water systems, which may be industry or facility specific. Condensate systems, which are covered in Steam and Condensate Systems, Module 8, are also not included.

System Descriptions

Uses of the previously listed water systems:

- *Potable or domestic water systems* supply water to many areas including washrooms, kitchens, and drinking fountains. These hot or cold water systems are usually installed using copper, polyvinyl chloride (PVC), or chlorinated polyvinyl chloride (CPVC) pipe and fittings. In these systems, the pressure seldom exceeds 350 kPa(gauge) and the temperature varies between 5 and 65°C.
- *Process water systems* supply hot or cold water for process applications. Typical examples of this would be dilution water, ionized water, and wash water. Piping materials could be copper, steel, galvanized steel, or plastic pipe such as PVC or CPVC. In most process water systems, the pressure would not exceed 1375 kPa(gauge) and the temperature would range between 5 and 95°C.

- *Hot water systems* distribute low, medium, or high temperature hot water for process or heating applications. Piping material is normally carbon steel, but could be other material. The following summary gives the usual maximum temperature and pressure for each of these systems.

System	Maximum Temperature	Maximum Pressure
Low Temperature	121°C	207 kPa(gauge)
Medium Temperature	176°C	1034 kPa(gauge)
High Temperature	230°C	2068 kPa(gauge)

- *Cooling water systems* supply cooling water to various items of process equipment. Piping material is normally carbon steel, but could be other material. Cooling water can be supplied directly from a municipal water system and discharged to the sewer after use. The alternative is a closed loop system, where heat gained by the water during the cooling process is rejected to the atmosphere, either by evaporative cooling ponds or cooling towers. Temperatures range between 5 and 30°C and pressure does not normally exceed 865 kPa(gauge).
- *Chilled water systems* are a form of cooling water systems. The temperature of the water is reduced by a chiller, which is a mechanical refrigeration device. Piping material is normally carbon steel, but could be other material. Temperatures range between 5 and 13°C and pressure does not usually exceed 865 kPa(gauge).
- *Condenser water systems,* sometimes used in connection with cooling towers, city, or well water services, supply water to remove heat from water cooled refrigerant condensers. Piping material is normally carbon steel, but could be other material.
- *Discharge water collection systems* are used to collect the water discharged from heating and cooling applications. This water may be reused or discharged. Piping materials vary, depending on the application.
- *Glycol* solutions are commonly used in water systems, where there is a danger of freezing. Glycol can be used in snow melting applications, or in systems supplying heating coils subjected to 100% outdoor air. Glycol is also used in isolated parts or zones of a heating or cooling system, where intermittent operation or long runs of exposed piping increase the risk of freezing. It should be noted that glycol is expensive and tends to create corrosion problems unless suitable corrosion inhibitors, specifically selected for the application, are used. However, in many cases, glycol may be the only practical solution to avoid freezing problems.

Water Treatment

Water can contain numerous impurities which can cause:

- The formation of a scale deposit on heat transfer surfaces. This scale acts as an insulation material and can significantly reduce the cooling or heating efficiency of the equipment.
- Scale buildup on the inside of the piping and water cooled equipment, which will reduce the inside diameter of the pipe or the water flow channels through the equipment. This reduction in diameter reduces the water flow through the system and, in extreme cases, pipes or water flow channels may become blocked.
- Damage or destruction of pipelines and equipment due to corrosion.
- Rapid wear rates on moving parts such as pumps, shafts, or seals. The wear is caused by increased friction due to particulate impurities entering the space between the moving parts.

It is difficult to correct problems caused by water impurities. Water treatment specialists, who will analyze the water supply, examine use, and make recommendations for the correct treatment required to reduce or eliminate potential problems should be consulted. These recommendations may include filtration, and chemical treatment.

Filtration

Filters mechanically remove suspended solids from a water supply. Sand or mesh filters are used, depending on the type and size of suspended solids. These filters, which trap suspended solids, require periodic cleaning.

Chemical Treatment

A water treatment specialist can recommend the best chemical treatment to reduce or eliminate the problems caused by water borne impurities. Chemically treated water systems must not be connected in a manner that allows the treated water into potable or domestic water systems. If the systems must be interconnected, backflow preventers are mandatory.

Piping Systems

The force required to move one kilogram of liquid, at the desired flow rate, from the suction point to the discharge point is called the total head of a system or, more commonly, the system head. The pump has to supply this force. The total head developed by the pump must equal the total head required by the system.

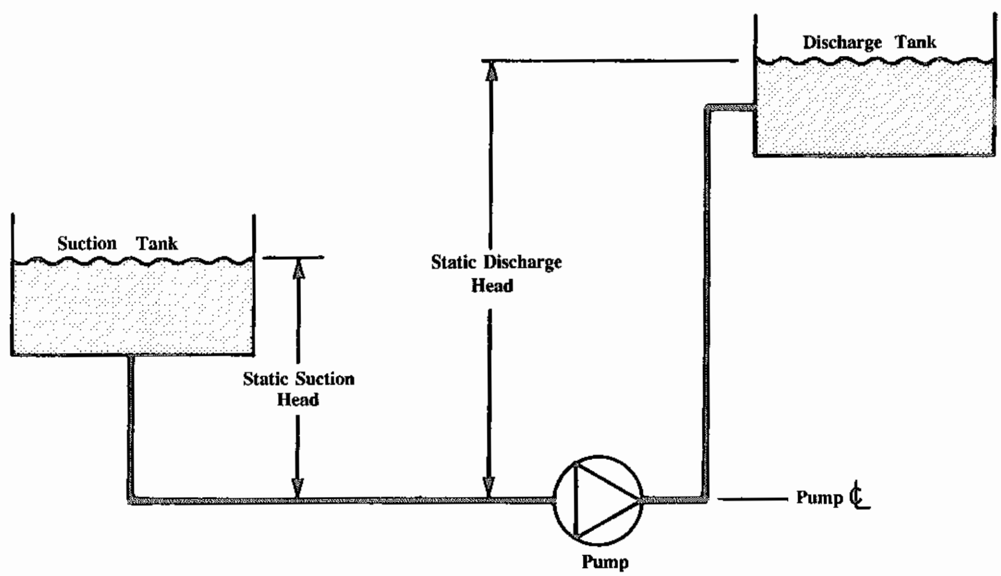
In normal practice, the system head is subdivided into two parts. The head required to move a liquid from the suction tank to the pump is called the total suction head, while the head resisting the flow of liquid from a pump is called the total discharge head. These heads are further broken down into static, pressure, and friction heads. This module contains the general concepts for an overall appreciation of the subject. For more details, reference should be made to Fans and Pumps, Module 13.

Static Head

Static head is defined as the height difference, in metres, between the surface of the liquid in the suction tank, and the centreline of the pump suction (Figure 1). The static suction head is negative when the suction tank is below the pump centreline.

Static head, on the discharge side of the pump, is defined as the height of the highest liquid surface above the pump centreline. When the height of the highest liquid surface is below the pump centreline, the static discharge head is negative.

Many pumping systems begin or end in tanks that are not at atmospheric pressure. The pressure on the tank liquid surface affects the static head. The surface pressure, converted to metres of liquid, is called surface suction pressure on the inlet side of the pump, and surface discharge pressure on the outlet side of the pump.



Suction and Discharge Static Head
Figure 1

Friction Head

Friction head is the energy required per kilogram of liquid pumped, to overcome friction losses that occur as liquid is pumped through a piping system. Friction head is also separated into suction and discharge components.

The friction losses are a function of the material being pumped, flow quantity, fluid velocity in the pipe, pipe length, diameter, internal finish, fittings, and other devices installed in the pipeline. Tables are available in piping handbooks to establish friction losses for various pipe fittings, expressed as equivalent lengths of piping. Similarly, tables and graphs are available to convert flow, pipe diameter, and length into system friction losses (Table 1).

System Head

Total Suction Head and *Total Discharge Head* may now be calculated using the following equations.

Total Suction Head = Suction (Static Head + Pressure Head + Friction Head)

Total Discharge Head = Discharge (Static Head + Pressure Head + Friction Head)

Once the various heads have been established, it is a simple matter to calculate the *Total System Head* for a specific flow rate. The rate of flow affects the friction losses, which, in turn, change the Total System Head.

Please note that all factors must be expressed in the same units (metres of liquid). The Total System Head can be shown as:

Total System Head = Total Discharge Head − Total Suction Head.

The total system head is used to allow selection of the pump and motor required for the specific pumping application.

Water Flow in Piping Systems

When water flows through a pipe, friction is caused by fluid particles rubbing each other and the pipe. The friction is a function of the fluid flow rate, pipe length, diameter, internal finish, and types of valves and fittings used. The friction causes a drop in pressure in the flow direction. Published tables provide the pressure drops per unit length of carbon steel pipe, for various diameters and flow rates. These tables also provide the velocity in the pipe (Table 1).

For piping systems, the term Schedule is an assigned number that relates to the pressure and stress capability of a pipe. The term NPS is a short form for the words Nominal Pipe Size. The number following NPS is the nominal pipe size designated in inches (e.g. NPS 2 means nominal 2 inch pipe). Additional piping information may be obtained from the Piping Handbook, by Crocker and King, published by McGraw Hill.

Pressure drop per 100 metres, and velocity, for 15°C water at various flow rates flowing in NPS 2, Schedule 40 pipe is given in Table 2. For a water flow rate of 1.66 L/s the water velocity would be 0.77 m/s and the pressure drop per 100 metres would be 14.1 kPa(gauge).

From Table 2, it is clear that the higher the flow, the greater the velocity and pressure drop. In piping distribution systems a rule of thumb is that the water velocity should not be less than 1.5 and not exceed 3 m/s. In short sections of piping that connect equipment to distribution systems, velocities are allowed to increase beyond the stated 3 m/s. This rule of thumb applies to piping between NPS 2 and NPS 10. To discourage settlement, if the water contains suspended solids, the velocity should be greater than 2 m/s.

Whenever the water flowing in a straight pipe encounters an impediment that changes the flow direction of any part of the stream, the characteristics of the flow pattern are altered. The impediment creates turbulence, causing a greater energy loss than would normally be expected. Since valves and fittings cause disturbances to the flow, they produce additional pressure loss. Tables and graphs have been prepared by manufacturers, which express the pressure loss for valves and fitting in equivalent length of piping (Table 3).

Suction and discharge friction heads can be calculated when the piping system configuration, size, and water flow rate are known.

A typical Pump Calculation Sheet is included as Worksheet 12-1.

Heat Loss in Piping Systems

Any pipe carrying material that is hotter than the temperature of the surroundings will lose heat. The greater the temperature difference between the pipe and the surroundings, the greater the heat loss.

Effect of Insulation

The application of insulation to non or poorly insulated piping systems carrying hot or cold fluids can save energy and dollars. Tables 4 and 5 show the heat loss from bare steel and tarnished bare copper pipe respectively. For NPS 6 bare steel pipe carrying hot water at 65°C, Table 4 has been marked to indicate that the heat loss is 290 Wh/(m.h).

Process Insulation, Module 1, provides tables that show the heat loss from insulated piping at various temperatures, and the recommended thickness for a series of insulating materials.

If the pipe in the previous example, were insulated with 50 mm of fibreglass insulation, the heat loss per lineal metre would be reduced to 20.19 Wh/m.h) and the surface temperature of the insulation reduced to 21.6°C.

Pipeline length 100 m

Pipeline operating time 8760 hours per year

Reduction in heat loss = 290 Wh/(m.h) – 20.19 Wh/(m.h)

= 269.81 Wh/(m.h)

Annual heat loss = 269.81 Wh/(m.h) x 100 m x 8760 h/yr

= 236 353 560 Wh/yr

or $\frac{236\ 353\ 560\ \text{Wh/yr}}{1000\ \text{W/kW}}$

= 236 354 KWh/yr

On the basis of electricity costing $0.05 per kWh

Dollar savings = 236 354 kW x $0.05

= $11,818

Where possible, all valves, fittings and flanges should also be insulated. These items, if left uninsulated, contribute to heat energy losses. An additional advantage of insulation is that it eliminates a potential personnel burn hazard.

Compressed Air Systems

Many advances have been made in the development of air operated devices and tools to improve productivity in the Industrial, Commercial and Institutional sectors. These tools and devices have become more efficient, but their performance can be adversely affected by the compressed air system.

Neglected compressed air distribution systems can cause leaks. This results in the additional use of energy to compress the air and possible reduced equipment efficiency, since the air may not be delivered at the correct pressure.

Compressed air capacity is expressed as *free air flow* which is flow at atmospheric pressure. This avoids the burden of stating the actual pressure for each application. However, by monitoring power bills it is obvious that compressed air is expensive. This is demonstrated by the worked examples in this module.

This module reviews the distribution system used to transport the air to the points of use. Air compression is covered in Compressors and Turbines, Module 14. Compressed air systems are divided into two types:

- Plant Air, which is compressed air normally used to supply air operated tools and equipment.
- Instrument Air, which is compressed air used to supply pneumatically operated instrumentation and controls.

In most establishments, these types of air are generated and distributed separately, because the moisture content and cleanliness of instrument air is more critical than that of plant air.

Compressed air is expensive, and the management of the air system influences the cost. Areas in which energy management can be practiced in the operation of compressed air distribution systems include the following items.

1. Avoid leaks.
2. Operate the system at the lowest suitable pressure.
3. Minimize the pressure drop through the distribution system.
4. Avoid water in the distribution system.

The benefits of managing compressed air systems wisely can be demonstrated by examples.

1. It is important to *avoid leaks* in compressed air systems. Major loss of air can occur at joints, valves, fittings and hose connections. During regular operation, leaks can be difficult to locate because of background noise. It is worth the effort to find and repair leaks because they are a major source of waste.

Typical air leakage rates are given in Table 6. The table demonstrates that a small leak can account for many dollars of energy cost. Leakage can represent up to 30 per cent of compressed air consumption. This is one area where Energy Management can pay large dividends with small investments. Tables providing air leakage rates, for various sized openings at various pressures, have been published by manufacturers, and should be used.

A simple test can be undertaken to establish system air leakage. When the facility is not in operation, start the air compressor and let it build up to full line pressure so that the compressor unloads. Note the time. Due to air leaks the system pressure will fall and the compressor will load again. Again note the time. Allow the system pressure to drop and build up at least 4 times. In each case note the load and unload times. After these four tests are recorded, the mean average load and unload time should be established.

The following calculation can now be performed.

$$\text{Leakage} = \frac{Q \times T}{T + t}$$

Where, Leakage = System Leakage (L/s)

Q = Delivered free air capacity (L/s)

T = Time running loaded (s)

t = Time running unloaded (s)

Worksheet 12-2 is used for this calculation and an example follows.

2. It is desirable to *operate the system at the lowest suitable pressure.* Air is often compressed to higher than required pressure. In some cases, tools or devices that needed the higher pressure have been removed from the facility and the higher pressure is no longer required. In other cases, poor tool or device maintenance, such as poor lubrication, or undersized air lines, may require higher pressures to satisfy the tool operation.

3. Design should *minimize the pressure drop throughout the distribution system.* Often, plant expansions, equipment additions, or equipment relocations take place without corresponding modifications to air distribution systems. Piping has been added, new connections made, and, in some cases, the volume of air flow through systems may have increased because of a greater use of compressed air. Increased air flow through pipes and fittings increases the friction losses, thus the pressure drop. These losses can be significant, depending on the air flow and pipe diameter. Since the air pressure required at the use point is fixed, the required increase in line pressure leads to greater power requirements at the compressor. Table 7 provides typical pressure drops for different diameter pipes and flow rates.

4. Care must be taken to *avoid water in the distribution system.* Water, or the mixture of compressor lubrication oil and water, causes corrosion on the inside of air distribution lines. Corrosion increases the internal resistance and the pressure drop through the system. Reduced air pressure decreases the efficiency of the air consuming tool or device. Corrosion also causes pits and pockets in the piping system which weakens it and causes leakage at joints, traps, and valves. The solution is to install a refrigerated or chilled air dryer on the compressor to eliminate moisture in the system. This is extremely important for instrument air systems where the operation of the instruments can be adversely affected.

Simplified Air Leakage Test
Worksheet 12-2

Company: ABC COMPANY LTD. Date: JULY 31, 1984

Location: ANYTOWN By: MBE

Compressor Number: 2- PLANT AIR

Delivered free air capacity of compressor 236 L/s (Q)
(obtain from compressor nameplate)

1 Run compressor until it unloads

2 Record time until compressor loads

3 Record time until compressor unloads

4 Repeat for at least 4 cycles

Cycle	Time: load to unload (T Seconds)	Time: unload to load (t Seconds)
1	30	180
2	32	178
3	33	188
4	30	182
Total	125 s	728 s

Average $T = \frac{\text{Total}}{4} = \frac{125}{4} = 31.25\text{ s}$ $t = \frac{\text{Total}}{4} = \frac{728}{4}\text{ s} = 182\text{ s}$

$$\text{Leakage} = \frac{Q \times T}{T + t} = \frac{236 \times 31.25}{31.25 + 182}$$

$$= 34.58 \text{ L/s}$$

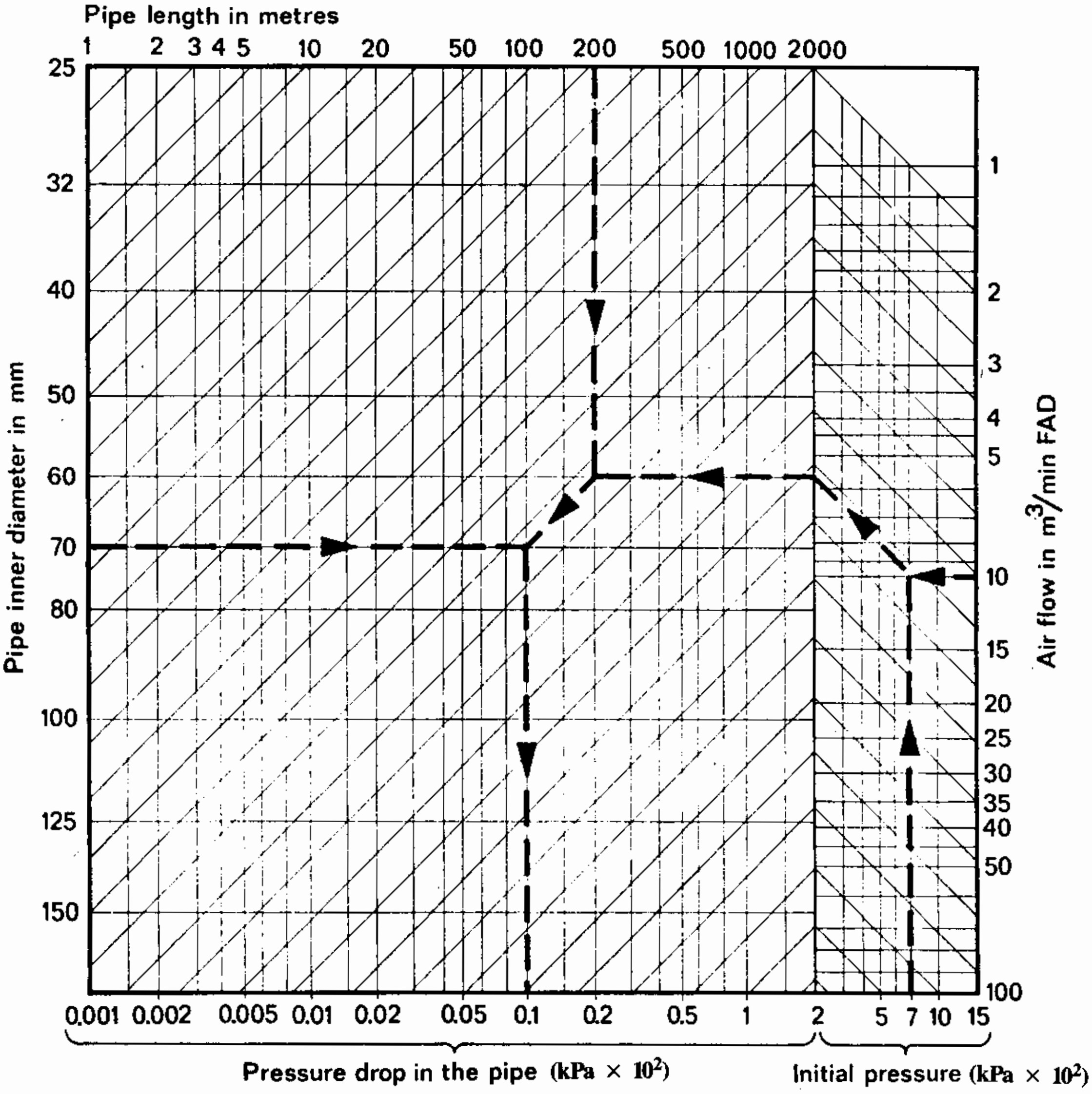
Refer to Compressors and Turbines, Module 14, for compressor information.

Air Flow in Piping System

Nomographs (Figure 2) can be used to calculate the pressure drop in air distribution systems. The equivalent length of the piping system will have to be increased, to account for the various valves and fittings in the distribution piping network.

Figure 2 is marked to show the following example.

Initial pressure in the system	700 kPa(gauge)
Air flow	10 m^3/min (166.66 L/s)
Overall pipe length	200 metres
Pipe diameter	70 mm
Pressure drop in the pipe (from the nomograph)	10 kPa



Air Distribution System Pressure Drop Nomograph
Figure 2

Energy Audit Methods

Energy Management Opportunities exist in water and compressed air 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. Typical energy saving items noted during a walk through audit are water hoses or taps left running, leaking connections, damaged insulation on hot or cold water piping, manually drained air line filter bowls filled with water or other material, and empty air line lubricators. Alert management, operating staff, and good maintenance procedures can reduce energy waste, improve energy use efficiency, and save money.

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 chilled water supply line is not insulated and may be gaining heat from the surroundings areas. The immediate reaction may be that the line should be insulated to reduce the heat gain. 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 the existing energy gain, and potential energy reductions. The reduction in energy use establishes the dollar saving. With this, plus the estimated cost to supply and install 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*. Examples of these are repair of leaks, preventive maintenance programs or insulation repair programs.
- *Low cost*, refers to an energy management action that is *done once and for which the cost is not considered great*. Examples of low cost items are installation of flow regulators, air line lubricators and air line filters.
- *Retrofit*, refers to an energy management action that is *done once and for which the cost is significant*. Examples of retrofit items are insulation of hot or chilled water piping systems, installation of air dryers on air compressors, or the entire replacement of piping systems.

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

Many energy and cost saving opportunities exist in water and compressed air systems, which, when recognized and acted upon by management and operating staff, can reap dividends. Alert personnel, with an awareness of energy management techniques, can easily learn to recognize these opportunities.

In compressed air systems the elimination of leaks, which account for the largest waste of compressed air, can result in considerable energy and dollar savings. Other items which should be investigated:

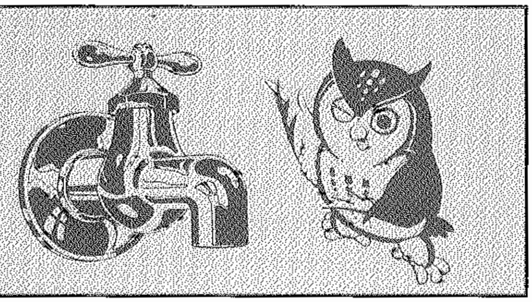
- Are hoses and couplings in good condition? Can they be replaced with fixed piping?
- Are air lines filters properly selected and maintained?
- Are air line lubricators operating correctly? Are they checked and filled on a regular basis?
- Is the system being operated at the correct pressure? Can the system pressure be reduced?
- Is the air compressor properly selected for the application?

Water systems also include many situations where energy management can result in energy and dollar savings. Investigate the following:

- Is water temperature correct for the application? Can the temperature be reduced?
- Are hot and cold water systems adequately insulated?
- Can system pressure be reduced?
- Can a once through system be converted to a circulating system?
- Can the heat energy in waste streams be utilized?
- Is water treatment being used to eliminate water borne impurities?

The subject of energy management must be approached with an open mind to expose previously accepted, but inefficient practices. The opportunities listed in the Energy Management Opportunities section of this module may generate similar or additional ideas which are specific to the facility. Energy Management awareness on the part of management, operating and maintenance staff, combined with an active energy management program, can pay dividends in energy and cost reduction.

EQUIPMENT SYSTEMS



Water Systems

The following is a description of common water system components.

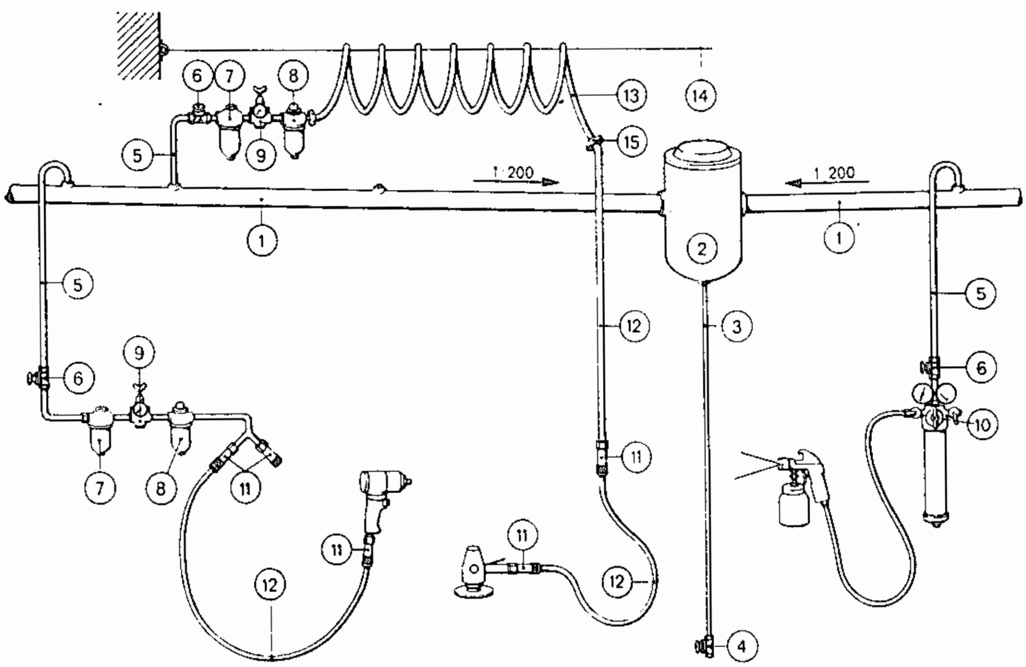
- Pump(s) to force the water through the system.
- Piping distribution system consisting of pipe, valves and fittings used to transport the water.
- Expansion tanks used in hot water systems to allow for water expansion.
- Instrumentation and control devices such as pressure and temperature gauges, flow measurement devices and pressure reducing valves.

Water systems can be divided into once through and circulating systems. In a once through system the water is used once, and discharged (e.g. water used for showers). A circulating system is one where the water is reused. An example is a hot water recirculation system where the water is heated, pumped to an operation where the heat is used, and the water is returned to be reheated.

Compressed Air Systems

The following is a description of the components in air distribution systems.

- A system consisting of pipes, valves, and fittings (Figure 3) is used to transport the compressed air from the air receiver to the tool or device that requires the air for operation.



1 Mains
2 Moisture Trap
3 Drain Pipe
4 Drain Valve
5 Service Line
6 Shut-off valve
7 Air Filter
8 Fog Lubricator
9 Pressure Regulator
10 Pressure regulator with air cleaner
11 Automatic coupling
12 Air Hose
13 Spiral Hose
14 Plastic-coated wire
15 Claw coupling

Arrangement Of Air Line And Air Tools
Figure 3

- A refrigerated or chilled water dryer is a mechanical device used to lower the dew point, preventing condensation of water vapor within the piping system. The dryer also removes any compressor oil which may have been carried with the compressed air stream.
- An air receiver is a tank normally located between the dryer and the distribution system. The receiver provides air system storage to accommodate demand surges and eliminates the need for the compressor to operate continuously loaded. The volume of the air receiver should be 10 per cent to 15 per cent of the capacity of the compressor (e.g. If the compressor has a capacity of 400 L/s then the volume of the air receiver should be approximately 60 litres). If the distribution system contains a piece of equipment that suddenly demands an increased amount of compressed air for a short period, an extra air receiver near the point of the equipment connection may avoid the need to provide extra compressor capacity, and also save energy. Another method, sometimes used to solve this problem, is to oversize the distribution headers and provide extra capacity similar to the local air receiver.

System Components

Compressed air systems are usually constructed from carbon or galvanized steel piping and include the normal complement of fittings such as elbows, tees, reducers, and valves. Other items, which are typically found in compressed air systems include:

- Hose and hose couplings, which are a major source of air leakage.
- Copper or brass fittings, which have the potential for air leakage because of possible cross threading.
- Air filters, installed ahead of equipment such as instrumentation, to ensure clean air. The degree of filtration should be related to the specific application, because the finer the pore size of the filter, the more dirt will be collected, increasing the pressure drop and ultimately choking the air supply.
- Air lubricators, installed upstream of equipment such as pneumatic cylinders, to provide lubrication. The quantity of lubrication is metered and adjusted to suit each application.
- Air regulators, which are used to reduce system pressure for specific equipment or tool use.

ENERGY MANAGEMENT OPPORTUNITIES

Energy Management Opportunities (EMOs) is the term that represents 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 water and compressed air 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. Repair all leaks.
2. Ensure that all water and air systems are under close control and waste is not occurring.
3. Review all hot water systems and reduce temperature to minimum required levels.
4. Shut down systems or equipment when not required.
5. Maintain proper control over water treatment to ensure that design flow rates are maintained.
6. Review filter maintenance programs to ensure that partially or totally plugged filters are not causing increased pipeline pressure losses.
7. Ensure that monitoring and control equipment is properly maintained.
8. Eliminate items such as hoses and couplings on air systems wherever practical, to reduce the possibility of leakage.
9. Ensure that lubricators are working properly to reduce friction on air operated equipment.

Housekeeping Worked Examples

1. Repair Leaks

During a walk through audit it was noted that an air system operating at 600 kPa(gauge) was leaking in four separate locations. Each leak source was estimated at 3 mm diameter. The system operated 8760 hours per year.

From Table 6 it is established that air leakage at 600 kPa(gauge) through a 3 mm opening is 10 L/s.

$$\text{Annual air loss} = \frac{n \times Q \times 3600 \times h}{1000}$$

Where, n = number of leaks

Q = leakage rate (L/s)

3600 = seconds per hour (s/h)

h = hours per year (h/yr)

1000 = litres per cubic metre (L/m^3)

$$\text{Annual air loss} = \frac{n \times Q \times 3600 \times h}{1000}$$

$$\text{Annual air loss} = \frac{4 \times 10 \text{ L/s} \times 3600 \text{ s/h} \times 8760 \text{ h/yr}}{1000 \text{ L/m}^3}$$

$$= 1\ 261\ 440 \text{ m}^3\text{/yr}$$

From the same table it is established that the cost of air per leak is $111 per month.

Annual dollar savings if leaks are repaired = 4 x $111/mth x 12 mth/yr

= $5,328

Estimated cost for labour and material to repair the leaks is $275.

$$\text{Simple payback} = \frac{\$\ 275}{\$5{,}328}$$

$$= 0.052 \text{ years (19 days)}$$

A benefit of reducing leakage is that additional compressed air will be available for other uses. Consequently, the purchase of additional compressor capacity may not be required or may be delayed.

2. Control Water and Air Streams

On an inspection tour of the facility it was noted that two 12 mm wash down hoses had been left running. Pressure on the water supply line to these stations was 210 kPa(gauge). Water was distributed from the municipal water supply.

From published tables, it is established that the flow per hose is approximately 1.89 L/s. By shutting off these hoses the savings in water would be:

$$\text{Water savings} = 2 \times 1.89$$

$$= 3.78 \text{ L/s}$$

If the two hoses are left running 384 hours per year:

$$\text{Water wasted} = 3.78 \text{ L/s} \times 3600 \text{ s/h} \times 384 \text{ h/yr.}$$

$$= 5\ 225\ 472 \text{ L/yr}$$

Since a pump is not used in the facility for this application, the immediate reaction may be that the example is not an Energy Management Opportunity. In the global picture, the municipal water supply treatment and pumping costs are reduced; and water and sewer charges from the Municipality to the Company would be reduced. At a cost of $0.41/m³ the dollar savings would be:

$$\text{Dollar savings} = \frac{5\ 225\ 472 \text{ L/yr} \times \$0.41\text{/m}^3}{1000 \text{ L/m}^3}$$

$$= \$2{,}142 \text{ per year}$$

3. Reduce Hot Water Temperature

In reviewing hot water usage it was found that a steam fed heat exchanger, used to supply water to a product rinse operation, was set to maintain water at 60°C. This water is used in a once through system because it was contaminated in the rinsing operation. The incoming water to the heat exchanger was 20°C.

Experimentation indicated that the water temperature could be reduced to 48°C with no effect on the rinse operation. The water flow rate was 1 L/s and operation was 800 hours per year. The heat exchanger supply steam pressure was 270 kPa(absolute) and the heat transfer efficiency was 85 per cent.

To perform the calculation, the heat content of the water and steam must be obtained from published steam tables. The term for the measure of the heat content of steam is *enthalpy*, which is expressed as kJ/kg. A section of steam tables is found in Table 8. Care must be taken in using the steam tables to select the correct enthalpy figure. For water, the figure in the column labeled h_f should be used. For steam, use the figure in column h_g. Enthalpy must be selected for the appropriate temperature and pressure.

Energy required to heat water to 60°C

Enthalpy of water at 60°C 251.09 kJ/kg

Enthalpy of water at 20°C 83.86 kJ/kg

Annual water usage = 1 L/s x 3600 s/h x 800 h/yr

= 2 880 000 L/yr

For this calculation assume 1 L = 1 kg

Annual heat energy required = Water usage x enthalpy difference

= 2 880 000 kg/yr x (251.09 - 83.86)kJ/kg

= 481 622 400 kJ/yr

Energy required to heat water to 48°C

Enthalpy of water at 48°C 200.89 kJ/kg

Enthalpy of water at 20°C 83.86 kJ/kg

Annual water usage 2 880 000 L/yr

Annual heat energy required = Water usage x enthalpy difference

= 2 880 000 kg/yr x (200.89 - 83.86)kJ/kg

= 337 046 400 kJ/yr

Energy saving = 481 622 400 − 337 046 400

= 144 576 000 kJ/yr

Enthalpy of steam at 270 kPa(absolute) 2719.85 kJ/kg

Enthalpy of condensate at 270 kPa(absolute) 546.15 kJ/kg

Available energy per kg of steam = Steam enthalpy − condensate enthalpy

= 2719.85 − 546.15

= 2173.7 kJ

Based on a heat exchanger efficiency of 85 per cent this equals 2173.7 x 0.85 = 1847.645 kJ/kg

$$\underline{\text{Steam saving}} = \frac{144\ 576\ 000\ \text{kJ/yr}}{1847.645\ \text{kJ/kg}} = 78\ 249\ \text{kg/yr}$$

Based on a steam cost of \$22/1000 kg the savings in energy cost = 78 249 kg/yr x \$22/1000 kg

= \$1721 per year

Another potential benefit is that there would be 78 249 kg of 270 kPa(absolute) steam available for other uses. This could delay the need for additional boiler capacity.

4. Equipment Shut Down

During a systematic review of a facility it was found that air operated liquid mixers were operating even when the containers were empty. Investigation revealed that 7 units were being operated in this manner. Nameplate data indicated that air consumption for each unit was 4 L/s. Air pressure in the plant was 600 kPa(gauge).

During a two week period it was established that, on the average, 6 units could be found operating in this manner at any time, including weekends and plant shutdown periods.

Unnecessary air consumption can be calculated:

Air = 6 x 4 L/s x 3600 s/h x 8760 h/yr

= 756 864 000 L/yr

From Table 6 it is established that an air leakage rate of 26.7 L/s cost \$298 per month.

Air operated equipment should be shut off when not in use.

Dollar savings = \$298 x 12

= \$3,576 per year

There is no cost to shut off the air operated mixers because personnel are always in the vicinity.

$$\text{Reduction in air usage} = \frac{756\ 864\ 000\ \text{L/yr}}{1000\ \text{L/m}^3} = 756\ 864\ \text{m}^3\text{/yr}$$

5. Control Water Treatment

Reports from the production manager indicated that adequate product cooling was not being achieved by the cooling water system, and the product bath residence time would have to be increased. Cooling water valves had been progressively opened to solve the problem, but this solution no longer worked. The incoming temperature of the in-process material had not changed during the past 3 years.

Subsequent investigation indicated that scaling had reduced internal diameter of the pipe to 12 mm instead of the original 25 mm. Water pressure in the supply header was 70 kPa(gauge) and the length of the pipe to the cooling equipment was 10 metres. From table 1 it is established that this length of 25 mm pipe would supply 2.08 L/s of water with a pressure drop of 70 kPa(gauge). With the effective pipe diameter reduced to 12 mm, the flow of cooling water is reduced to 0.58 L/s which is approximately 1/4 of the original cooling water flow, and is not adequate to satisfy the cooling requirement. The immediate solution is to replace the 25 mm pipe to the equipment, however, this is not the ultimate solution. If the branch piping to one item of equipment is scaling, the entire piping system is probably in the same condition. A water treatment specialist should be retained to investigate the facility water usage, and establish the correct treatment for removing the dissolved salts from the incoming water.

A short term, but not recommended solution, is to increase the discharge pressure on the pump by installing a larger impeller and motor. This solution may not be safe because the pressure design limit of the existing piping may be exceeded. Further, increasing pressure on the pump will increase energy requirements.

6. Filter Maintenance Program

Discussions with the production superintendent indicated that air tools and other air operated devices were not functioning correctly. The production superintendent was about to issue a request to the facility engineer to increase the plant air distribution pressure from 689 kPa(gauge) to 760 kPa(gauge) in an attempt to overcome the operational problems. Further discussions with the facility engineer revealed that no preventive maintenance routine had ever been established for air line filters.

A pressure gauge installed downstream from an existing air line filter indicated that, instead of receiving 689 kPa(gauge), the pressure was only 550 kPa(gauge). Because the tools were designed to operate at air pressures between 620 and 689 kPa(gauge) the reduced pressure was unacceptable. Filter replacement increased the air pressure to 665 kPa(gauge) and the air tool operated satisfactorily. Changing the filters on the remaining air tools produced the same result. This experience provided the incentive to establish a filter preventive maintenance program.

In this case there are no direct energy savings. However, if the air pressure had been increased, additional energy would have been required to compress the air to a higher pressure.

7. Monitoring and Control Equipment Calibration

In many facilities, monitoring and control equipment receive little attention until a problem develops. Consider a flow meter indicating the flow of cooling water to a process operation. If the flow meter goes out of calibration and indicates lower flow than is actually taking place, the equipment operator will unknowingly increase the cooling water flow beyond the required rate. Pumping energy will be required to provide the additional cooling water.

An operation requires 5.0 L/s of cooling water at a pressure of 117.4 kPa(gauge). From Table 9, the theoretical pumping energy required is 0.588 kW.

If the flow was increased to 7.5 L/s at the same pressure, the theoretical pumping energy would be 0.882 kW. The increased pumping energy is therefore 0.882 - 0.588=0.294 kW. The equipment operates 6000 hours per year and power costs $0.05 per kWh.

$$\text{Additional pumping cost} = 0.294 \text{ kw} \times 6000 \text{ h/yr} \times \$0.05/\text{kWh}$$

$$= \$88.20 \text{ per year}$$

This does not include the additional water which may have to be purchased.

$$\text{Water purchased} = 2.5 \text{ L/s} \times 3600 \text{ s/h} \times 6000 \text{ h/yr}$$

$$= 54\ 000\ 000 \text{ L/yr}$$

Based on a water charge of $\$0.41/m^3$ the cost of the additional water would be:

$$\text{Additional water cost} = \frac{54\ 000\ 000 \text{ L/yr} \times \$0.41/\text{m}^3}{1000 \text{ L/m}^3} = \$22{,}140 \text{ per year}$$

8. Hoses and Couplings

In reviewing an institutional facility it was noted that connections to air operated equipment were made using flexible hoses and quick attach hose couplings. Many of these units (prime sources of air leakage) were found to be leaking. It was estimated that the total leakage was equivalent to a 5 mm opening. The air line pressure was 600 kPa(gauge).

From Table 6 it is established that, under these conditions, the air lost from the system equalled 26.7 L/s at a cost of $298 per month. The annual cost would then be $3,576.

Because only one end of each hose required a quick attach coupling, 50 per cent of the quick attach couplings were replaced with nonleaking fixed piping. The annual air saving is 435 197 m^3 of free air and the dollar saving is $1,788 per year.

Estimated replacement cost including labour and material is $1,000.

$$\text{Simple payback} = \frac{\$1{,}000}{\$1{,}788} = 0.56 \text{ years (7 months)}$$

9. Airline Lubricator Operation and Maintenance

During a facility tour the plant manager noted that certain automatic lubricators bowls in the plant air system were empty. Closer examination indicated that the rod seals on the air cylinders fed by these lubricators were dry and leaking. Of the 40 air cylinders checked, 7 were found to be leaking air at the rod seal. Plant air pressure at 600 kPa(gauge) was applied to the rod end of the cylinder for 30 seconds out of every minute. Each leak was estimated to be the equivalent of a 1 mm opening. The equipment was used 160 hours per month. Leaking rod seals were replaced and a preventive maintenance program was set up to ensure that automatic lubricators were filled and adjusted on a cyclic basis.

From Table 6 it is established that a 1 mm diameter opening at 600 kPa(gauge) will leak at the rate of 1 L/s and the cost for this leak is $10.74/mth.

$$\text{1 L/s leak rate} = \text{1 L/s x 3600 s/h x 24 h/day x 30 day/mth}$$

$$= \text{2 592 000 L/mth}$$

$$\text{Potential monthly air savings} = \text{7 units x 1 L/s x 30 s/min x 60 min/h x 160 h/mth}$$

$$= \text{2 016 000 L/mth}$$

$$\text{Potential annual dollar saving} = \frac{2\ 016\ 000}{2\ 592\ 000} \text{ x \$10.74 x 12}$$

$$= \text{\$100.24 per year}$$

Cost to replace rod seals including labour and materials is $300.

$$\text{Simple payback} = \frac{\$300}{\$100.24}$$

$$= \text{2.99 years}$$

Along with this investment recovery opportunity, there is an additional operating benefit. Without the lubricators, the existing leaks will get worse and other seals will start to leak. This will waste additional compressed air and eventually the cylinder performance will be downgraded.

Low Cost Opportunities

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

1. Cover open surfaces of heated liquids to reduce evaporation.
2. Install flow regulators, pressure reducing valves or even hand valves to control the flow of water or air to the minimum acceptable quantity.
3. Review pump requirements and reduce the diameter of (trim) existing impellers, or install new impellers.
4. Replace existing pumps with high efficiency pumps.

Low Cost Worked Examples

1. Tank Surface Insulation

Management was concerned about the surface heat loss from an otherwise well insulated open top tank containing 2900 kg of sodium dichromate solution at 94°C. The steam flow to the tank was metered, establishing the steam requirements to maintain the tank at the correct temperature.

As a next step 50 mm polypropylene balls were added to the tank to cover the liquid surface and steam flow readings were again taken.

Steam requirement without polypropylene balls	825 kg/h
Steam requirement with polypropylene balls	360 kg/h
Steam cost	$22/1000 kg
Hourly steam savings	465 kg/h
Annual heating time	5040 h/yr

Steam Savings = 465 kg/h x 5040 h/yr.

= 2 343 600 kg

Annual dollar savings = 2 343 600 kg x $22/1000 kg

= $51,559

Cost for polypropylene balls was $3,000

$$\text{Simple payback} = \frac{\$\ 3{,}000}{\$51{,}559}$$

= 0.058 years (22 days)

2.Flow Regulators

The 12 showers in the locker rooms at a YM/YWCA were unrestricted full flow units. The flow rate was 0.284 L/s per shower head. Hot water for the showers was heated to 48°C using electric heaters and was tempered for shower use with 10°C water from the municipal water supply. It was estimated that shower use was equivalent to all heads operating 4 hours per day. It was further estimated that 75% of the water used was hot water at 48°C. The YM/YWCA operated 350 days per year.

To save on energy and water, consideration was given to the installation of reduced flow shower heads to limit the flow per head to 0.1895 L/s.

Hot water use with full flow heads = 12 heads x 0.284 L/s x 3600 s/h x 4 h/d x 350 d/yr. x 0.75

= 12 882 240 L/yr of 48°C water

Hot water use with reduced flow heads = 12 heads x 0.1895 L/s x 3600 s/h x 4 h/d x 350 d/yr x 0.75

= 8 595 720 L/yr of 48°C water

Potential hot water savings = 12 882 240 − 8 595 720

= 4 286 520 L/yr 48°C water

Since the hot water distribution lines were short and well insulated, and the water was heated electrically, the conversion efficiency between electricity and hot water is 100%. One litre of water = 1 kg.

Enthalpy of water at 48°C	200.89 kJ/kg
Enthalpy of water at 10°C	41.99 kJ/kg

Heat energy required to heat 4 286 520 litres of water from 10° to 48°C is water savings x enthalpy difference.

Heat Energy required = 4 286 520 kg x (200.89 − 41.99)kJ/kg

= 681 128 028 kJ

or $\frac{681\ 128\ 028 \text{ kJ}}{1000 \text{ kJ/MJ}}$

= 681 128.028 MJ

1 kWh = 3.6 MJ

Electrical energy required = $\frac{681\ 128.028 \text{ MJ}}{3.6 \text{ MJ/kWh}}$

= 189 202 kWh

Cost for electricity is $0.05 per kWh

Annual cost reduction = 189 202 kWh x $0.05/kWh

= $9,460

Estimated supply and installation cost for 12 reduced flow shower heads is $1,500.

Simple payback = $\frac{\$1,500}{\$9,460}$

= 0.16 years (2 months)

3. Review Pumping Requirements

With the removal of some water-using equipment, the flow and discharge head requirements on a water pump could be reduced.

Conditions:

Item	Previous	New Requirements
Total Discharge Head	895 kPa(gauge)	671 kPa(gauge)
Flow	31.5 L/s	25.2 L/s

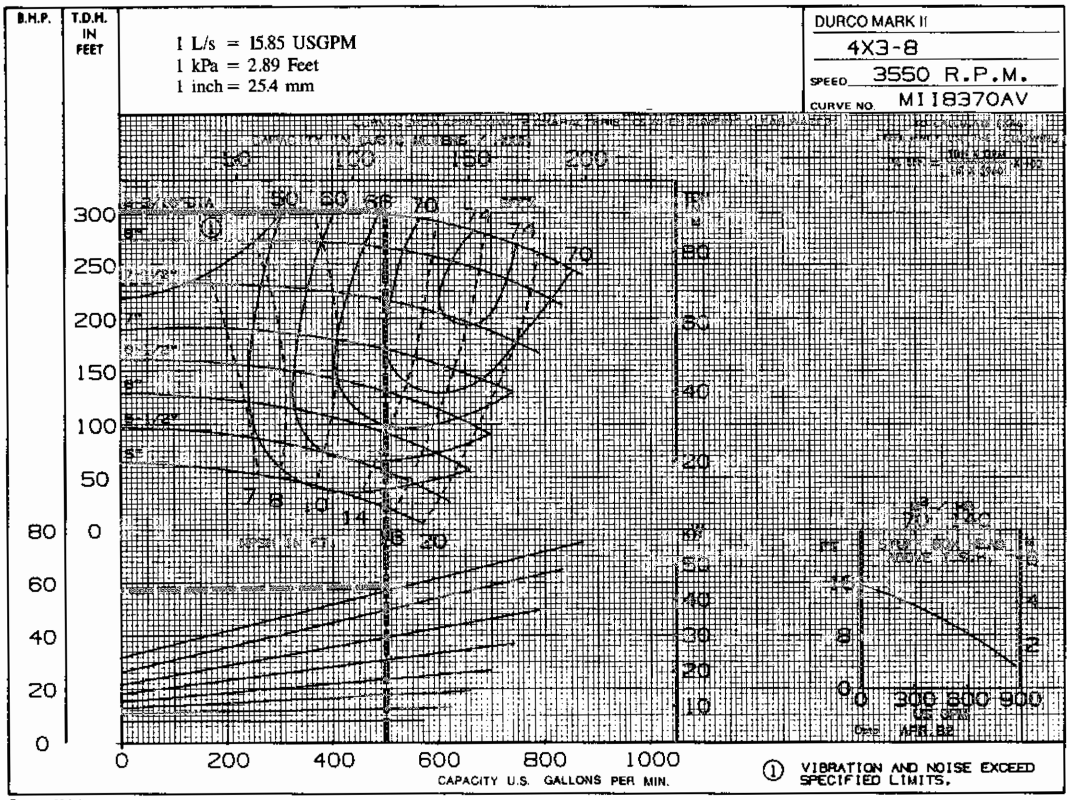
From the existing pump performance curve (Figure 4) it is noted that, by reducing the impeller diameter from 207.9 mm to 190.5 mm, the new requirements, using the existing pump, can be met.

Power requirement change is:

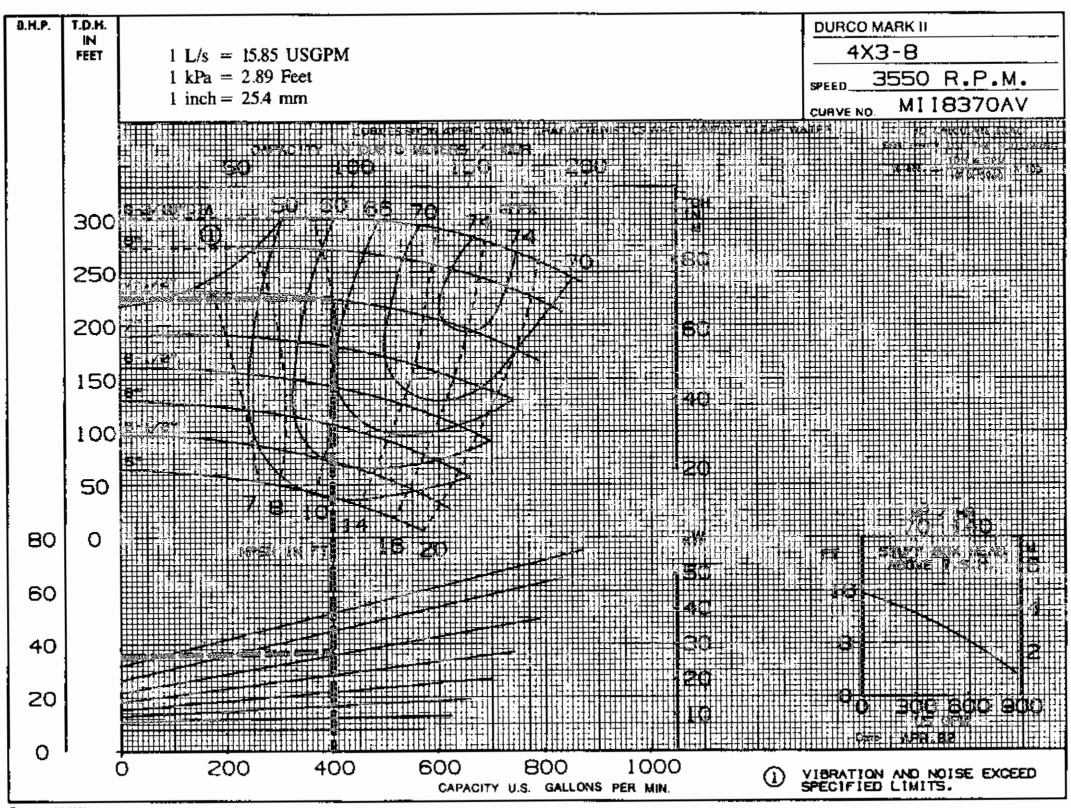
Previous power requirement 41.03 kW

New power requirement 26.11 kW

Pump operation 3500 h/yr



Previous Requirements



New Requirements

Figure 4

With the Courtesy of Duriron Canada Inc.

Energy savings = (41.03- 26.11) kW x 3500 h/yr

= 52 220 kWh per year

Cost of electricity is $0.05/kWh

Annual dollar savings = 52 220 kWh x $0.05/kWh

= $2,611

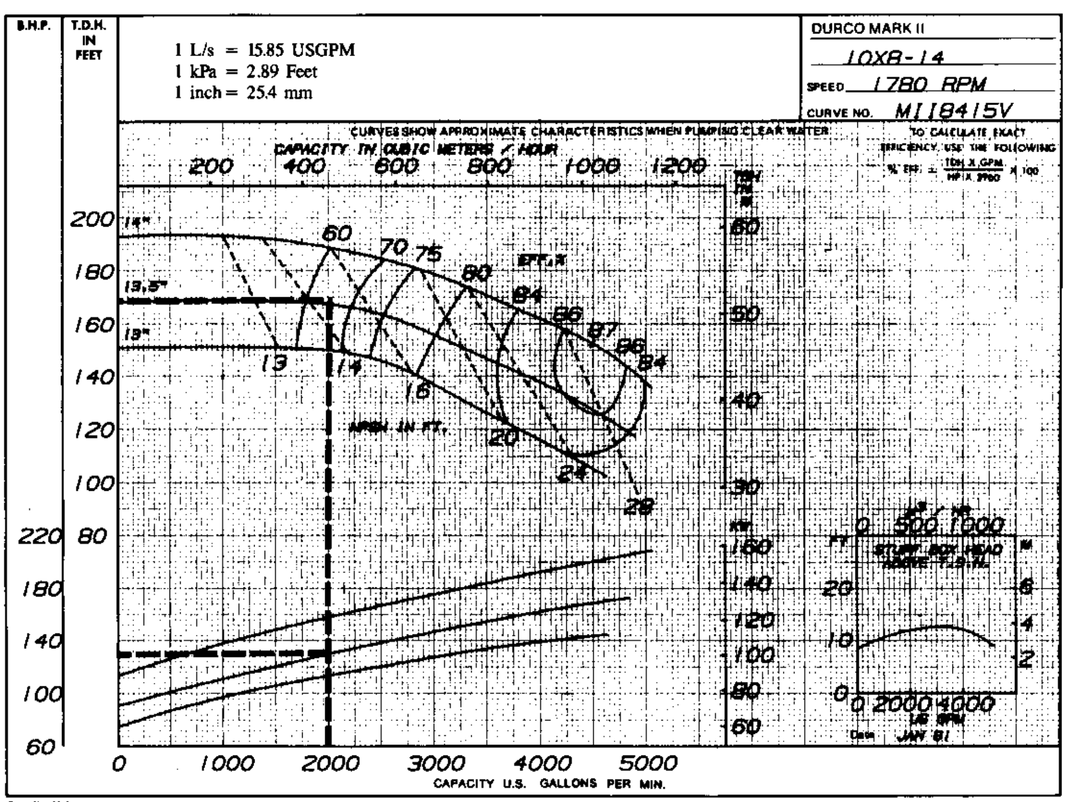
Cost to trim the impeller, including labour to dismantle and reassemble the pump, is estimated at $500.

Simple payback = $\frac{\$\ 500}{\$2,611}$

= 0.19 years (3 months)

4. Higher Efficiency Pumps

In reviewing pumping requirements for a large facility it was noted that a water pump, which had been in operation for many years, would soon have to be replaced. From the existing pump performance curve (Figure 5) it was established that the pump characteristics are:



Existing Pump
Figure 5

With the Courtesy of Duriron Canada Inc.

Inlet	250 mm
Outlet	200 mm
Impeller diameter	337.5 mm
Total discharge head	507 kPa(gauge)
Flow rate	126 L/s
Power required	100.7 kW at 1780 rpm
Efficiency	65%

Rather than purchasing an exact replacement for the existing pump it was decided to investigate the possibility of purchasing an energy efficient unit.

After establishing that the same discharge head and flow rate had to be maintained, a new pump, with the following characteristics was selected (Figure 6).

Inlet	200 mm
Outlet	150 mm
Impeller diameter	347 mm
Total discharge head	507 kPa(gauge)
Flow rate	126 L/s
Power required	89.5 kW at 1780 rpm
Efficiency	71%

Installation of the higher efficiency pump would provide a power saving.

Power saving = 100.7 - 89.5

= 11.2 kW

The pump operates 4,000 hours per year and electricity costs $0.05/kWh.

Annual dollar savings = 11.2 kW x 4000 h/yr. x $0.05/kWh

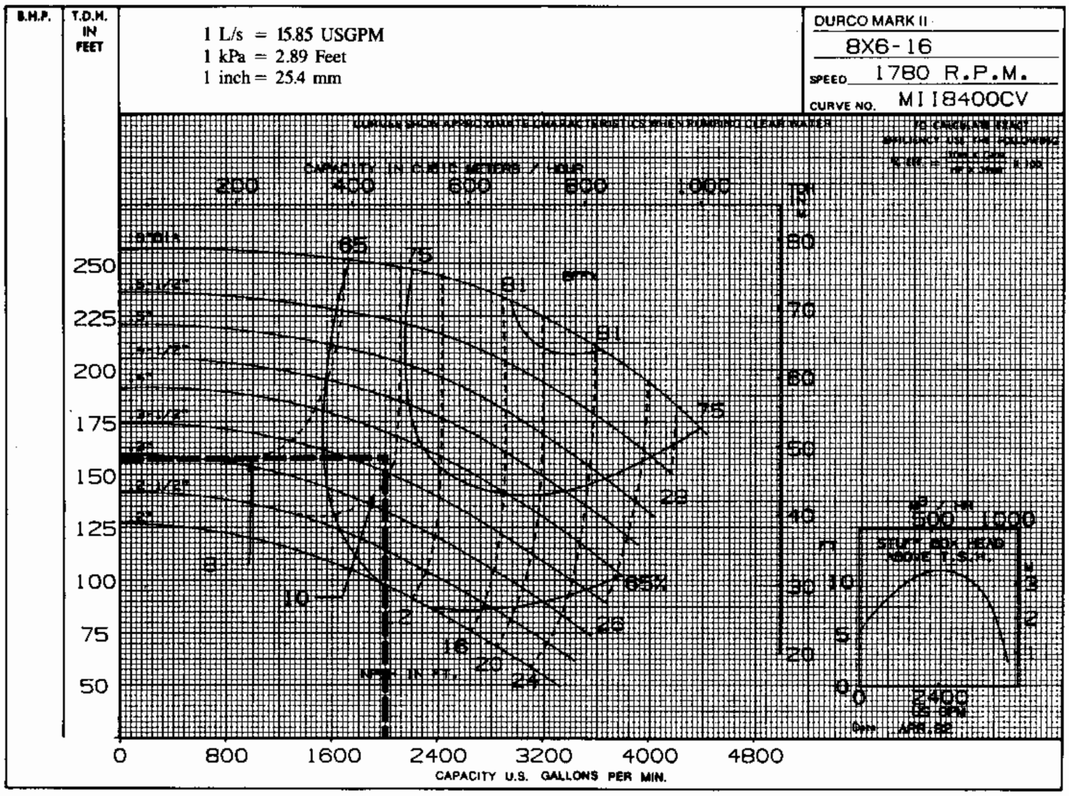
= $2,240 per year

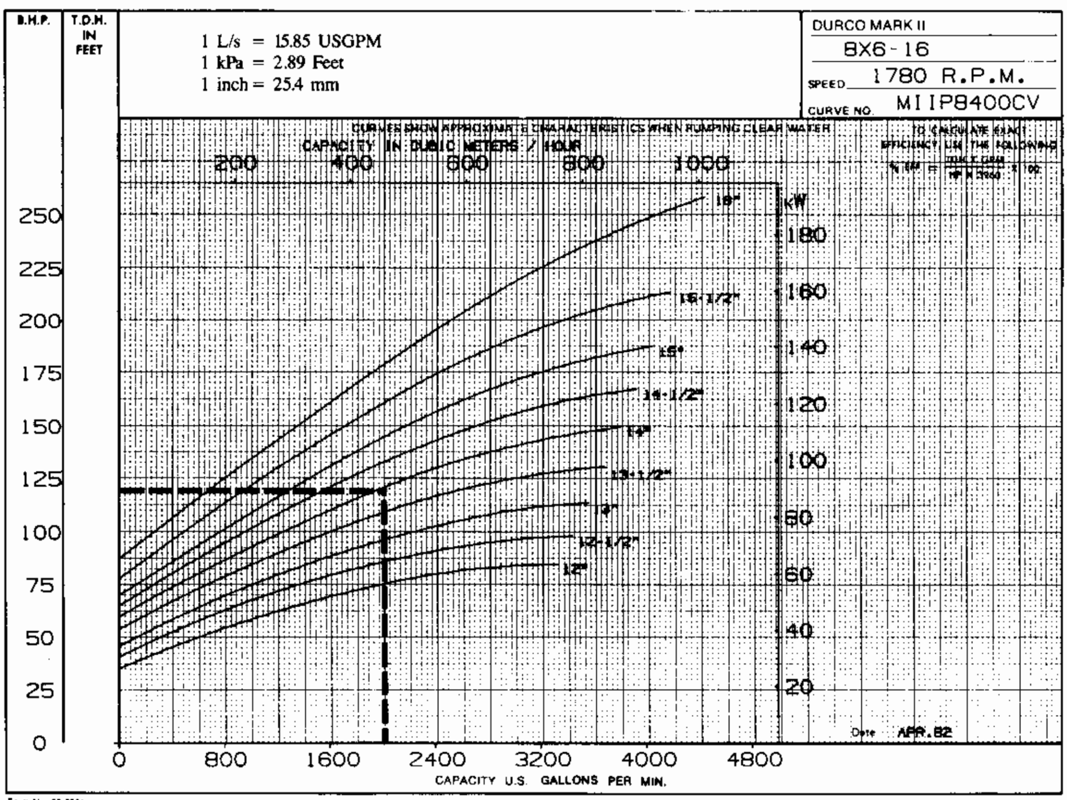
The pump inlet and discharge piping had to be revised at a cost of $1,500.

$$\text{Simple payback} = \frac{\$1,500}{\$2,240}$$

= 0.67 years (8 months)

The capital cost of the new pump has been excluded from the calculation of simple payback, because the pump was due for replacement. Also, the cost of the selected pump would be the same as an exact replacement of the existing lower efficiency pump.





Proposed Pump

Figure 6

With the Courtesy of Duriron Canada Inc.

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. Review potential energy loss in waste streams leaving the facility.
2. Review entire system with the objective of eliminating any excess or redundant flows.
3. Install mist eliminators on cooling towers to reduce drift loss and minimize make-up requirements.
4. Install air dryers to eliminate moisture in the air stream.
5. Replace piping systems with lower friction loss materials.
6. Insulate hot water or cold water piping to eliminate heat loss or gains.
7. Convert once through to closed loop cooling systems with an evaporative cooling unit or cooling tower.
8. Install booster pumps to satisfy isolated high pressure requirements rather than running the entire system at the higher pressure.
9. Install low pressure drop filtering equipment.
10. Install in-plant treatment systems to allow recirculation of waste water streams.
11. Install air receivers in air distribution systems near high demand equipment.
12. Replace old air compressors with newer, high efficiency units.
13. Install expansion tanks on piping systems.
14. Replace high pressure drop valves and fittings to reduce the friction loss.

Retrofit Worked Examples

1. Waste Stream Heat Recovery

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

There is an opportunity to recover some of the heat energy in the waste stream, by preheating the process water prior to it entering the steam to process water heat exchanger. This can be done with the installation of a second heat exchanger (Figure 7).

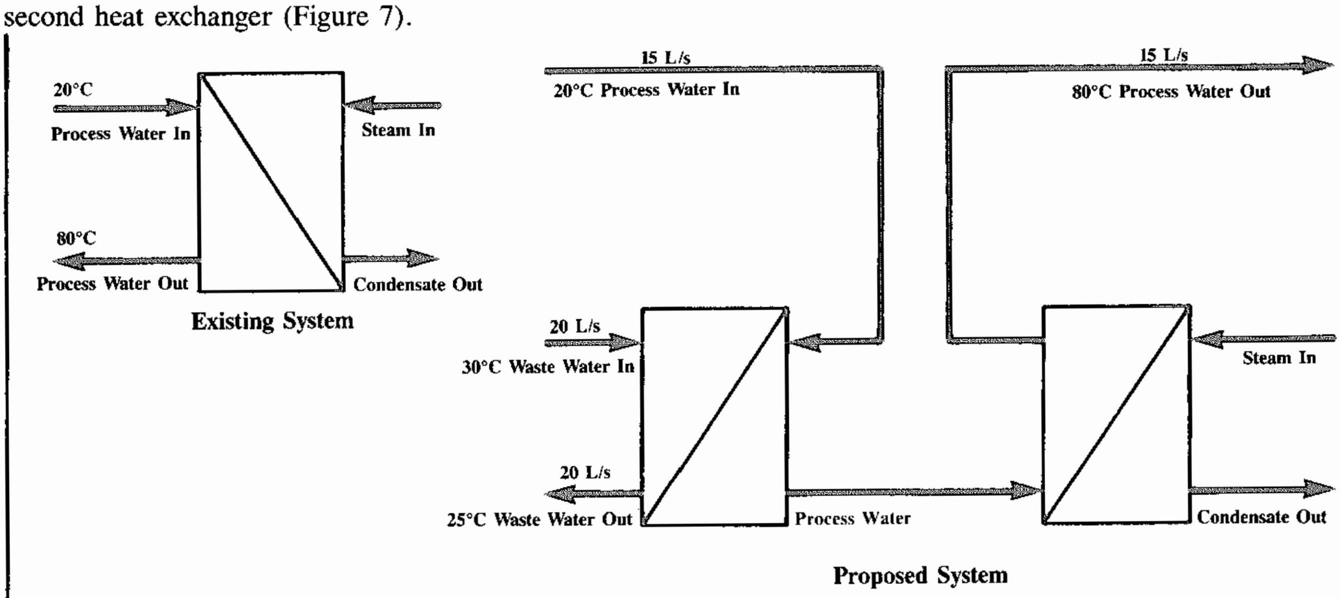


Figure 7

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

The equation used to provide the approximate heat transmission by water at normal heating system temperature is:

$$Q = f_w \times (t_1 - t_2) \times 15$$

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

f_w = Water flow (L/s)

t_1 = Temperature of incoming water (°C)

t_2 = Temperature of outgoing water (°C)

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

Using this equation yields the following:

f_w 20 L/s

t_1 30°C

t_2 25°C

$$Q = 20 \times (30 - 25) \times 15 = 1500 \text{ MJ/h}$$

$$\text{or } \frac{1500 \text{ MJ/h}}{3600 \text{ s/h}} = 0.416 \text{ MJ/s}$$

With 80 per cent heat exchanger efficiency the heat available to the process water stream is:

Heat available = 0.416 MJ/s x 0.8

= 0.333 MJ/s

To complete the calculation, the heat content of the steam must be obtained from steam tables (Table 8).

Enthalpy of steam at 700 kPa(absolute) 2762.0 kJ/kg

Enthalpy of condensate at 700 kPa(absolute) 697.1 kJ/kg

Heat available from steam = 2762.0 − 697.1

= 2064.9 kJ/kg

Based on heat exchanger efficiency of 80 per cent, heat available to process water is:

Heat available = 2064.9kJ/kg x 0.8

= 1651.9 kJ/kg

$$\text{or } \frac{1651.9 \text{ kJ/kg}}{1000 \text{ kJ/MJ}} = 1.6519 \text{ MJ/kg}$$

$$\text{Steam saving by adding waste heat recovery} = \frac{0.333 \text{ MJ/s}}{1.6519 \text{ MJ/kg}} = 0.20 \text{ kg/s}$$

The facility operates 6000 hours per year.

Annual steam savings = 0.20 kg/s x 3600 s/h x 6000 h/y

= 4 320 000 kg of steam at 700 kPa(gauge)

With a steam cost of \$22/1000 kg the saving would be:

Annual dollar saving = 4 320 000 x \$22/1000

= \$95,040 per year

Estimated cost to supply and install the new heat exchanger complete with piping modifications, is \$40,000.

$$\text{Simple payback} = \frac{\$40{,}000}{\$95{,}040}$$

= 0.42 years (5 months)

2. Reduce Air Consumption

In reviewing the facility air system it was noted that, although one department had ceased operation 2 years previously, the air mains in the area were still pressurized to the facility standard of 600 kPa(gauge). It was also noted that some fittings were leaking air. Because the long range plan was to convert this space into a storage facility for incoming raw material, a decision was made to remove all air piping. This would eliminate the air losses, the cost to repair the leaks, and other continuing maintenance costs.

It was estimated that the leakage of air was the equivalent of a 5 mm diameter opening. From Table 6 it is established that the air leakage rate is 26.7 L/s at a cost of \$298 per month.

The system was pressurized 8760 hours per year.

Total free air loss = 26.7 L/s x 3600 s/h x 8760 h/yr

= 842 011 200 L/yr.

$$\text{or } \frac{842\ 011\ 200 \text{ L/yr}}{1000 \text{ L/m}^3}$$

= 842 011 m^3/yr.

Leak elimination will make this quantity of compressed air available for other uses.
Annual dollar savings in eliminating leakage would be:

Annual dollar savings = 12 x \$298

= \$3,576

Estimated cost to remove redundant piping, less salvage value, is \$4,200.

$$\text{Simple payback} = \frac{\$4{,}200}{\$3{,}576}$$

= 1.2 years

3. Cooling Tower Mist Eliminators

A mist or liquid drift eliminator can reduce the water losses from a cooling tower. This reduces the quantity of make-up water required to maintain water level in the cooling tower circuit.

The manufacturer of the cooling tower should be consulted on this subject.

4. Compressed Air Dryers

Water in compressed air lines causes corrosion and increased pressure drop, and can be reduced with the installation of an air dryer. Compressor manufacturers, considering air use and dryness, can recommend the correct type of dryer. Equipment modifications required for the installation of the dryer should also be reviewed.

5. Lower Friction Piping System

Old pipe and fittings are often corroded because of poor water treatment, or water carryover into air piping. In cases where corrosion or scale build up in the pipe necessitates pipe replacement, or for new piping systems, consideration should be given to using material with a lower coefficient of friction. This will reduce internal friction losses and pumping or compressor energy requirements. Financial payback will dictate the final decision.

6. Insulate Piping

Bare piping carried 75°C water to a wash area with an ambient temperature of 20°C. The 150 metre long pipe was NPS 6. The water was heated with electric immersion heaters.

From Table 4 it is determined that the heat loss from this pipe is 360 Watt hrs per lineal metre per hour.

$$\text{Heat loss per hour (bare pipe)} = 360 \times 150$$

$$= 54\ 000 \text{ Watt hrs}$$

From tables in the Process Insulation, Module 1, using fibreglass insulation 51 mm thick, and no wrap, the heat loss would be 22.0 watts per linear metre per hour. Thus, with insulation, total heat loss per hour would be:

$$\text{Heat loss per hour (insulated pipe)} = 22.0 \times 150$$

$$= 3300 \text{ Watt hrs}$$

$$\text{Hourly heat savings} = 54\ 000 - 3300$$

$$= 50\ 700 \text{ Wh}$$

$$\text{or } \frac{50\ 700 \text{ Wh}}{1000 \text{ Wh/kWh}} = 50.7 \text{ kWh}$$

Cost of electricity is \$0.05/kWh.

$$\text{Hourly dollar savings} = 50.7 \times \$0.05 = \$2.54$$

The system operates for 8760 hours per year.

$$\text{Annual dollar savings} = \$2.54 \times 8760$$

$$= \$22{,}250/\text{yr}$$

Installed cost of insulation is \$6,000.

$$\text{Simple payback} = \frac{\$\ 6{,}000}{\$22{,}250}$$

$$= 0.27 \text{ years (3 months)}$$

7. Closed Loop Cooling System

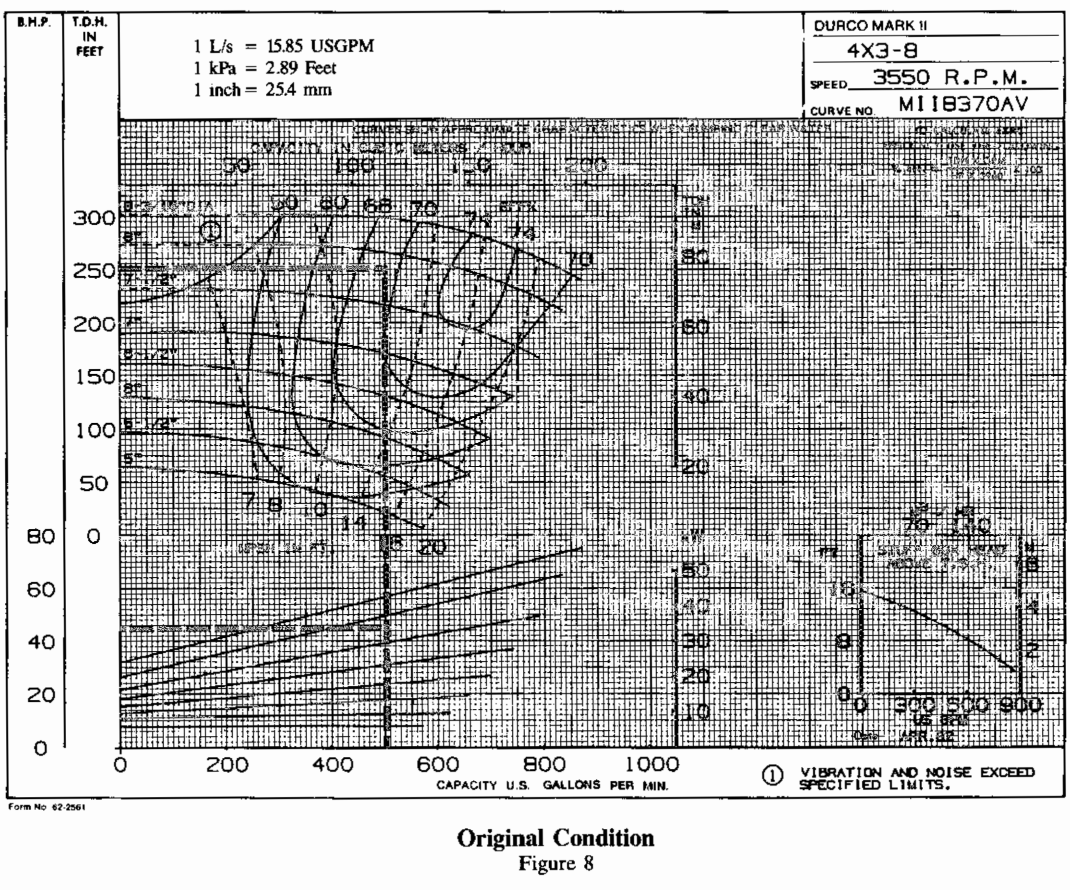
When cooling water is not contaminated, it may be advantageous to convert a once through system to a closed loop system, with the installation of a cooling tower or other evaporative type cooling device, such as a cooling pond. In this type of equipment, water is cooled by evaporation, either forced or natural, and the water is reused. These units are suitable for water flow rates in the range of 6 L/s and higher. Cooling tower manufacturers, or engineers should be contacted for detailed information on this subject.

8. Booster Pumps

During a walk through audit of a facility it was noted that the discharge pressure on a cooling water pump was maintained at 620 kPa(gauge) to satisfy one item of equipment. The remaining equipment in the plant required a maximum pressure of 447 kPa(gauge). Total water flow was 31.5 L/s while the flow to the high pressure equipment was 8 L/s. It was agreed that a diagnostic audit should be done to establish the viability of reducing the system pressure to 447 kPa(gauge) and installing a booster pump to raise the pressure of the 8 L/s requirement from 447 to 620 kPa(gauge). A cushion tank was not required because the water use was continuous.

<u>Main Supply Pump — Original Conditions (Figure 8)</u>

Flow	31.5 L/s
Discharge head	746 kPa(gauge)
Power required	37.3 kW at 3,600 rpm.

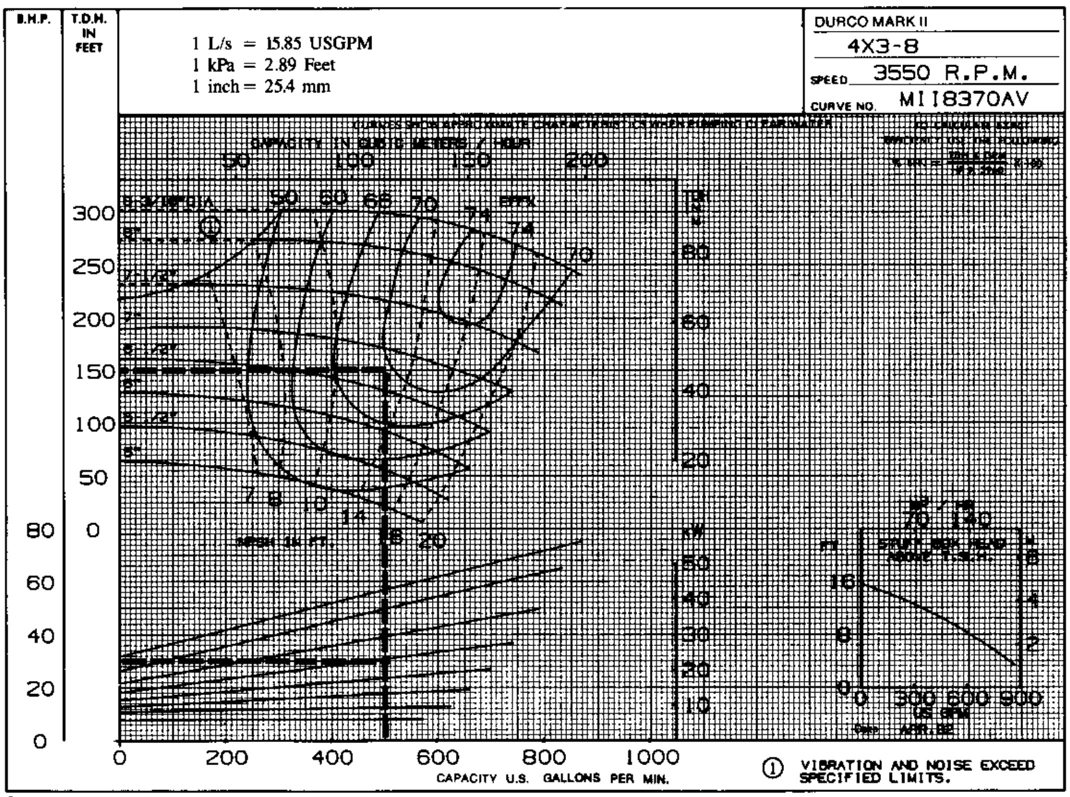


Original Condition
Figure 8

With the Courtesy of Duriron Canada Inc.

Main Supply Pump — Revised Conditions (Figure 9)

Flow	31.5 L/s
Discharge head	447 kPa(gauge)
Power required	18.65 kW at 3,600 rpm



Revised Condition
Figure 9

With the Courtesy of Duriron Canada Inc.

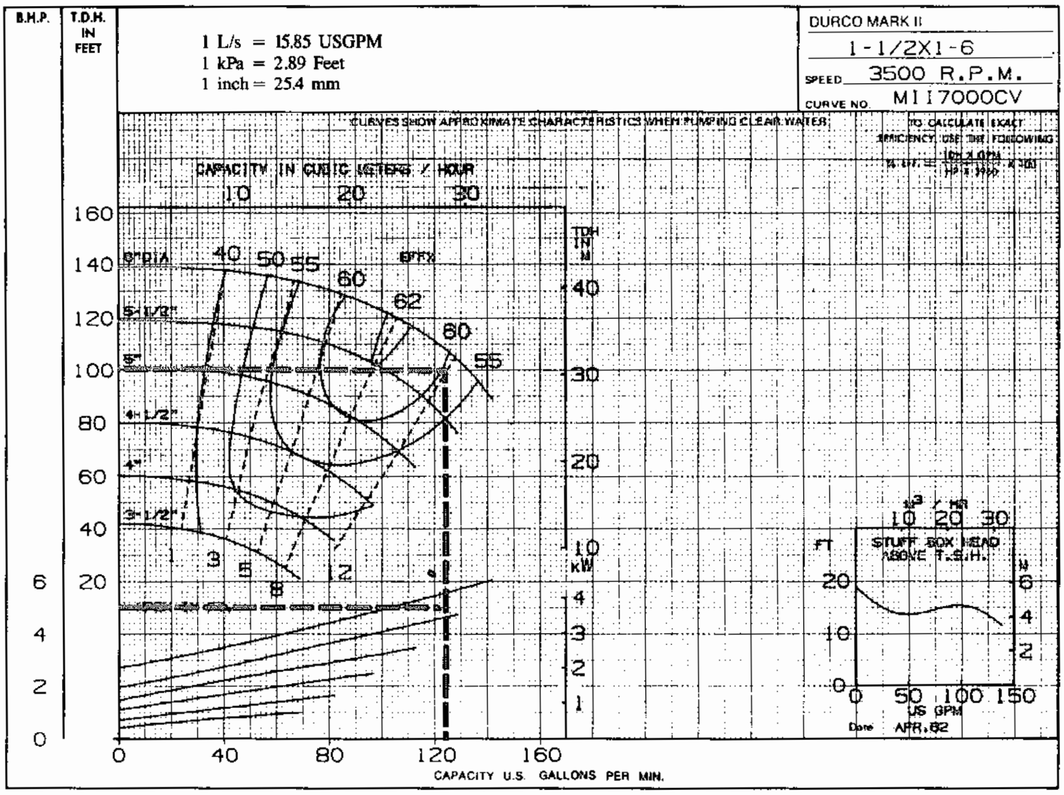
Booster Pump — Condition (Figure 10)

Flow	8 L/s
Discharge pressure	746 kPa(gauge)
Inlet pressure	447 kPa(gauge)
Differential pressure	299 kPa
Power required	4 kW at 3,600 rpm.

The equipment operates 24 hours per day, 200 days per year and electricity costs $0.05/kWh.

Annual dollar savings = 24 h/d x 200 d/yr x (37.3 − (18.65 + 4))kW x $0.05/kWh

= $3,516 per year



Booster Pump
Figure 10

With the Courtesy of Duriron Canada Inc.

Estimated cost to purchase and install the booster pump including piping changes, wiring, and trimming the existing pump impeller is $8,500.

$$\text{Simple payback} = \frac{\$8,500}{\$3,516}$$

$$= 2.42 \text{ years}$$

9. Filter Pressure Loss

The media used for filtering suspended solids from water and air streams should be sized to trap the specific particle size. The smaller the pore size in a filter, the higher the pressure drop across the filter, and the greater the chance of plugging. The greater the pressure drop, the higher the energy cost to produce the required pressure.

10. Plant Water Treatment

In reviewing water systems in the facility it was realized that two streams were being directed to a sewer because of potential contamination. The total flow was calculated at 3.15 L/s. It was further established that, in the past 12 months, this contamination situation had occurred twice, and, in each case, it was corrected in 8 hours. There were applications in the facility where the water could be reused if it had not been contaminated.

Discussions with suppliers indicated that a conductivity analyzer could be installed to measure the contamination of the waste stream. A control system would operate a valve to divert the contaminated water to sewer, and open a second valve to supply fresh water for the operation. At the same time an alarm would warn operating personnel that contamination was present.

The plant operates 6000 hours per year.

$$\text{Annual water savings} = (6000 \text{ h/yr} - 16 \text{ h/yr}) \times 3.15 \text{ L/s} \times 3600 \text{ s/h}$$

$$= 67\ 858\ 560 \text{ L/yr}$$

Since this water is purchased directly from the Municipality there would be a saving in water and sewer charges. Energy would be saved by the Municipality because the quantity of water delivered, and the amount of sewage treated, would be reduced.

Based on water costing $\$0.41/m^3$ the direct dollar savings in water purchases would be:

$$\text{Annual dollar savings} = \frac{67\ 858\ 560\ \text{L/y}}{1000\ \text{L/m}^3} \times \$0.41/\text{m}^3$$

$$= \$27{,}822 \text{ per year}$$

The estimated cost of the analyzer, valves, and controls is \$9,000.

$$\text{Simple payback} = \frac{\$\ 9{,}000}{\$27{,}822}$$

$$= 0.323 \text{ years (4 months)}$$

11. Air System Surge Reduction

Air receivers are used to provide compressed air storage, which accommodates demand surges and eliminates the need for the compressor to operate continuously loaded. Usually, receivers are installed at the compressor. Additional receivers can be installed in areas of sudden demand, to reduce the air distribution systems pressure fluctuations. This improved pressure regulation may allow the overall system pressure to be reduced.

12. High Efficiency Air Compressors

When purchasing an air compressor, it is important to review the various types available and to choose, consistent with cost, the most energy efficient unit. For additional information on compressors refer to Compressors and Turbines, Module 14.

13. Water System Expansion Tanks

Expansion tanks in water piping systems serve two purposes. In hot water systems, the water expands when heated and the tank acts as a reservoir for the increased volume. Without an expansion tank, the pressure in a filled system would increase as the system is heated,and water may be lost through pressure relief valves. Then, when the system is allowed to cool, the water would contract and additional water would be required to keep the system filled.

In cold water systems these units are normally called cushion tanks and serve two functions. Cushion tanks provide water storage and reduce system pressure fluctuations.

In both cases there is the potential for energy savings, because pumping requirements may be reduced.

14. Friction Loss Reduction

Table 3 shows that the equivalent length of pipe differs for various valves and fittings. For example, the equivalent length for an NPS 2 screwed globe valve is 16.46 metres, while for an NPS 2 screwed gate valve it is 0.46 metres. If 10 globe valves are replaced with 10 gate valves, in an NPS 2 piping system, the equivalent length saving would be:

$$\text{Equivalent length savings} = 10 \times (16.46 - 0.46) = 10 \times (16)$$

$$= 160 \text{ metres}$$

If this pipeline had a pressure drop of 15.1 kPa(gauge) per 100 metres, the reduction in pressure drop would be:

$$\text{Pressure drop reduction} = \frac{160}{100} \times 15.1 \text{ kPa(gauge)}$$

$$= 24.16 \text{ kPa(gauge)}$$

Based on the system, and the number of fittings that could be replaced, the savings could be significant.

APPENDICES

A Glossary of Terms
B Tables
C Common Conversions
D Worksheets

Glossary

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

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

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

Compressed Air — Air which is contained in a distribution system and is at a pressure higher than atmospheric.

CPVC Piping — Chlorinated Polyvinyl Chloride piping material which is similar to PVC piping. Maximum service temperature is 99° C.

Dew Point — The temperature at which a vapor condenses when it is cooled at constant pressure.

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 (EMO), 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 (EMO), low cost — Potential energy saving improvements that are done once and for which the cost is not considered great.

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

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

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

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

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

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

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

PVC Piping — Polyvinyl Chloride piping material which is the most widely used of all the plastic piping materials. Has high physical properties and resistance to corrosion. Maximum service temperature is 60°C.

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

Thermal Resistance(R) — Thermal Resistance is a number indicating the relative insulating value or resistance to heat flow of a material or combination of materials. The units are ($m^2 \cdot {}^\circ C/W$).

FLOW OF WATER THROUGH SCHEDULE 40 STEEL PIPE

TABLE 1

Courtesy of Crane

Pressure Drop per 100 metres and Velocity in Schedule 40 Pipe for Water at 15 C

Discharge Litres per Minute	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars	Velocity Metres per Second	Press. Drop bars
	1/8"		1/4"		3/8"		1/2"		3/4"		1"					
1	0.459	0.726	0.251	0.17												
2	0.918	2.59	0.501	0.60	0.272	0.136	0.170	0.044								
3	1.38	5.59	0.752	1.22	0.407	0.29	0.255	0.091	0.144	0.023						
4	1.84	9.57	1.00	2.09	0.543	0.48	0.340	0.151	0.192	0.038	0.120	0.012				
5	2.29	14.45	1.25	3.18	0.679	0.70	0.425	0.223	0.241	0.057	0.150	0.017				
													1 1/4"		1 1/2"	
6	2.75	20.29	1.50	4.46	0.815	0.98	0.510	0.309	0.289	0.077	0.180	0.024				
8	3.67	35.16	2.01	7.36	1.09	1.69	0.680	0.524	0.385	0.129	0.240	0.041	0.138	0.011		
10			2.51	11.81	1.36	2.52	0.850	0.798	0.481	0.193	0.300	0.061	0.172	0.015	0.127	0.008
15			3.76	25.67	2.04	5.37	1.28	1.69	0.722	0.403	0.450	0.124	0.258	0.032	0.190	0.015
20					2.72	9.24	1.70	2.84	0.962	0.683	0.600	0.210	0.344	0.054	0.254	0.026
	2"		2 1/2"													
30	0.231	0.016					2.55	6.17	1.44	1.45	0.900	0.442	0.517	0.114	0.380	0.053
40	0.308	0.027	0.216	0.010			3.40	10.72	1.92	2.50	1.20	0.758	0.689	0.193	0.507	0.091
50	0.385	0.039	0.270	0.017					2.41	3.83	1.50	1.14	0.861	0.290	0.634	0.135
60	0.462	0.055	0.324	0.023					2.89	5.41	1.80	1.61	1.03	0.400	0.761	0.187
70	0.539	0.098	0.378	0.031					3.37	7.27	2.10	2.15	1.21	0.541	0.888	0.248
					3"		3 1/2"									
80	0.616	0.092	0.432	0.039	0.280	0.014			3.85	9.27	2.40	2.76	1.38	0.690	1.01	0.315
90	0.693	0.115	0.486	0.048	0.315	0.017	0.235	0.008			2.70	3.47	1.55	0.862	1.14	0.397
100	0.770	0.141	0.540	0.059	0.350	0.020	0.261	0.010			3.00	4.25	1.72	1.05	1.27	0.488
									4"							
150	1.15	0.295	0.810	0.125	0.524	0.042	0.392	0.021	0.304	0.011	4.50	9.30	2.58	2.26	1.90	1.03
200	1.54	0.512	1.08	0.212	0.699	0.072	0.523	0.036	0.405	0.019			3.44	3.91	2.54	1.81
											5"					
250	1.92	0.773	1.35	0.322	0.874	0.108	0.653	0.053	0.507	0.028					3.17	2.74
300	2.31	1.10	1.62	0.449	1.05	0.152	0.784	0.074	0.608	0.040	0.387	0.014			3.80	3.82
													6"			
350	2.69	1.47	1.89	0.606	1.22	0.203	0.915	0.099	0.710	0.053	0.452	0.018			4.44	5.18
400	3.08	1.92	2.16	0.780	1.40	0.264	1.05	0.128	0.811	0.068	0.516	0.023	0.357	0.009	5.07	6.69
450	3.46	2.39	2.43	0.979	1.57	0.329	1.18	0.161	0.912	0.084	0.581	0.028	0.402	0.012	5.71	8.45
500	3.85	2.95	2.70	1.20	1.75	0.403	1.31	0.196	1.01	0.101	0.646	0.034	0.447	0.014		
550	4.23	3.55	2.97	1.44	1.92	0.479	1.44	0.232	1.11	0.122	0.710	0.041	0.491	0.016		
600	4.62	4.20	3.24	1.69	2.10	0.566	1.57	0.273	1.22	0.146	0.775	0.047	0.536	0.019		
650	5.00	6.88	3.51	1.97	2.27	0.658	1.70	0.319	1.32	0.169	0.839	0.055	0.581	0.022		
700	5.39	5.63	3.78	2.28	2.45	0.759	1.83	0.368	1.42	0.194	0.904	0.063	0.625	0.025		
750	5.77	6.44	4.05	2.60	2.62	0.863	1.96	0.420	1.52	0.218	0.968	0.072	0.670	0.029		
															8"	
800			4.32	2.95	2.80	0.977	2.09	0.473	1.62	0.246	1.03	0.081	0.715	0.032		
850			4.59	3.31	2.97	1.09	2.22	0.528	1.72	0.277	1.10	0.091	0.760	0.036	0.439	0.009
900					3.15	1.22	2.35	0.585	1.82	0.308	1.16	0.010	0.804	0.041	0.465	0.010
950					3.32	1.35	2.48	0.649	1.93	0.342	1.23	0.111	0.849	0.045	0.491	0.012
1000					3.5	1.50	2.61	0.714	2.03	0.377	1.29	0.122	0.894	0.049	0.516	0.013
1100					3.85	1.75	2.87	0.860	2.23	0.452	1.42	0.147	0.983	0.059	0.568	0.015
1200					4.20	2.14	3.14	1.02	2.43	0.534	1.55	0.172	1.07	0.069	0.620	0.018
1300							3.40	1.19	2.64	0.627	1.68	0.200	1.16	0.080	0.671	0.021
1400							3.66	1.37	2.84	0.722	1.81	0.232	1.25	0.091	0.723	0.024
1500							3.92	1.56	3.04	0.818	1.94	0.264	1.34	0.105	0.775	0.027
	10"															
1600							4.18	1.78	3.24	0.924	2.07	0.297	1.43	0.118	0.826	0.031
1700							4.44	1.99	3.45	1.04	2.19	0.331	1.52	0.132	0.878	0.035
1800	0.590	0.012							3.65	1.16	2.32	0.369	1.61	0.147	0.930	0.039
1900	0.622	0.014							3.85	1.28	2.45	0.410	1.70	0.163	0.981	0.042
2000	0.655	0.015							4.05	1.41	2.58	0.452	1.79	0.181	1.03	0.046
			12"													
2200	0.721	0.018							4.46	1.70	2.84	0.545	1.97	0.217	1.14	0.056
2400	0.786	0.021									3.10	0.645	2.14	0.253	1.24	0.065
2600	0.852	0.025	0.600	0.010							3.36	0.749	2.32	0.296	1.34	0.076
					14"											
2800	0.917	0.028	0.646	0.012							3.61	0.859	2.50	0.339	1.45	0.087
3000	0.983	0.032	0.692	0.013	0.573	0.008					3.87	0.982	2.68	0.387	1.55	0.099
							16"									
3500	1.15	0.043	0.810	0.018	0.668	0.011					4.52	1.33	3.13	0.526	1.81	0.134
4000	1.31	0.055	0.923	0.023	0.764	0.014					5.16	1.72	3.57	0.673	2.07	0.172
4500	1.47	0.068	1.04	0.029	0.860	0.018	0.658	0.009					4.02	0.853	2.32	0.214
5000	1.64	0.084	1.15	0.034	0.955	0.022	0.731	0.011					4.47	1.04	2.58	0.262
									18"							
6000	1.96	0.118	1.38	0.049	1.15	0.031	0.877	0.016					5.36	1.47	3.10	0.373
7000	2.29	0.158	1.61	0.065	1.34	0.042	1.02	0.021	0.808	0.012			6.25	2.0	3.61	0.499
8000	2.62	0.204	1.84	0.085	1.53	0.054	1.17	0.027	0.924	0.015			7.15	2.59	4.13	0.650
9000	2.95	0.256	2.08	0.107	1.72	0.067	1.31	0.033	1.04	0.019					4.65	0.816
											20"					
10 000	3.28	0.313	2.31	0.130	1.91	0.081	1.46	0.041	1.15	0.023					5.16	0.992
													24"			
12 000	3.93	0.447	2.77	0.184	2.29	0.114	1.75	0.057	1.38	0.032	1.11	0.019			6.20	1.41
14 000	4.59	0.600	3.23	0.246	2.67	0.153	2.05	0.077	1.62	0.044	1.30	0.025			7.23	1.91
16 000	5.24	0.776	3.69	0.317	3.06	0.198	2.34	0.099	1.85	0.056	1.49	0.032	1.03	0.013	8.26	2.48
18 000	5.90	0.975	4.15	0.398	3.44	0.246	2.63	0.124	2.08	0.069	1.67	0.040	1.16	0.016		
20 000	6.55	1.19	4.61	0.487	3.82	0.302	2.92	0.152	2.31	0.084	1.86	0.049	1.28	0.020		
25 000	8.19	1.83	5.77	0.758	4.77	0.469	3.65	0.234	2.89	0.130	2.32	0.076	1.61	0.030		
30 000			6.92	1.08	5.73	0.669	4.38	0.332	3.46	0.183	2.79	0.108	1.93	0.043		
35 000			8.07	1.46	6.68	0.903	5.12	0.446	4.04	0.248	3.25	0.144	2.25	0.057		
40 000			9.23	1.90	7.64	1.17	5.85	0.578	4.62	0.319	3.72	0.186	2.57	0.074		
45 000			10.38	2.39	8.59	1.47	6.58	0.726	5.19	0.400	4.18	0.233	2.89	0.092		
50 000					9.55	1.81	7.31	0.888	5.77	0.491	4.64	0.284	3.21	0.113		
55 000							8.04	1.07	6.35	0.594	5.11	0.343	3.53	0.136		
60 000							8.77	1.27	6.93	0.708	5.58	0.411	3.86	0.161		
65 000							9.5	1.49	7.50	0.822	6.04	0.475	4.18	0.189		
70 000							10.2	1.70	8.08	0.955	6.51	0.552	4.50	0.216		
75 000							11.0	1.98	8.66	1.10	6.97	0.628	4.82	0.246		

VELOCITY AND PRESSURE DROP PER 100m IN NPS 2 PIPES
TABLE 2

Water Flow L/s	Velocity m/s	Pressure drop kPa(gauge)
0.5	0.23	11.6
0.666	0.30	82.7
0.833	0.38	53.9
1.0	0.46	25.5
1.17	0.53	99.8
1.333	0.616	10.2
1.5	0.693	11.5
1.666	0.770	14.1
2.5	1.15	29.5
3.333	1.54	51.2
4.166	1.92	77.3
5.0	2.311	10
5.83	32.691	47
6.66	3.081	92

FRICTION HEAD LOSS FOR WATER

TABLE 3

EQUIVALENT LENGTH IN FEET OF NEW STRAIGHT PIPE FOR VALVES AND FITTINGS FOR TURBULENT FLOW ONLY

FITTINGS			PIPE SIZE																				
			1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	8	10	12	14	16	18	20	24
REGULAR 90° ELL	SCREWED	STEEL	2.3	3.1	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11	13	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	9.0	11	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	.92	1.2	1.6	2.1	2.4	3.1	3.6	4.4	5.9	7.3	8.9	12	14	17	18	21	23	25	30
		C. I.	...	...	...	...	...	...	...	...	...	3.6	4.8	...	7.2	9.8	12	15	17	19	22	24	28
LONG RADIUS 90° ELL	SCREWED	STEEL	1.5	2.0	2.2	2.3	2.7	3.2	3.4	3.6	3.6	4.0	4.6	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	3.3	3.7	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	1.1	1.3	1.6	2.0	2.3	2.7	2.9	3.4	4.2	5.0	5.7	7.0	8.0	9.0	9.4	10	11	12	14
		C. I.	...	...	...	...	...	...	...	...	...	2.8	3.4	...	4.7	5.7	6.8	7.8	8.6	9.6	11	11	13
REGULAR 45° ELL	SCREWED	STEEL	.34	.52	.71	.92	1.3	1.7	2.1	2.7	3.2	4.0	5.5	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	3.3	4.5	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	.45	.59	.81	1.1	1.3	1.7	2.0	2.6	3.5	4.5	5.6	7.7	9.0	11	13	15	16	18	22
		C. I.	...	...	...	...	...	...	...	...	...	2.1	2.9	...	4.5	6.3	8.1	9.7	12	13	15	17	20
TEE-LINE FLOW	SCREWED	STEEL	.79	1.2	1.7	2.4	3.2	4.6	5.6	7.7	9.3	12	17	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	9.9	14	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	.69	.82	1.0	1.3	1.5	1.8	1.9	2.2	2.8	3.3	3.8	4.7	5.2	6.0	6.4	7.2	7.6	8.2	9.6
		C. I.	...	...	...	...	...	...	...	...	...	1.9	2.2	...	3.1	3.9	4.6	5.2	5.9	6.5	7.2	7.7	8.8
TEE-BRANCH FLOW	SCREWED	STEEL	2.4	3.5	4.2	5.3	6.6	8.7	9.9	12	13	17	21	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	14	17	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	2.0	2.6	3.3	4.4	5.2	6.6	7.5	9.4	12	15	18	24	30	34	37	43	47	52	62
		C. I.	...	...	...	...	...	...	...	...	...	7.7	10	...	15	20	25	30	35	39	44	49	57
180° RETURN BEND	SCREWED	STEEL	2.3	3.1	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11	13	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	9.0	11	...	...	...	...	...	...	...	...	...	...
	REG. FLANGED	STEEL	...	...	.92	1.2	1.6	2.1	2.4	3.1	3.6	4.4	5.9	7.3	8.9	12	14	17	18	21	23	25	30
		C. I.	...	...	...	...	...	...	...	...	...	3.6	4.8	...	7.2	9.8	12	15	17	19	22	24	28
	LONG RAD. FLANGED	STEEL	...	...	1.1	1.3	1.6	2.0	2.3	2.7	2.9	3.4	4.2	5.0	5.7	7.0	8.0	9.0	9.4	10	11	12	14
		C. I.	...	...	...	...	...	...	...	...	...	2.8	3.4	...	4.7	5.7	6.8	7.8	8.6	9.6	11	11	13
GLOBE VALVE	SCREWED	STEEL	21	22	22	24	29	37	42	54	62	79	110	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	65	86	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	38	40	45	54	59	70	77	94	120	150	190	260	310	390	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	77	99	...	150	210	270	330	...	...	...	...	...
GATE VALVE	SCREWED	STEEL	.32	.45	.56	.67	.84	1.1	1.2	1.5	1.7	1.9	2.5	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	1.6	2.0	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	...	...	...	...	...	2.6	2.7	2.8	2.9	3.1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
		C. I.	...	...	...	...	...	...	...	...	...	2.3	2.4	...	2.6	2.7	2.8	2.9	2.9	3.0	3.0	3.0	3.0
ANGLE VALVE	SCREWED	STEEL	12.8	15	15	15	17	18	18	18	18	18	18	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	15	15	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	15	15	17	18	18	21	22	28	38	50	63	90	120	140	160	190	210	240	300
		C. I.	...	...	...	...	...	...	...	...	...	23	31	...	52	74	98	120	150	170	200	230	280
SWING CHECK VALVE	SCREWED	STEEL	7.2	7.3	8.0	8.8	11	13	15	19	22	27	38	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	22	31	...	...	...	...	...	...	...	...	...	...
	FLANGED	STEEL	...	...	3.8	5.3	7.2	10	12	17	21	27	38	50	63	90	120	140	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	22	31	...	52	74	98	120	...	...	...	...	...
COUPLING OR UNION	SCREWED	STEEL	.14	.18	.21	.24	.29	.36	.39	.45	.47	.53	.65	...	...	...	...	...	...	...	...	...	...
		C. I.	...	...	...	...	...	...	...	...	...	.44	.52	...	...	...	...	...	...	...	...	...	...
	BELL MOUTH INLET	STEEL	.04	.07	.10	.13	.18	.26	.31	.43	.52	.67	.95	1.3	1.6	2.3	2.9	3.5	4.0	4.7	5.3	6.1	7.6
		C. I.	...	...	...	...	...	...	...	...	...	.55	.77	...	1.3	1.9	2.4	3.0	3.6	4.3	5.0	5.7	7.0
	SQUARE MOUTH INLET	STEEL	.44	.68	.96	1.3	1.8	2.6	3.1	4.3	5.2	6.7	9.5	13	16	23	29	35	40	47	53	61	76
		C. I.	...	...	...	...	...	...	...	...	...	5.5	7.7	...	13	19	24	30	36	43	50	57	70
	RE-ENTRANT PIPE	STEEL	.88	1.4	1.9	2.6	3.6	5.1	6.2	8.5	10	13	19	25	32	45	58	70	80	95	110	120	150
		C. I.	...	...	...	...	...	...	...	...	...	11	15	...	26	37	49	61	73	86	100	110	140
	Y-STRAINER			4.6	5.0	6.6	7.7	18	20	27	29	34	42	53	61								
	SUDDEN ENLARGEMENT		$h = \frac{(V_1 - V_2)^2}{2g}$ FEET OF LIQUID; IF $V_2 = 0$ $h = \frac{V_1^2}{2g}$ FEET OF LIQUID																				

TABLE 4

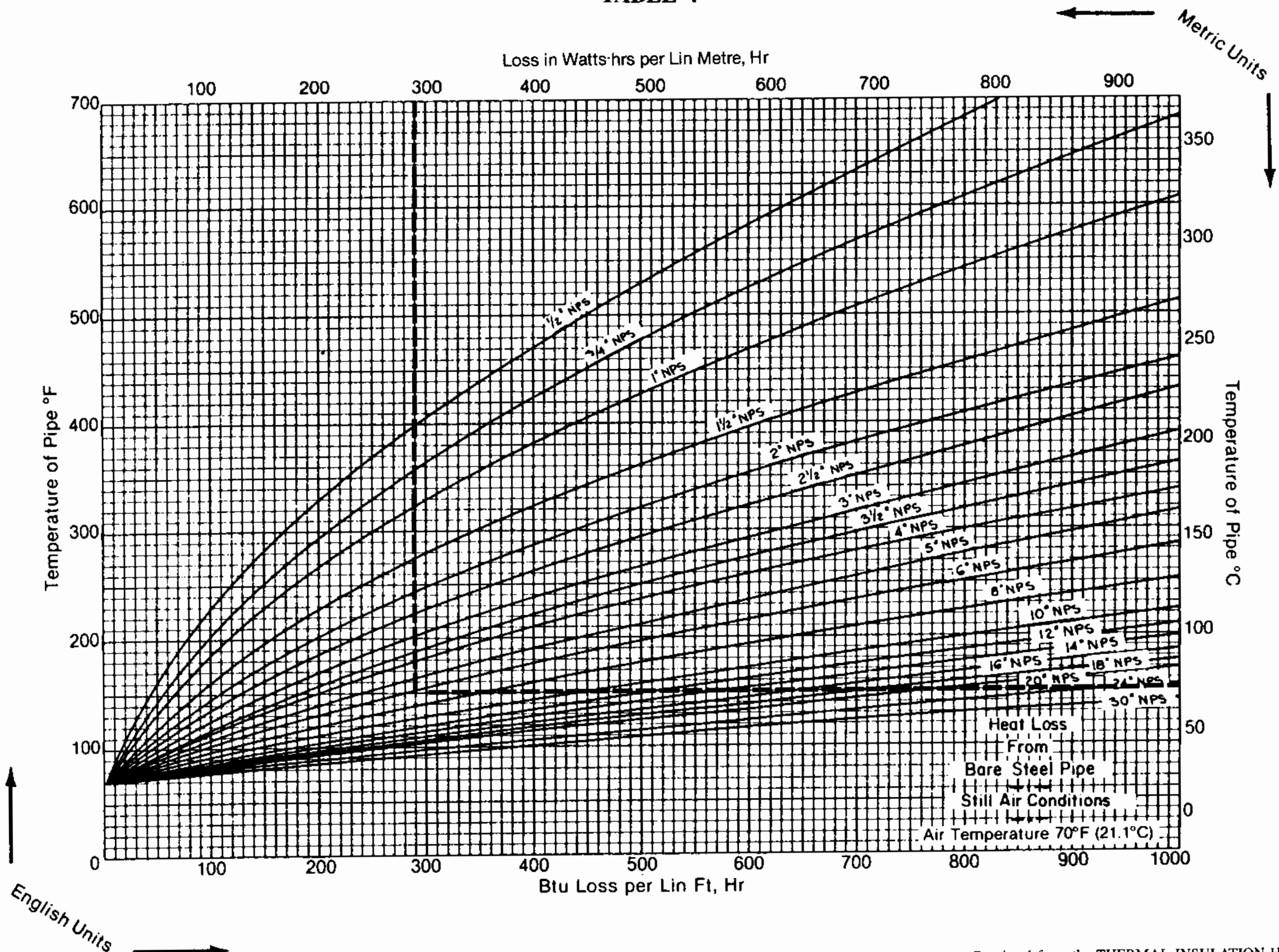


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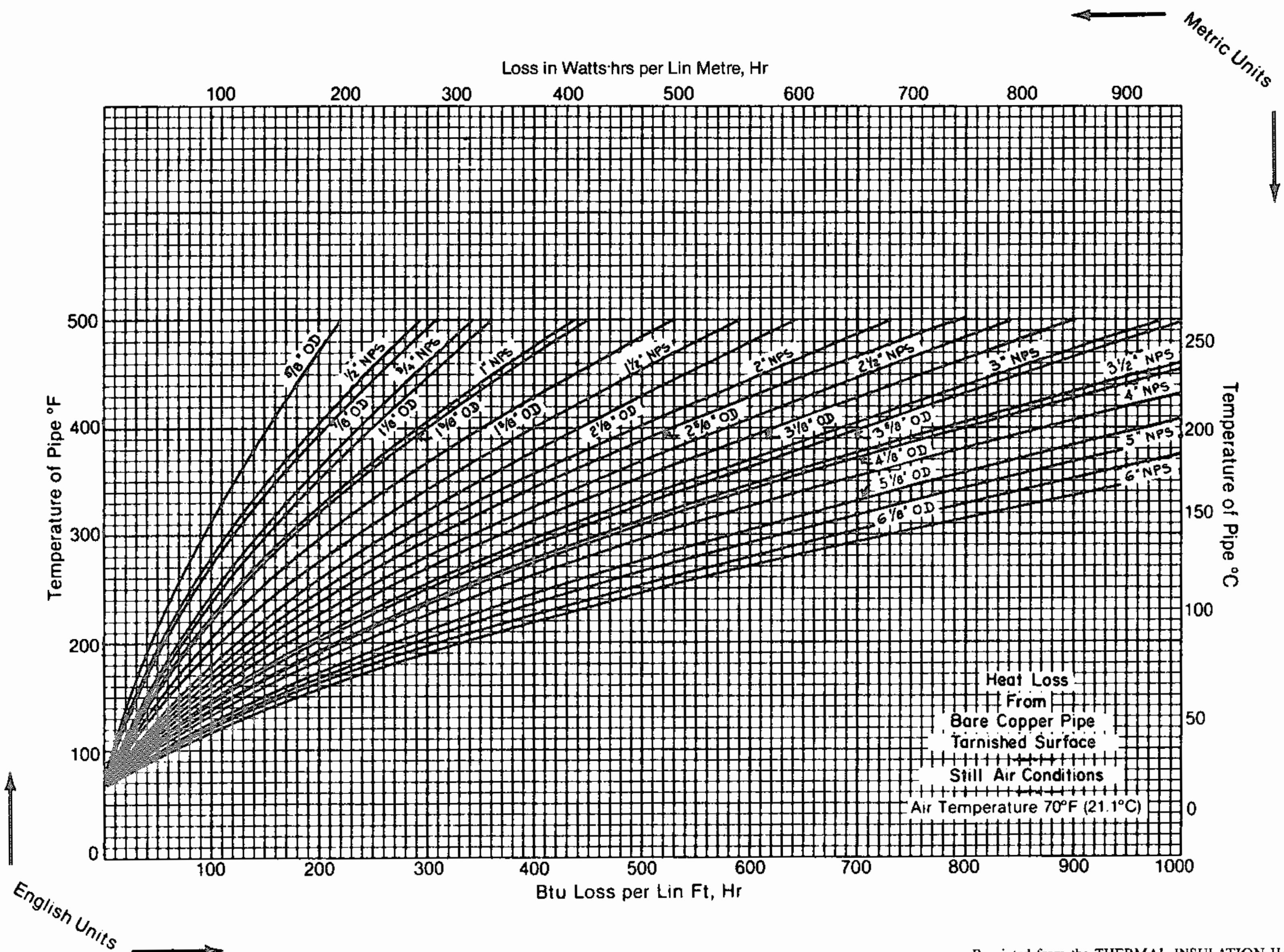
TABLE 5



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TYPICAL COMPRESSED AIR LEAKAGE
TABLE 6

Hole Diameter	Air Leakage at 600 kPa(gauge)	Cost per month $0.05/kWh
1 mm	1 L/s	$ 10
3 mm	10 L/s	$ 111
5 mm	26.7 L/s	$ 298
10 mm	105 L/s	$1,182

FLOW OF AIR THROUGH SCHEDULE 40 STEEL PIPE

TABLE 7

Courtesy of Crane Co.

Free Air q_m Cubic Metres per Minute at 15 C and 1.013 bar abs	Compressed Air Cubic Metres per Minute at 15 C and 7 bar gauge	Pressure Drop of Air In Bars per 100 Metres of Schedule 40 Pipe — For Air at 7 bar gauge pressure and 15 C Temperature								
		1/8″	1/4″	3/8″	1/2″					
0.03	0.0038	0.093	0.021	0.0045						
0.06	0.0076	0.337	0.072	0.016	0.0051					
0.09	0.0114	0.719	0.154	0.033	0.011	3/4″				
0.12	0.0152	1.278	0.267	0.058	0.018					
0.15	0.0190	1.942	0.405	0.087	0.027	0.0067	1″			
0.2	0.0253	3.357	0.698	0.146	0.047	0.011	0.0035			
0.3	0.0379	7.554	1.57	0.319	0.099	0.024	0.0073			
0.4	0.0506		2.71	0.548	0.170	0.041	0.012	1-1/4″		
0.5	0.0632		4.10	0.842	0.257	0.062	0.018			
0.6	0.0759		5.90	1.19	0.370	0.088	0.026	0.0066	1-1/2″	
0.7	0.0885		8.03	1.62	0.494	0.117	0.035	0.0086	0.0041	
0.8	0.101			2.12	0.634	0.150	0.044	0.011	0.0053	
0.9	0.114			2.64	0.803	0.187	0.055	0.014	0.0065	
1.0	0.126			3.26	0.991	0.231	0.067	0.017	0.0079	
1.25	0.158			4.99	1.55	0.353	0.102	0.026	0.012	2″
1.5	0.190			7.20	2.19	0.499	0.147	0.036	0.017	0.0048
1.75	0.221	2-1/2″		9.79	2.98	0.679	0.196	0.047	0.022	0.0064
2.0	0.253				3.82	0.871	0.257	0.062	0.029	0.0082
2.25	0.284	0.0042			4.84	1.10	0.325	0.076	0.036	0.010
2.5	0.316	0.0051			5.97	1.36	0.393	0.094	0.045	0.012
3.0	0.379	0.0073			8.6	1.92	0.565	0.135	0.063	0.018
3.5	0.442	0.0097	3″			2.61	0.754	0.184	0.086	0.024
4.0	0.506	0.012				3.41	0.984	0.236	0.110	0.030
4.5	0.569	0.016	0.0051			4.32	1.25	0.298	0.136	0.038
5.0	0.632	0.019	0.0063	3-1/2″		5.34	1.54	0.368	0.164	0.046
6	0.759	0.027	0.0090			7.68	2.17	0.518	0.236	0.066
7	0.885	0.036	0.012	0.0059			2.95	0.689	0.321	0.090
8	1.011	0.047	0.015	0.0075			3.85	0.900	0.419	0.115
9	1.138	0.058	0.019	0.0094			4.88	1.14	0.530	0.145
10	1.264	0.072	0.023	0.011	4″		6.02	1.41	0.640	0.179
11	1.391	0.085	0.028	0.014	0.0073		7.29	1.71	0.774	0.217
12	1.517	0.101	0.033	0.016	0.0085		8.67	2.02	0.921	0.252
13	1.643	0.119	0.039	0.019	0.0098			2.38	1.08	0.295
14	1.770	0.138	0.045	0.022	0.011			2.76	1.25	0.343
15	1.896	0.158	0.051	0.025	0.013			3.13	1.44	0.393
16	2.023	0.178	0.058	0.028	0.015			3.57	1.64	0.443
17	2.149	0.200	0.065	0.031	0.016			4.01	1.85	0.500
18	2.276	0.223	0.072	0.035	0.018	5″		4.49	2.07	0.558
19	2.402	0.247	0.081	0.039	0.020			5.01	2.31	0.618
20	2.528	0.266	0.089	0.043	0.022	0.0072		5.49	2.53	0.685
22	2.781	0.328	0.107	0.052	0.027	0.0086		6.65	3.07	0.825
24	3.034	0.388	0.126	0.061	0.032	0.010	6″	7.91	3.61	0.982
26	3.287	0.455	0.148	0.071	0.037	0.012		9.28	4.22	1.15
28	3.540	0.525	0.171	0.082	0.043	0.014	0.0054		4.86	1.33
30	3.793	0.603	0.197	0.094	0.049	0.016	0.0061		5.62	1.52
32	4.046	0.682	0.222	0.106	0.055	0.018	0.0069		6.39	1.73
34	4.298	0.770	0.251	0.119	0.062	0.020	0.0078		7.22	1.94
36	4.551	0.863	0.280	0.134	0.070	0.022	0.0087		8.09	2.17
38	4.804	0.957	0.312	0.148	0.077	0.024	0.0096			2.41
40	5.057	1.05	0.346	0.164	0.086	0.027	0.011			2.67
45	5.689	1.33	0.435	0.207	0.107	0.034	0.013	8″		3.36
50	6.321	1.65	0.534	0.254	0.132	0.042	0.016			4.15
60	7.585	2.37	0.765	0.363	0.188	0.059	0.023	0.0058		5.98
70	8.850	3.23	1.03	0.495	0.254	0.080	0.031	0.0077		8.14
80	10.11	4.22	1.35	0.639	0.332	0.104	0.040	0.010	10″	
90	11.38	5.34	1.70	0.808	0.418	0.130	0.051	0.013	0.0041	
100	12.64	6.59	2.10	0.992	0.513	0.160	0.062	0.015	0.0050	
110	13.91	7.97	2.54	1.19	0.621	0.192	0.075	0.019	0.0060	
120	15.17	9.49	3.02	1.42	0.739	0.228	0.089	0.022	0.0071	
130	16.43		3.55	1.67	0.862	0.267	0.103	0.026	0.0082	12″
140	17.70		4.12	1.93	1.00	0.308	0.120	0.029	0.0095	
150	18.96		4.73	2.22	1.15	0.353	0.138	0.034	0.011	0.0045
200	25.28		8.4	3.94	2.03	0.628	0.243	0.059	0.019	0.0078
250	31.61			6.16	3.17	0.975	0.378	0.090	0.029	0.012
300	37.93			8.88	4.56	1.40	0.540	0.129	0.041	0.017
350	44.25				6.21	1.90	0.735	0.174	0.056	0.023
400	50.57				8.11	2.48	0.960	0.227	0.072	0.030
450	56.89					3.14	1.215	0.286	0.091	0.037
500	63.21					3.88	1.50	0.352	0.112	0.046
550	69.53					4.69	1.82	0.424	0.134	0.055
600	75.85					5.58	2.16	0.504	0.160	0.066
650	82.17					6.55	2.54	0.592	0.188	0.076
700	88.50					7.60	2.94	0.686	0.218	0.089
750	94.82					8.72	3.38	0.788	0.248	0.101
800	101.1						3.84	0.896	0.282	0.115
850	107.5						4.34	1.01	0.319	0.130

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (TEMPERATURE)

TABLE 8

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	2348,8	2616,6	0,8809	6,9667	7,8477
66.0	339.15	26.150	0.0010205	5,947	5.948	276.21	2343,9	2620.1	0,9057	6,9111	7,8168
68.0	341.15	28.563	0.0010217	5,475	5,476	284,59	2338,9	2623,5	0,9303	6,8561	7,7864
70.0	343.15	31.16	0.0010228	5,045	5.046	292,97	2334,0	2626,9	0,9548	6,8017	7,7565
72.0	345.15	33,96	0.0010241	4,655	4.656	301,36	2329,0	2630,3	0,9792	6,7478	7,7270
74.0	347.15	36,96	0.0010253	4,299	4.300	309,74	2324,0	2633,7	1,0034	6,6945	7,6979
76.0	349.15	40.19	0.0010266	3,975	3,976	318,13	2318,9	2637,1	1,0275	6,6418	7,6693
78.0	351.15	43,65	0.0010279	3,679	3.680	326,52	2313,9	2640.4	1,0514	6,5896	7,6410
80.0	353.15	47,36	0.0010292	3.408	3.409	334,92	2308,8	2643,8	1,0753	6,5380	7,6132
82.0	355.15	51,33	0.0010305	3,161	3.162	343.31	2303,8	2647,1	1,0990	6,4868	7,5858
84.0	357.15	55,57	0.0010319	2,934	2,935	351,71	2298,6	2650,4	1,1225	6,4362	7,5588
86.0	359.15	60.11	0.0010333	2,726	2,727	360,12	2293,5	2653,6	1,1460	6,3861	7,5321
88.0	361.15	64,95	0.0010347	2,535	2,536	368,53	2288,4	2656.9	1,1693	6,3365	7,5058
90.0	363.15	70,11	0.0010361	2,3603	2,3613	376,94	2283,2	2660,1	1,1925	6,2873	7,4799
92.0	365.15	75,61	0.0010376	2,1992	2,2002	385,36	2278,0	2663,4	1,2156	6,2387	7,4543
94.0	367.15	81,46	0.0010391	2,0509	2,0519	393,78	2272,9	2666,6	1,2386	6,1905	7,4291
96.0	369.15	87,69	0.0010406	1,9143	1,9153	402,20	2267,5	2669,7	1,2615	6,1427	7,4042
98.0	371.15	94,30	0.0010421	1,7883	1,7893	410.63	2262,2	2672,9	1,2842	6,0954	7,3796
100.0	373.15	101.33	0.0010437	1.6720	1.6730	419.06	2256,9	2676,0	1,3069	6,0485	7,3554

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (TEMPERATURE)

TABLE 8

Temperature °C t	Temperature K T	Press. kPa p	Volume, m^3/kg Water v_f	Volume, m^3/kg Evap. v_{fg}	Volume, m^3/kg Steam v_g	Enthalpy, kJ/kg Water h_f	Enthalpy, kJ/kg Evap. h_{fg}	Enthalpy, kJ/kg Steam h_g	Entropy, kJ/kg K Water s_f	Entropy, kJ/kg K Evap. s_{fg}	Entropy, kJ/kg K Steam s_g
100.0	373.15	101.33	0.0010437	1.6720	1.6730	419.06	2256.9	2676.0	1.3069	6.0485	7.3554
105.0	378.15	120.80	0.0010477	1.4182	1.4193	440.17	2243.6	2683.7	1.3630	5.9331	7.2962
110.0	383.15	143.27	0.0010519	1.2089	1.2099	461.32	2230.0	2691.3	1.4185	5.8203	7.2388
115.0	388.15	169.06	0.0010562	1.0352	1.0363	482.50	2216.2	2698.7	1.4733	5.7099	7.1832
120.0	393.15	198.54	0.0010606	0.8905	0.8915	503.72	2202.2	2706.0	1.5276	5.6017	7.1293
125.0	398.15	232.1	0.0010652	0.7692	0.7702	524.99	2188.0	2713.0	1.5813	5.4957	7.0769
130.0	403.15	270.1	0.0010700	0.6671	0.6681	546.31	2173.6	2719.9	1.6344	5.3917	7.0261
135.0	408.15	313.1	0.0010750	0.5807	0.5818	567.68	2158.9	2726.6	1.6869	5.2897	6.9766
140.0	413.15	361.4	0.0010801	0.5074	0.5085	589.10	2144.0	2733.1	1.7390	5.1894	6.9284
145.0	418.15	415.5	0.0010853	0.4449	0.4460	610.59	2128.7	2739.3	1.7906	5.0910	6.8815
150.0	423.15	476.0	0.0010908	0.3914	0.3924	632.15	2113.2	2745.4	1.8416	4.9941	6.8358
155.0	428.15	543.3	0.0010964	0.3453	0.3464	653.77	2097.4	2751.2	1.8923	4.8989	6.7911
160.0	433.15	618.1	0.0011022	0.3057	0.3068	675.47	2081.3	2756.7	1.9425	4.8050	6.7475
165.0	438.15	700.8	0.0011082	0.2713	0.2724	697.25	2064.8	2762.0	1.9923	4.7126	6.7048
170.0	443.15	792.0	0.0011145	0.2414	0.2426	719.12	2047.9	2767.1	2.0416	4.6214	6.6630
175.0	448.15	892.4	0.0011209	0.21542	0.21654	741.07	2030.7	2771.8	2.0906	4.5314	6.6221
180.0	453.15	1002.7	0.0011275	0.19267	0.19380	763.12	2013.2	2776.3	2.1393	4.4426	6.5819
185.0	458.15	1123.3	0.0011344	0.17272	0.17386	785.26	1995.2	2780.4	2.1876	4.3548	6.5424
190.0	463.15	1255.1	0.0011415	0.15517	0.15632	807.52	1976.7	2784.3	2.2356	4.2680	6.5036
195.0	468.15	1398.7	0.0011489	0.13969	0.14084	829.88	1957.9	2787.8	2.2833	4.1821	6.4654
200.0	473.15	1554.9	0.0011565	0.12600	0.12716	852.37	1938.6	2790.9	2.3307	4.0971	6.4278
205.0	478.15	1724.3	0.0011644	0.11386	0.11503	874.99	1918.8	2793.8	2.3778	4.0128	6.3906
210.0	483.15	1907.7	0.0011726	0.10307	0.10424	897.73	1898.5	2796.2	2.4247	3.9293	6.3539
215.0	488.15	2106.0	0.0011811	0.09344	0.09463	920.63	1877.6	2798.3	2.4713	3.8463	6.3176
220.0	493.15	2319.8	0.0011900	0.08485	0.08604	943.67	1856.2	2799.9	2.5178	3.7639	6.2817
225.0	498.15	2550.	0.0011992	0.07715	0.07835	966.88	1834.3	2801.2	2.5641	3.6820	6.2461
230.0	503.15	2798.	0.0012087	0.07024	0.07149	990.27	1811.7	2802.0	2.6102	3.6006	6.2107
235.0	508.15	3063.	0.0012187	0.06403	0.06525	1013.83	1788.5	2802.3	2.6561	3.5194	6.1756
240.0	513.15	3348.	0.0012291	0.05843	0.05965	1037.60	1764.6	2802.2	2.7020	3.4386	6.1406
245.0	518.15	3652.	0.0012399	0.05337	0.05461	1061.58	1740.0	2801.6	2.7478	3.3579	6.1057
250.0	523.15	3978.	0.0012513	0.04879	0.05004	1085.78	1714.7	2800.4	2.7935	3.2773	6.0708
255.0	528.15	4325.	0.0012632	0.04463	0.04590	1110.23	1688.5	2798.7	2.8392	3.1968	6.0359
260.0	533.15	4694.	0.0012756	0.04086	0.04213	1134.94	1661.5	2796.4	2.8848	3.1161	6.0010
265.0	538.15	5088.	0.0012887	0.03742	0.03871	1159.93	1633.5	2793.5	2.9306	3.0353	5.9658
270.0	543.15	5506.	0.0013025	0.03429	0.03559	1185.23	1604.6	2789.9	2.9763	2.9541	5.9304
275.0	548.15	5950.	0.0013170	0.03142	0.03274	1210.86	1574.7	2785.5	3.0222	2.8725	5.8947
280.0	553.15	6420.	0.0013324	0.02879	0.03013	1236.84	1543.6	2780.4	3.0683	2.7903	5.8586
285.0	558.15	6919.	0.0013487	0.02638	0.02773	1263.21	1511.3	2774.5	3.1146	2.7074	5.8220
290.0	563.15	7446.	0.0013659	0.02417	0.02554	1290.01	1477.6	2767.6	3.1611	2.6237	5.7848
295.0	568.15	8004.	0.0013844	0.02213	0.02351	1317.27	1442.6	2759.8	3.2079	2.5389	5.7469
300.0	573.15	8593.	0.0014041	0.020245	0.021649	1345.05	1406.0	2751.0	3.2552	2.4529	5.7081
305.0	578.15	9214.	0.0014252	0.018502	0.019927	1373.40	1367.7	2741.1	3.3029	2.3656	5.6685
310.0	583.15	9870.	0.0014480	0.016886	0.018334	1402.39	1327.6	2730.0	3.3512	2.2766	5.6278
315.0	588.15	10561.	0.0014726	0.015383	0.016856	1432.09	1285.5	2717.6	3.4002	2.1856	5.5858
320.0	593.15	11289.	0.0014995	0.013980	0.015480	1462.60	1241.1	2703.7	3.4500	2.0923	5.5423
325.0	598.15	12056.	0.0015289	0.012666	0.014195	1494.03	1194.0	2688.0	3.5008	1.9961	5.4969
330.0	603.15	12863.	0.0015615	0.011428	0.012989	1526.52	1143.6	2670.2	3.5528	1.8962	5.4490
335.0	608.15	13712.	0.0015978	0.010256	0.011854	1560.25	1089.5	2649.7	3.6063	1.7916	5.3979
340.0	613.15	14605.	0.0016387	0.009142	0.010780	1595.47	1030.7	2626.2	3.6616	1.6811	5.3427
345.0	618.15	15545.	0.0016858	0.008077	0.009763	1632.52	966.4	2598.9	3.7193	1.5636	5.2828
350.0	623.15	16535.	0.0017411	0.007058	0.008799	1671.94	895.7	2567.7	3.7800	1.4376	5.2177
355.0	628.15	17577.	0.0018085	0.006051	0.007859	1716.63	813.8	2530.4	3.8489	1.2953	5.1442
360.0	633.15	18675.	0.0018959	0.005044	0.006940	1764.17	721.3	2485.4	3.9210	1.1390	5.0600
365.0	638.15	19833.	0.0020160	0.003996	0.006012	1817.96	610.0	2428.0	4.0021	0.9558	4.9579
370.0	643.15	21054.	0.0022136	0.002759	0.004973	1890.21	452.6	2342.8	4.1108	0.7036	4.8144
371.0	644.15	21306.	0.0022778	0.002446	0.004723	1910.50	407.4	2317.9	4.1414	0.6324	4.7738
372.0	645.15	21562.	0.0023636	0.002075	0.004439	1935.57	351.4	2287.0	4.1794	0.5446	4.7240
373.0	646.15	21820.	0.0024963	0.001588	0.004084	1970.50	273.5	2244.0	4.2326	0.4233	4.6559
374.0	647.15	22081.	0.0028427	0.000623	0.003466	2046.72	109.5	2156.2	4.3493	0.1692	4.5185
374.15	647.30	22120.	0.00317	0.0	0.00317	2107.37	0.0	2107.4	4.4429	0.0	4.4429

PROPERTIES OF SATURATED STEAM AND SATURATED WATER (PRESSURE)

TABLE 8

Press. kPa p	Temp. °C t	Volume, m³/kg Water v_f	Volume, m³/kg Evap. v_{fg}	Volume, m³/kg Steam v_g	Enthalpy, kJ/kg Water h_f	Enthalpy, kJ/kg Evap. h_{fg}	Enthalpy, kJ/kg Steam h_g	Entropy, kJ/kg K Water s_f	Entropy, kJ/kg K Evap. s_{fg}	Entropy, kJ/kg K Steam s_g	Energy, kJ/kg Water u_f	Energy, kJ/kg 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	0.0010018	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 8

Press. kPa p	Temp. °C t	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	Energy, kJ/kg Water u_f	Steam u_g
240.	126.09	0.0010663	0.7454	0.7465	529.6	2184.9	2714.5	1.5989	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.	175.36	0.0011213	0.21369	0.21481	742.6	2029.5	2772.1	2.0941	4.5250	6.6192	741.63	2578.8
1000.	179.88	0.0011274	0.19317	0.19429	762.6	2013.6	2776.2	2.1382	4.4446	6.5828	761.48	2581.9
1100.	184.07	0.0011331	0.17629	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

POWER REQUIRED FOR PUMPING

TABLE 9

Theoretical Power in kilowatts (kW) to Raise Water (at 15 C) to Different Heights

Litres per Min.	Metres														
	2	4	6	8	10	12	14	16	18	20	25	30	35	40	45
20	0.007	0.013	0.020	0.026	0.033	0.039	0.046	0.052	0.059	0.065	0.082	0.098	0.114	0.131	0.147
40	0.013	0.026	0.039	0.052	0.065	0.078	0.091	0.105	0.118	0.131	0.163	0.196	0.229	0.261	0.294
60	0.020	0.039	0.059	0.078	0.098	0.118	0.137	0.157	0.176	0.196	0.245	0.294	0.343	0.392	0.441
80	0.026	0.052	0.078	0.105	0.131	0.157	0.183	0.209	0.235	0.261	0.327	0.392	0.457	0.523	0.588
100	0.033	0.065	0.098	0.131	0.163	0.196	0.229	0.261	0.294	0.327	0.408	0.490	0.572	0.653	0.735
120	0.039	0.078	0.118	0.157	0.196	0.235	0.274	0.314	0.353	0.392	0.490	0.588	0.686	0.784	0.882
140	0.046	0.091	0.137	0.183	0.229	0.274	0.320	0.366	0.412	0.457	0.572	0.686	0.800	0.915	1.029
160	0.052	0.105	0.157	0.209	0.261	0.314	0.366	0.418	0.470	0.523	0.653	0.784	0.915	1.045	1.176
180	0.059	0.118	0.176	0.235	0.294	0.353	0.412	0.470	0.529	0.588	0.735	0.882	1.029	1.176	1.323
200	0.065	0.131	0.196	0.261	0.327	0.392	0.457	0.523	0.588	0.653	0.817	0.980	1.143	1.307	1.470
250	0.082	0.163	0.245	0.327	0.408	0.490	0.572	0.653	0.735	0.817	1.021	1.225	1.429	1.633	1.838
300	0.098	0.196	0.294	0.392	0.490	0.588	0.686	0.784	0.882	0.980	1.225	1.470	1.715	1.960	2.205
350	0.114	0.229	0.343	0.457	0.572	0.686	0.800	0.915	1.029	1.143	1.429	1.715	2.001	2.287	2.573
400	0.131	0.261	0.392	0.523	0.653	0.784	0.915	1.045	1.176	1.307	1.633	1.960	2.287	2.614	2.940
450	0.147	0.294	0.441	0.588	0.735	0.882	1.029	1.176	1.323	1.470	1.838	2.205	2.573	2.940	3.308
500	0.163	0.327	0.490	0.653	0.817	0.980	1.143	1.307	1.470	1.633	2.042	2.450	2.859	3.267	3.675
600	0.196	0.392	0.588	0.784	0.980	1.176	1.372	1.568	1.764	1.960	2.450	2.940	3.430	3.920	4.410
700	0.229	0.457	0.686	0.915	1.143	1.372	1.601	1.829	2.058	2.287	2.859	3.430	4.002	4.574	5.145
800	0.261	0.523	0.784	1.045	1.307	1.568	1.829	2.091	2.352	2.614	3.267	3.920	4.574	5.227	5.880
900	0.294	0.588	0.882	1.176	1.470	1.764	2.058	2.352	2.646	2.940	3.675	4.410	5.145	5.880	6.615
1000	0.327	0.653	0.980	1.307	1.633	1.960	2.287	2.614	2.940	3.267	4.084	4.900	5.717	6.534	7.351
1250	0.408	0.817	1.225	1.633	2.042	2.450	2.859	3.267	3.675	4.084	5.105	6.125	7.146	8.167	9.188
1500	0.490	0.980	1.470	1.960	2.450	2.940	3.430	3.920	4.410	4.900	6.125	7.351	8.576	9.801	11.03
2000	0.653	1.307	1.960	2.614	3.267	3.920	4.574	5.227	5.880	6.534	8.167	9.801	11.43	13.07	14.70

Litres per Min.	Metres						
	50	55	60	70	80	90	100
20	0.163	0.180	0.196	0.229	0.261	0.294	0.327
40	0.327	0.359	0.392	0.457	0.523	0.588	0.653
60	0.490	0.539	0.588	0.686	0.784	0.882	0.980
80	0.653	0.719	0.784	0.915	1.045	1.176	1.307
100	0.817	0.898	0.980	1.143	1.307	1.470	1.633
120	0.980	1.078	1.176	1.372	1.568	1.764	1.960
140	1.143	1.258	1.372	1.601	1.829	2.058	2.287
160	1.307	1.437	1.568	1.829	2.091	2.352	2.614
180	1.470	1.617	1.764	2.058	2.352	2.646	2.940
200	1.633	1.797	1.960	2.287	2.614	2.940	3.267
250	2.042	2.246	2.450	2.859	3.267	3.675	4.084
300	2.450	2.695	2.940	3.430	3.920	4.410	4.900
350	2.859	3.144	3.430	4.002	4.574	5.145	5.717
400	3.267	3.594	3.920	4.574	5.227	5.880	6.534
450	3.675	4.043	4.410	5.145	5.880	6.615	7.351
500	4.084	4.492	4.900	5.717	6.534	7.351	8.167
600	4.900	5.390	5.880	6.861	7.841	8.821	9.801
700	5.717	6.289	6.861	8.004	9.147	10.29	11.43
800	6.534	7.187	7.841	9.147	10.45	11.76	13.07
900	7.351	8.086	8.821	10.29	11.76	13.23	14.70
1000	8.167	8.984	9.801	11.43	13.07	14.70	16.33
1250	10.21	11.23	12.25	14.29	16.33	18.38	20.42
1500	12.25	13.48	14.70	17.15	19.60	22.05	24.50
2000	16.33	17.97	19.60	22.87	26.14	29.40	32.67

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	= 3600 kilojoules
1 Newton	= 1 kg-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}

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

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

4138T/T33(-4)

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

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

UNIT CONVERSION TABLES
IMPERIAL TO METRIC (cont'd)

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

* "L" as used in Lighting

4138T/T33(-2)

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

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

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

Pump Calculation Sheet

Pump No. ____________________ Date ____________________

Project ____________________ Location ____________________

Worksheet 12-1

Indicate pressure and elevations for each equipment item

Suction Pressure	Loop	A	B
Origin Pressure	kPa(absolute)	___	___
Static Hd. (m x sg x 9.79)	kPa(gauge)	___	___
− Loss (Line + Other) ΔP	kPa(gauge)		
Pump Suction Pressure	kPa(absolute)		
Net Positive Suction Head			
Static Hd.	m	___	___
− Line Loss (kPa x 0.1022/sg)	m	___	___
+ (Orig. Pr. − Vap. Pr.) (0.1022/sg)	m		
Available NPSH	m		
Discharge Pressure			
Delivery Pressure	kPa(absolute)	___	___
Static Head	kPa(gauge)	___	___
Line Loss	kPa(gauge)	___	___
ΔP Control Valves	kPa(gauge)	___	___
ΔP Exchangers	kPa(gauge)	___	___
ΔP Filters	kPa(gauge)	___	___
ΔP Orifices	kPa(gauge)	___	___
ΔP Other	kPa(gauge)		
Pump Discharge Pressure	kPa(absolute)		
Differential Pressure	kPa(absolute)	___	___
Discharge Pressure	kPa(absolute)	___	___
Suction Pressure	kPa(absolute)		
Total Pump ΔP	kPa(gauge)	___	___
Conversion to Metres	m		
Pump Power			

$$\frac{m^3/h \times m \times sg}{367 \times (\text{Pump Eff.})} = kW$$

Service	
Liquid Pumped	
Pumping Temperature (P.T.)	°C =
Viscosity @ P.T.	cp =
Vapor Press. @ Max. P.T.	kPa = (absolute)
Specific Gravity @ P.T.	
Flow, Normal @ 15 °C	m^3/h =
Flow, Normal @ P.T.	m^3/h =
Flow, Design @ P.T.	m^3/h =

Remarks

Simplified Air Leakage Test

Worksheet 12-2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Compressor Number: ______________

Delivered free air capacity of compressor __________ L/s (Q)
(obtain from compressor nameplate)

1 Run compressor until it unloads

2 Record time until compressor loads

3 Record time until compressor unloads

4 Repeat for at least 4 cycles

Cycle	Time: load to unload (T Seconds)	Time: unload to load (t Seconds)
1	....	....
2	....	....
3	....	....
4	....	....
Total	______________ s	______________ s

Average $T = \frac{\text{Total}}{4} = \frac{\_\_\_}{4} = \_\_\_ \text{ s}$ $t = \frac{\text{Total}}{4} = \frac{\_\_\_ \text{ s}}{4} = \_\_\_ \text{ s}$

$$\text{Leakage} = \frac{Q \times T}{T + t} = \frac{\quad \times \quad}{\quad + \quad}$$

$$= \qquad \text{L/s}$$

Refer to Compressors and Turbines, Module 14, for compressor information.

Heat Loss From Bare Piping

Worksheet 12-3

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Pipeline Diameter ____________ m

Pipeline Length ____________ m

Temperature of fluid ____________ °C

Ambient Temperature (t) ____________ °C

Fluid Flow Rate (f_w) ____________ L/s

Hours of operation per year Wh/(m·h) ____________ h

Heat Loss/metre = ____________ Select from Table 4 or 5

Total heat loss = Heat Loss/metre x length x hours/year

= __________x__________

= ____________ Wh/yr

Heat Energy Available From Water Stream

(Approximate Method)
Worksheet 12-4

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Water Stream: ______________________________

Water Flow (f_w) ____________ L/s

Water Entering Temperature (t_1) ____________ °C

Water Leaving Temperature (t_2) ____________ °C

Total Heat Transmitted (Q) = f_w x ($t_1 - t_2$) x 15 MJ/h

= ______ x (___ – ___) x 15

= ____________ MJ/h

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

(Approximate Method)

Worksheet 12-5

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Waste Water Stream: ______________________________

Water Flow (f_w) ____________ L/s

Present Water Temperature (t_1) ____________ °C

Proposed Water Leaving Temperature (t_2) (Obtain this figure from heat exchanger manufacturer) ____________ °C

Heat available (Q) = f_w x (t_1 − t_2) x 15 MJ/h

= ____ x (____ − ____) x 15

= ____________ MJ/h

or $\dfrac{\_\_\_\_\_\_\_\_}{3600}$ MJ/s

= ____________ MJ/s (1)

Proposed Heat Exchanger Efficiency (from heat exchanger manufacturer) ____________ %

Heat Available = ____________ MJ/s x ____________ %

= ____________ MJ/s

Heat Energy Available From Waste Water Stream
To Preheat A Water Stream
(Approximate Method)
Worksheet 12-5
Page 2 of 2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Process Stream

Water Flow (f_w) __________ L/s

Entering Water Temperature (t_1) __________ °C

Required Water Temperature (t_2) __________ °C

Heat Required Q = f_w x (t_1 — t_2) x 15

= ______ x (–) x 15

= – __________ MJ/h

or = $\frac{\text{\_\_\_\_\_\_\_\_\_\_}}{3600}$ MJ/h (drop negative sign)

= __________ MJ/s (2)

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

= (2) MJ/s – (1) MJ/s

= ______ – ______

= ______ MJ/s (3)

Note: Worksheet 12-5 may also be used for cooling applications. In cooling application (1) will be negative indicating an ability to accept heat energy. The negative sign is dropped for the remaining calculations.

Steam Requirements To Heat Water In Steam To Water Heat Exchanger

(Approximate Method)
Worksheet 12-6
Page 1 of 2

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

Steam

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

Condensate

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

Heat available from Steam	=	(1) – (2)		kJ/kg	
	=	________ – ________		kJ/kg	
	=	____________		kJ/kg	(3)
Heat exchanger efficiency (obtain from heat exchanger manufacturer)			________	%	(4)
Heat available to process water	=	(3) x (4)		kJ/kg	
	=	________ x ________			
	=	____________		kJ/kg	
	or	$\frac{\text{\_\_\_\_\_\_\_\_\_\_\_\_}}{1000}$		$\frac{\text{kJ/kg}}{\text{kJ/MJ}}$	
	=	____________		MJ/kg	(5)
Steam required by process steam (no heat recovery)	=	$\frac{\text{worksheet 12-5 (3)}}{\text{worksheet 12-6 (5)}}$			
	=	____________		$\frac{\text{MJ/s}}{\text{MJ/kg}}$	
	=	____________		kg/s	(6)

Steam Requirements To Heat Water In Steam To Water Heat Exchanger

(Approximate Method)

Worksheet 12-6

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

Steam required by process stream (with heat recovery)	=	$\frac{\text{worksheet 12-5 (2)}}{\text{worksheet 12-6 (5)}}$		
	=	____________	MJ/s / MJ/kg	
		____________	kg/s	(7)
Steam Saving due to waste heat recovery	=	(6) − (7)		
	=	______ − ______		
	=	____________	kg/s	(8)
Hours of operation per year	=	____________	h	(9)
Annual steam saving due to heat recovery	=	(8) x (9) x 3600		
	=	______ x ______ x 3600		
	=	____________	kg/yr	(10)
Steam cost	=	$ ____________	/1000 kg	(11)
Annual dollar savings	=	(10) x (11)		
	=	$ ____________	per year	(12)
Cost (installed) of heat recovery equipment	=	$ ____________		(13)
Simple payback	=	$\frac{(13)}{(12)}$		
	=	________ years		