TECHNICAL GUIDE 13.0

Steam efficiency – a systematic approach to reducing energy wastage

Steam is an important energy carrier for industry and the costs can vary significantly. This guide outlines the key components of a steam system and where energy savings opportunities are typically available. Taking a systematic approach reduces a business's overall energy bill, helps all related systems operate more efficiently, and improves profitability.

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1 Introduction

1.1 Why review your steam system?

Many managers and accountants see energy costs involved in producing and using steam as a fixed line item in the accounts.

Like all energy costs, however steam costs should be treated as a variable cost that can be controlled.

Costs vary depending on how steam is produced and used, and how the steam system is operated and maintained. A poorly operated and maintained system can easily use twice the amount of fuel that a well-operated and maintained system will use.

This guide provides an overview of each stage of a steam system and the potential energy cost saving opportunities.

1.2 What is steam?

Steam is water in a gaseous state and is generated by heating water.

It is used in numerous New Zealand industries, such as in the manufacture of car tyres, processing of canned food and for sterilisation in hospitals.

Steam system losses can be substantial unless steam systems are carefully designed, well maintained and properly operated. Losses can result in reduced efficiency and increased costs.

An understanding of the properties of steam and steam systems will assist in detecting and addressing system losses. A brief discussion on the properties and characteristics of steam, and some basic thermodynamics, is included in Appendix I.

1.3 Why do inefficiencies occur?

Even the best systems lose some energy, mostly in the form of heat. This is unavoidable because perfect combustion in boilers is impossible, and zero-heat-loss insulation is unavailable.

The good news is that in most systems, there are opportunities to minimise losses and make savings. A systematic approach that considers the whole system will have a greater impact in the reduction of energy costs than simply targeting one isolated part of the system. Case studies published by EECA give examples where paybacks of between ten months and three years are achieved.

2 A typical steam system – components and costs

2.1 The main components

Figure 1 shows a typical steam system in diagrammatic form.

A steam system can be broken down into five basic components:

- Steam generation plant
- Steam distribution system
- Steam-using equipment
- Process heat recovery
- Condensate recovery system.

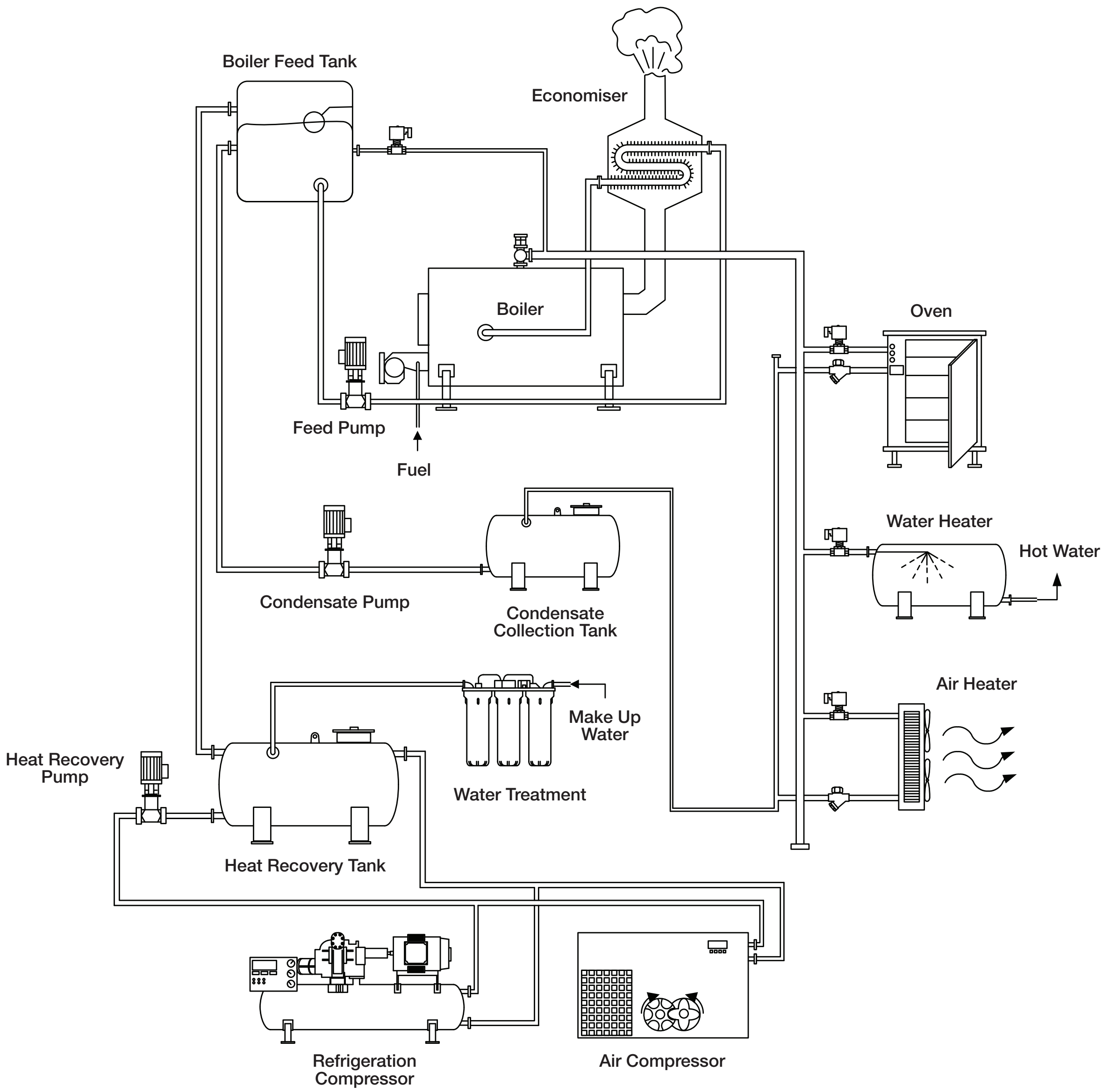

Figure 1: Outline Diagram of a Typical Steam System

The **steam generation plant** can take various forms and use a range of fuels. **Boiler** is the general term used for this plant, although the term **steam generator** is often used when referring to a specific type of plant. Boiler technology is well established and the basic concept has not changed for many years. Efficiencies have improved with the use of modern technology, mainly in respect to controlling the combustion process.

The **steam distribution system** is primarily made up of pipes and valves that transport the steam from the generation plant to various points of use. This can be a major source of energy inefficiencies if poorly designed or maintained.

The **steam-using equipment** typically uses steam to convert heat into another form, such as hot air for drying or boiling water to cook a product. The equipment can range in size from a large milk dryer to a small food cooker. Other applications include space heating, where steam is used to heat air or water through heat exchangers.

In recent years, due to the increase in boiler fuel prices and advancements in technology, **process heat recovery** systems have become more common. These systems utilise waste heat from other equipment or processes to either preheat boiler feedwater or simply replace the use of steam, reducing the system's overall load.

In most situations, after the steam is used it will condense back into hot water, which contains significant energy in the form of heat. This hot water is collected and returned to the boilerhouse through the **condensate recovery system**. In the boilerhouse, condensate is stored in boiler feedwater tanks (sometimes referred to as hot wells) and eventually pumped back into the boilers and generally mixed with some fresh (makeup) water.

2.2 Operating costs of a steam system

When considering the overall costs in operating a steam system, three main categories must be accounted for. These are the cost of fuel, other operating and maintenance costs, and the steam system efficiency.

Fuel costs

The cost of fuel is a major factor and can range from near zero where waste product is used (e.g. wood waste), through to $30 or more per gigajoule (GJ) where oil-based fuels are used. The table below sets out typical fuel cost ranges (current as at October 2011):

Fuel	Cost per GJ
Natural gas	$8 to $15
LPG	$30 to $40
Coal	$4 to $6
Oil	$20 to $30

In all cases, the cost is heavily influenced by the quantity used. The lower fuel costs would apply to larger consumers. Location and transport costs will also influence the final cost.

For the purposes of this guide, we have adopted $12 per GJ as an average cost.

Other operation and maintenance costs

In a normal steam system, the majority of operating costs – typically 97 percent – are associated with fuel. Water, chemicals and electricity each add a further one percent to this cost. Operation and maintenance costs vary widely and may add another $1 to $4 per tonne of steam.

The easiest way to reduce these additional operating costs is often through improvements in energy efficiency. Reducing the amount of steam required, fixing failed steam traps, repairing steam leaks and improving distribution will reduce these costs. Returning condensate and flash steam can also significantly reduce both chemical and water costs.

When a high level of makeup water is required, proper water treatment can result in significant boiler maintenance savings.

These opportunities are discussed further in Section 3.

System efficiency

The overall efficiency of a steam system often has the largest bearing on the system's overall operational costs. The maximum overall efficiency of a steam system is determined by the type of system installed. It is often difficult to achieve high efficiencies with extensive networks, highly variable steam loads and high-pressure systems.

The cost of steam is a common term when talking about a boiler's efficiency. Although simplified, it is a useful tool when determining potential energy savings. The cost of steam simply takes into account the boiler efficiency and fuel price, but can be useful to make rough energy saving calculations throughout the demand and network side. For example, if the cost of steam was $60 per tonne and repairing failed steam traps would result in an estimated steam reduction of 100 tonnes per year, then the annual saving by doing so would be $6,000 per annum.

However, for the purposes of this guide, the cost of steam does not offer enough detail. Instead, the cost of useful energy is used. This takes into account all losses from steam generation through to distribution, conversion and finally the end use, as shown in the following examples.

Figure 2 shows an example of a system with poor efficiency.

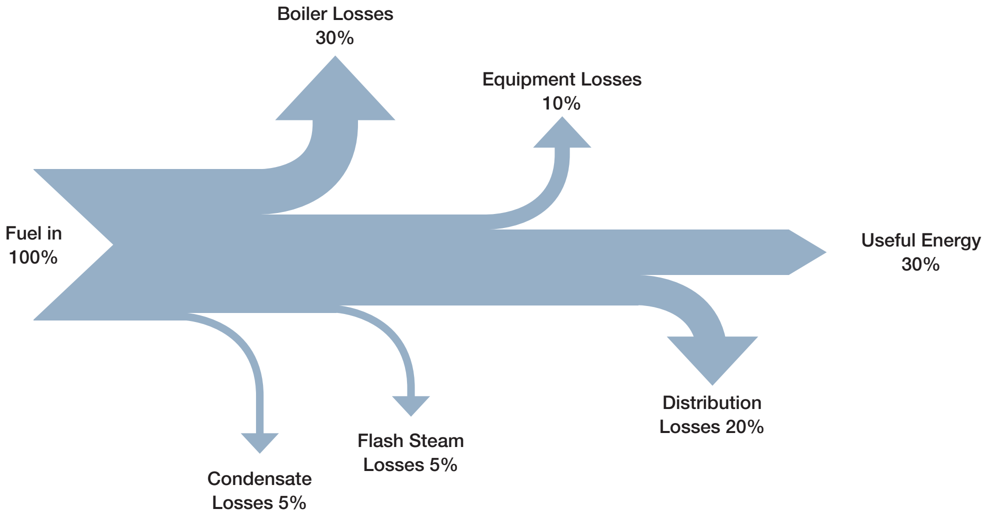

Figure 2: Steam System Energy Balance "Poor" System Efficiency

This example shows a high loss rate through the boiler, large losses in the distribution network and little or no condensate or flash steam recovery. This level of efficiency is not uncommon within steam systems throughout New Zealand.

In this example, the cost per GJ of useful energy based on fuel costs alone is $40.

Through making some minor maintenance and system improvements, the efficiency of this system can be dramatically improved.

The following actions can be implemented:

- cleaning and tuning the boiler
- repairing steam leaks
- inspecting and repairing or replacing any faulty steam traps
- improving insulation on distribution pipelines
- improving insulation on end users
- adding a condensate recovery system.

Figure 3 shows the efficiency of a typical steam system.

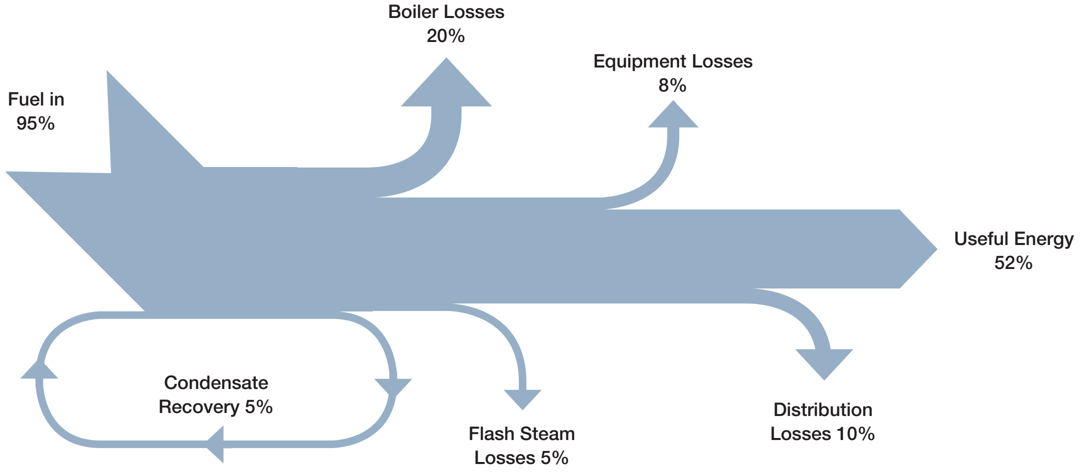

Figure 3: Steam System Energy Balance "Average" System Efficiency

In this example, boiler and distribution losses have been significantly reduced. In addition to this, the condensate energy that was once being lost is now recovered, reducing the required fuel input through the boiler. The overall system efficiency has been dramatically increased for little capital expenditure.

As a result, the cost per GJ of useful energy has dropped from $40 to $22. Other operational costs and maintenance costs would also have decreased dramatically.

Although this example is considered typical for industrial steam systems in New Zealand, further savings are still possible.

The following actions can be implemented:

- adding a feedwater economiser to the boiler
- installing an automatic blowdown system
- insulating fittings or valves using removable jackets
- installing a flash steam heat recovery system
- installing a process heat recovery system.

Figure 4 shows the efficiency of a good steam system.

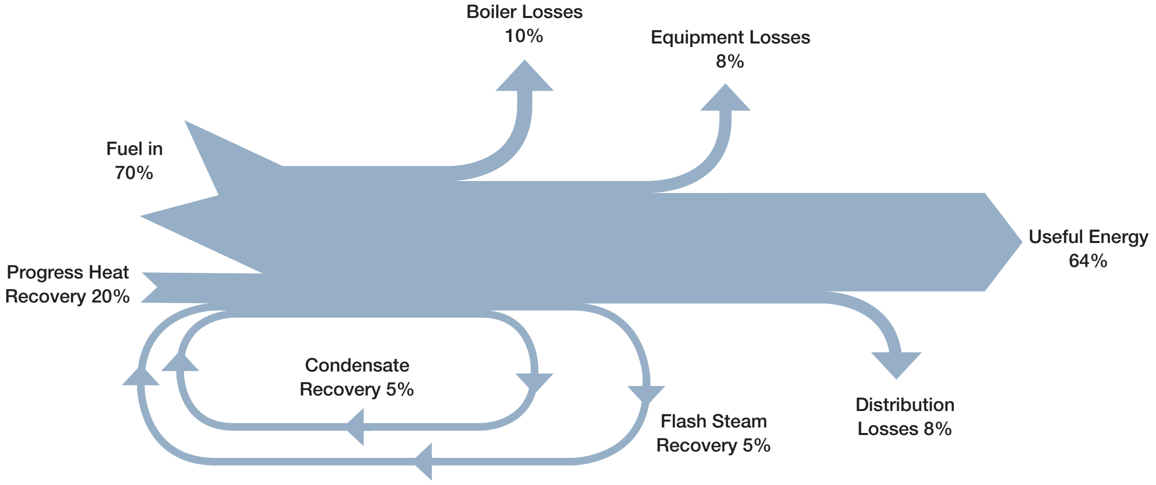

Figure 4: Steam System Energy Balance "Good" System Efficiency

In this example, boiler losses have been further reduced, flash steam is now being recovered and 20 percent of the plant's total steam demand has been eliminated through the implementation of a process heat recovery system. This is now considered a best-practice system.

The cost per GJ of useful energy has decreased to $13, as compared to $22 for the average system and $43 for the poor system.

A more detailed explanation of how these savings can be achieved is given in Section 3.

3 Identifying savings – the whole system

3.1 Definition of the processes

The whole process, from generation to utilisation, is made up of the five stages shown in Figure 5 and listed below:

- The heating load or process
- The conversion process
- Distribution
- Condensate heat recovery
- Process heat recovery
- Steam generation.

A systematic approach that considers the whole steam system will be more effective in reducing energy costs than targeting one isolated part of the system.

The order in which these are listed above reflects the impact of any efficiency improvements in each process on the overall system. A reduction in energy consumption in the heating load will be amplified in terms of fuel savings because each further stage of the process is less than one hundred percent efficient.

For example, in the system illustrated in Figure 4, and assuming that daily energy required in the heating process can be reduced by 100GJ, the energy input required by the boiler will be reduced by more than 200GJ.

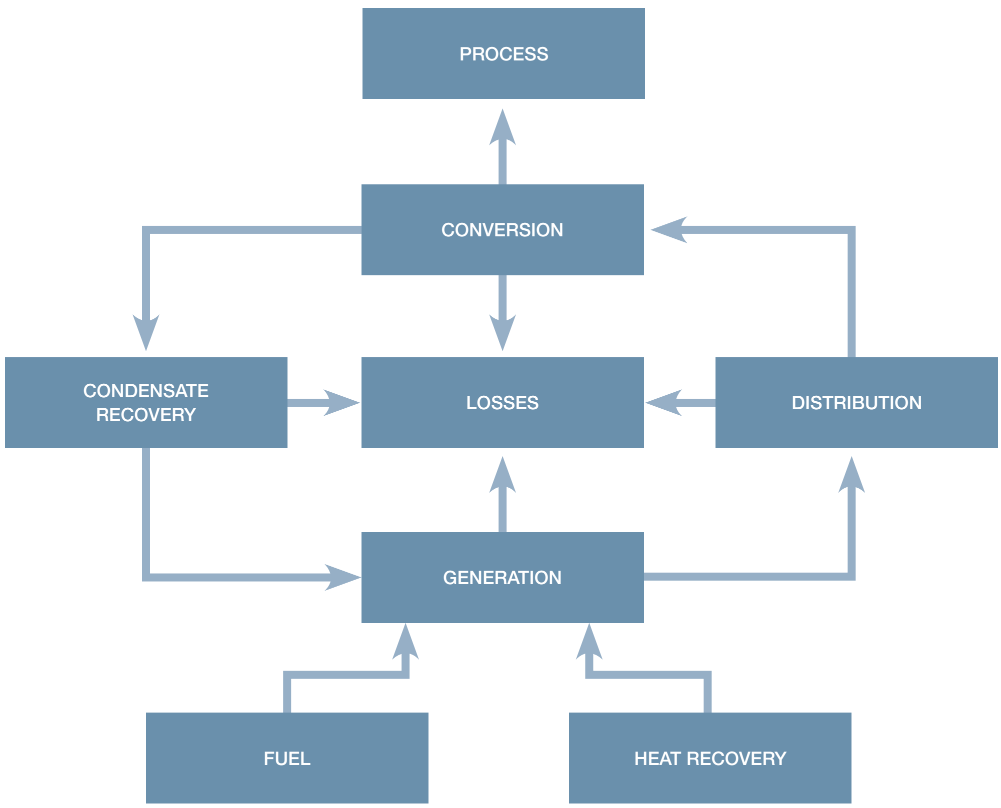

Figure 5: The Steam Process

3.2 The heating load or process

Typical processes include:

- heating air to dry a product e.g. milk processing, timber processing
- cooking or processing, either in a jacketed pan or directly in a pressure-cooker
- evaporators
- digesters
- laundry and dry cleaning e.g. washers, dryers, irons and presses.

Another relatively common process is to provide space heating. The steam is used to heat air or water which is used in radiators or similar appliances.

Common areas of saving can include:

- reducing the process temperature
- managing a process differently e.g. changing the time of operations to reduce peak loads
- turning off equipment when not in use. Often steam equipment is left on 24 hours a day unnecessarily
- using an alternative to steam. This can be particularly appropriate where a single item of equipment is supplied through a relatively long steam pipeline
- reducing steam pipe length by relocating equipment closer to the generation process
- reviewing the process control system. This is particularly relevant in the case of space heating systems
- incorporating flash steam energy recovery into the process
- heat recovery from the process e.g. commercial laundry washing machines discharge large quantities of warm water from which heat can be recovered and used to pre-heat cold water.

Case Study:

Hutt Hospital achieved a six-month payback by adjusting the control of its space heating system. These savings were achieved as an outcome of an energy audit carried out by Hutt Hospital's Building Services team with the assistance of a consultant.

A warm air ventilation system, providing ventilation to a ward block, ran 24 hours a day. The cost of heating the air, using hot water generated from steam, was about $8,000 per year. A check of the air quantity found that the system provided over twice the amount of fresh air required by the New Zealand Building Code.

A simple speed-control system was installed which reduced the fresh air quantity by 50 percent whenever the outside temperature dropped to below 16°C. At 16°C, heating commenced. The original level of ventilation was used during warmer weather when it was most required. Savings achieved were $4,000 per year at a cost of less than $2,000.

3.3 The conversion process

In most cases, the conversion process involves heat exchange equipment designed to transfer heat from steam to another medium, usually air or water. Most of the heat transferred is latent heat, given out as steam condenses to water. In some applications, steam is used directly e.g. in sterilisation. Direct injection is sometimes used to pre-heat boiler feedwater as part of the process to remove air and dissolved gases.

Conversion equipment can offer a number of energy cost savings opportunities but is often overlooked. This is particularly true for older items of equipment.

Energy efficiency can be improved through the measures listed below:

1. **Checking the general condition of equipment**. Ensure there are no steam leaks and insulation is in good condition, with all hot surfaces properly insulated.

   Note: This is also important for health and safety reasons.

2. **Testing and maintaining process steam traps on a regular basis.** As process steam traps usually have relatively large capacities, losses due to steam passing through a failed trap can be considerable.

3. **Correct plant sizing.** Oversized heat-exchange equipment is not energy efficient, as output is difficult to control and heat losses are increased through greater surface area. Alternatively, undersized or incorrectly selected steam traps can result in poor exchanger performance and inefficiencies.

4. **Control system improvement**. In some cases e.g. laundry tumble dryers, the amount of heat required reduces over the process cycle. By fitting controls that reduce steam flow, the amount of unused heat can be reduced.

   Note: Some care needs to be taken when retrofitting control valves in steam systems, and modifications to steam trapping may be required. Please seek specialist advice.

5. **Heat exchange surfaces being kept clean of product build-up**. By cleaning surfaces regularly, and by increasing product velocity by mechanical stirring or careful arrangement of product flow, heat resistance is much reduced.

6. **Removal of air from the system**. On the steam side, the most significant barrier is air film. Air is a very effective insulator of heat. An air film which is only 0.025 mm thick will resist heat transfer as much as a wall of copper 330 mm thick. Air is always present in the steam system on start-up, while other non-condensable gases may be formed in the boiler during operation, with similar negative results. Air should be removed by a combination of correctly fitted air vents and steam traps, allowing air to pass. Some steam plant, such as heater batteries and jacketed pans, need separate air vents fitted. These will reduce maintenance and improve batch times, heat transfer rate and product quality. This subject is discussed further in Section 3.4.

7. **Incorporating flash steam recovery into the process**. Using flash steam in the process from which it is created is generally the easiest way to balance the flash steam generation rate to the flash steam usage. An example may be a steam heat exchanger used to heat water. The flash steam from the steam heat exchanger condensate may be passed through a separate heat exchanger that is used to preheat the incoming water. Changes in the hot water heating load, and hence the amount of flash steam generated, will have corresponding changes in preheating load, enabling the system to be designed to balance the flash steam generation and usage.

3.4 Steam distribution

Figure 6 shows in simplified form a typical steam distribution system and illustrates where energy losses occur.

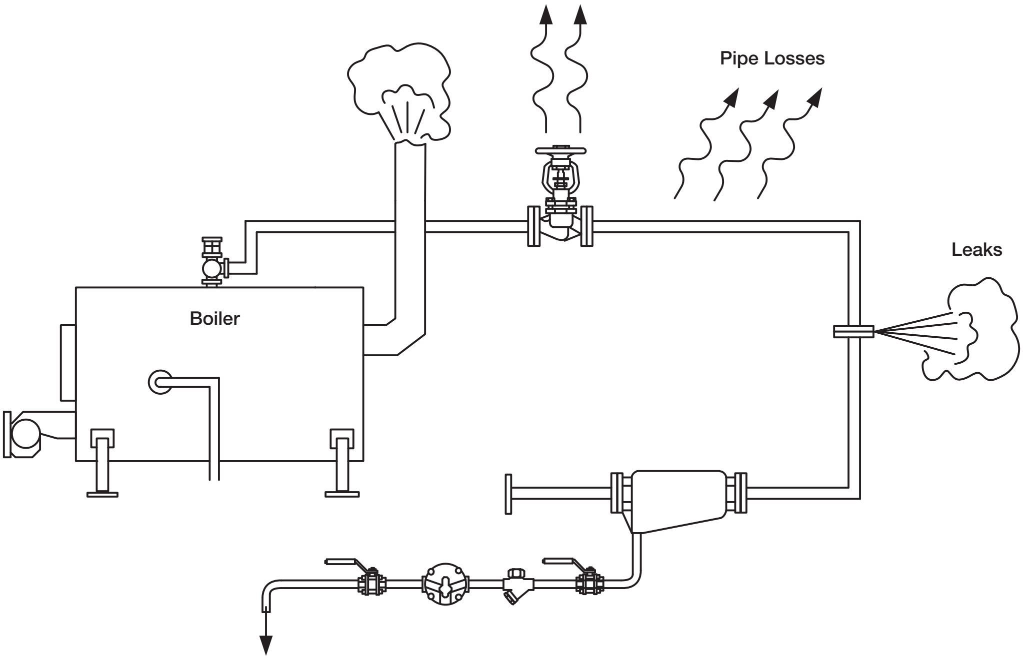

Figure 6: Distribution System Losses

Distribution system losses can vary from two to 50 percent and average around 15 percent. These losses can have a major impact on the cost of steam. Reducing these losses presents a good opportunity for savings.

Overall system design

When a system is being designed or remodelled, the following principles should be followed:

1. Total length of the system pipework should be kept as short as possible.
2. Valves should be kept to the minimum necessary for effective maintenance and safe operation.

If practicable, steam pipelines not in use should be turned off. This can be time consuming and the benefits of this should be analysed. Ideally, measures should be taken at the design stage to minimise problems with which this is associated.

Case Study:

Lower Hutt company Rembrandt Suits was able to achieve gas consumption reductions of about 10 percent by replacing or refurbishing steam traps and renewing some sections of pipe lagging.

Even relatively new (less than 12 months old) traps can become faulty and require regular checking. A regular inspection programme is now in place.

As a second stage, the steam distribution was rationalised to reduce the number of steam and condensate branches. By moving plant, such as steam irons, to serve a number of machines rather than one branch serving one machine, gas consumption dropped by a further 10 percent.

The importance of effective insulation

Heat loss through transporting steam at 10 bar through 10 metres of well-insulated 100mm diameter steam pipe will be about 750 watts. If the system operates 24 hours a day all year, annual losses will be 24GJ. This will cost approximately $360 per year, assuming fuel costs of $12 per GJ and a boiler operating at 80 percent efficiency.

If the same pipework is poorly insulated or the insulation is damaged, losses can increase substantially. If the same 10-metre length is uninsulated, losses increase tenfold, to approximately 7,500W.

Note: Special care must be taken in respect to pipework installed outside and exposed to the weather. Obviously, the insulation thickness should be reviewed to allow for wind and low ambient temperatures but, most importantly, the insulation must be provided with waterproof cladding.

Valves and flanges are often left uninsulated, resulting in substantial losses. The level of heat loss will depend on valve design, but a typical 100mm steam-valve will emit approximately 1,500W which, at $12 per GJ for fuel, would cost about $700 per year, depending on boiler efficiency.

Insulation blankets can easily be clipped on to valves and are readily available. These can be expected to reduce energy loss by at least 75 percent.

As a rule of thumb, any pipe at 50°C or above should be insulated for both economic and safety reasons. An exception is a drain or vent pipe, which cannot be accidentally touched by anyone.

The impact of steam leaks

Steam is an unforgiving medium and, even in the best installed and maintained system, leaks will occur – particularly at flanges, screwed joints and valve glands. Early attention to steam leaks is the key as leaks tend to get worse over time and are expensive.

A conservative estimate of the cost of steam leaking from a 2mm-diameter gap is about $2,000 per year if left unattended. Minimise the use of screwed joints as they are more likely to leak than other types of joint.

Steam traps

Steam traps are essential to a distribution system. These devices drain the condensate that forms in pipework when warming up and during normal usage. As there is no such thing as a perfectly insulated system, condensate cannot be avoided. Steam traps are designed to drain water without losing steam.

Condensate cannot be allowed to accumulate in pipework as this will result in water hammer. This occurs as the steam flow picks up slugs of condensate and slams them against bends, tees or items of plant and equipment.

While steam traps are an essential part of a steam system, they have the potential for heat losses – mainly through leakage of steam through traps themselves.

In a system with no regular trap maintenance programme, 15 to 25 percent of traps may malfunction at any one time. An effective trap maintenance programme will reduce overall distribution losses by 10 to 20 percent.

Steam traps can be tested by conventional methods such as checking sight-glasses downstream of traps or listening for the noise of steam passing through the trap. Another sign will be excessive steam venting from a condensate receiver.

More sophisticated testing methods are now available, whereby steam traps can either be monitored remotely or ultrasonic detectors can be used on a steam trap to determine if it is working correctly. Sites with larger steam networks should consider purchasing this equipment themselves, although external companies that offer these services can also be engaged.

Detailed information on the correct location and selection of steam traps is beyond the scope of this guide.

System hygiene

Unwanted air, gases, oil, grease and scale in steam pipework can all reduce the effectiveness and efficiency of steam-using plant and equipment. As such, an effective water treatment programme is vital. Advice from companies specialising in steam boiler and distribution water treatment is always recommended.

Air, minerals and gases, such as CO_2, exist in water. As well as impacting on steam equipment operation, these gases can cause corrosion.

Oil, grease and other materials, particularly in the milk processing industry, present a high risk of contaminating feedwater. In cases where condensate is contaminated, a heat-exchanger can be used to recover heat while avoiding contamination.

Boiler scale results from materials such as calcium, magnesium and silica precipitating to form a hard scale on the tube. This scale reduces heat transfer and eventually causes tubes to overheat and fail. Tube scaling can reduce boiler efficiency by as much as 10 to 12 percent.

When a newly installed system or alteration to an existing system is commissioned, every effort should be made to ensure the pipe interior is thoroughly cleaned of dirt, scale, welding slag, oil and grease.

3.5 Condensate and flash steam heat recovery

The condensate heat recovery process is the collection and return of condensate from the conversion or steam-using equipment and steam traps. In most cases, the condensate is pumped into the boiler feedwater tanks, where it is mixed with any cold makeup water required to compensate for blowdown, flash steam and losses in the conversion process, which may include direct steam injection processes.

Due to heat energy in the condensate, recovering condensate reduces the amount of boiler fuel required by at least 15 percent. Typically, increasing the feedwater temperature by 6°C reduces fuel consumption by one percent.

In addition, recovering the condensate reduces the amount of make-up water required and consequently, the amount of water treatment chemicals to be added.

Common areas where savings may be achieved in condensate heat recovery are:

1. **General condition of the return system.** Check for leaks and inadequate or damaged insulation. A damp environment and low temperatures can make corrosion a major problem. Condensate can sometimes be high in iron, which can cause water treatment problems.
2. **Return condensate at the maximum temperature possible.** Condensate should be returned at the highest temperature possible to maximise the energy going back to the boiler feedwater tank. However, pumping near-boiling condensate can result in cavitation of pumps and must be considered. Steam displacement type pumps are not affected by cavitation and are often a simple and effective method of pumping back condensate.
3. **Flash steam heat recovery.** When steam condenses in a process, the condensate formed is usually at the same pressure and temperature as the steam. When the condensate is removed from the process by the steam trap, it is discharged to a lower pressure, typically atmospheric pressure, and some of the condensate will flash off. This is known as flash steam and can vary from five to 20 percent, depending on the steam pressure in the process (the higher the steam pressure, the greater percentage of flash steam produced). It can be seen then that designing and running a process at the lowest steam pressure possible to meet the process requirements is beneficial in reducing flash steam generation.

Flash steam is typically vented from condensate collection receivers. This vented flash steam represents a direct loss of energy.

Flash steam losses can be reduced in a number of ways, including:

1. **Recovery of flash steam to use in a low-pressure steam system.** The challenge here is to have a steady demand for low-pressure steam which matches the production of flash steam. As outlined in Section 3.3, incorporating flash steam recovery into the process from which it is produced is usually a good way of balancing flash steam generated to flash steam usage.
2. **Passing hot condensate through a heat exchanger.** The transferred heat would then be used to pre-heat cold water for use as part of a process or to pre-heat boiler feedwater.

Case Study:

Amcor Kiwi Packaging was able to save $140,000 per year at its Wiri plant, representing 11 percent of its fuel bill.

These savings were made through the installation of a heat exchanger which recovered heat from hot condensate (at 154°C) and used this heat to raise the temperature of the boiler feedwater.

The capital cost involved was around $14,000, including a new well-insulated feed tank, achieving a simple payback of just over one month.

3.6 Process heat recovery

Heat recovery from processes or machinery on site is now commonplace, particularly on large industrial installations. On industrial sites, there are often several sources of waste energy where heat is produced as a by-product of the process's primary function.

Typical heat recovery options found on industrial sites include air compressors, refrigeration compressors and waste product heat recovery such as high-temperature wastewater. The amount and quality (temperature) of the waste energy available largely determine the economics of such projects.

Process heat recovery can reduce a plant's steam demand via two avenues:

- Assisting in the heating of boiler makeup water. This is particularly applicable on sites which have a high makeup water requirement through the direct use of steam.
- Eliminating the use of steam. Where sites are using large quantities of low-quality (temperature) energy such as space heating, process heat recovery can often eliminate the need for steam to be used.

Due to the rising fuel prices and the uptake of heat recovery technologies in New Zealand, the economics of process heat recovery systems are becoming increasing more attractive.

Case Study:

Tegel Foods was able to save more than $110,000 annually in gas and electricity, and the project was able to pay for itself in only two years.

Tegel uses high quantities of water at 40°C for hand washing and showering and at 60°C for washing down process equipment. Before the heat recovery system was installed, mains water at 14°C was heated using a natural gas boiler to the desired temperatures.

Now heat energy recovered from the site's refrigeration system preheats water to 35°C, resulting in annual gas savings of $84,500 per year. Additional electrical savings of $27,400 were achieved through the refrigeration system, as the heat recovery system has lowered the operating temperature of the refrigeration compressors, helping the system to run more efficiently.

An unexpected benefit of the heat recovery system is that a proposed upgrade of the refrigeration system's cooling plant is now not required, averting an estimated cost of $300,000.

The system has worked so well that Tegel Foods is considering further heat recovery projects, which would save an additional $30,000 to $40,000 a year.

3.7 Steam generation

Steam generation plant can range in size from 30MW water tube boilers at a milk processing plant down to a 12kW electric boiler supplying steam to a hospital steriliser.

A wide range of fuel is used, with gas, coal, waste products, biomass and electricity being most common.

Compared with hot-water boilers, steam boilers are expensive to manufacture and to operate. This is due to the high temperatures and pressures involved and a need for sound design and operating practices.

While boilers have to be well maintained for safety reasons, it is still possible to operate a boiler safely but inefficiently.

Boiler types

For the purposes of this guide, three boiler types are mentioned:

- Water tube: typically used in larger installations of 8MW output and above.
- Fire tube: the most common type in installations of up to 6MW.
- Steam generators: these are found at the small end of the market.

Boiler efficiency

Boiler efficiency is the term used when comparing the amount of heat supplied to the boiler with energy that comes from the boiler in the form of steam. In an well-operated and maintained boiler, efficiency is expected to be around 80 to 84 percent at full load. If an economiser is fitted, the efficiency can be increased by another two to five percent for a simple economiser and up to 10 percent for a condensing economiser.

Cautionary note: In New Zealand, the convention is to base efficiency calculations on the gross calorific value, sometimes referred to as the higher heating value, of the fuel. This value includes heat energy required to convert water produced during the combustion process (from the hydrogen content of the fuel) to water vapour. The net calorific value (or lower heating value) excludes the heat of evaporation and, in the case of gas, is about 10 percent less than the gross calorific value. To confuse matters, the convention in some countries is to use the net calorific value and some boiler manufacturers use this figure in technical literature when quoting efficiencies for boilers. These figures are typically 10 percent higher than figures based on gross calorific value.

As the above percentages imply, some loss is inevitable. Figure 7 shows where these can occur.

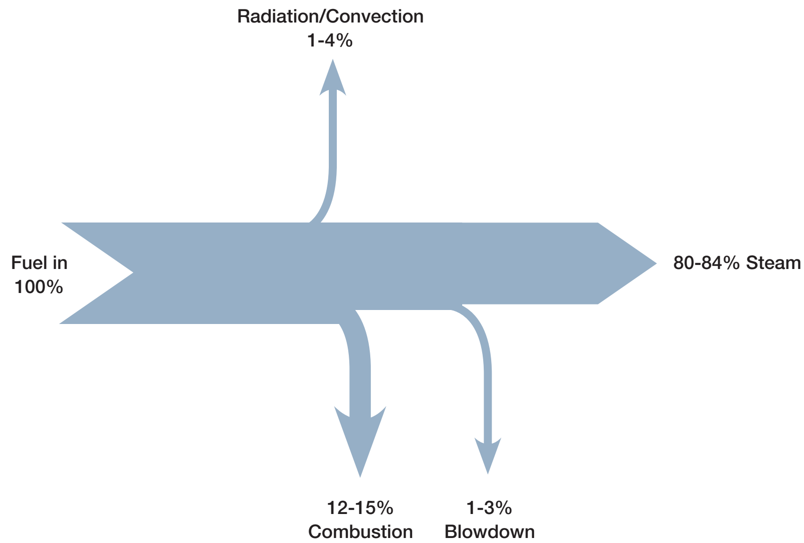

Figure 7: Typical Boiler Energy Losses

Considering each element in turn:

Radiation and convection losses

Generally referred to as the standing or fixed losses, these losses comprise heat lost from the boiler structure and typically amount to between one and four percent. These can be minimised by good insulation, which should include boiler mountings and access openings, e.g. manhole and mudhole doors. The losses from an uninsulated manhole door will be substantial – around 2kW, which over one year could amount to 65GJ or over $700.

Another less obvious from of convection loss is standby convection loss through the boiler. Boilers with strong convective draft, particularly in systems with tall stacks and systems with induced draft fans, can lose significant amounts of energy, sometimes as high as 10 percent when they are not operating. When a boiler is not firing and a strong convection draft exists, the boiler essentially operates in reverse. Cold air is drawn in, heated by the mass of steam and water contained in the boiler, and this energy is lost up the stack.

To combat this, dampers can be introduced into the system to prevent convection through the boiler when it is not firing, greatly reducing its standby losses. If systems have exhaust fans to help remove combusted gases, these should be linked to the burner so that they do not operate when the burner is not firing.

It is important to remember that the one to four percent standing loss is constant and relates to the boiler rating rather than output at any given time. Often, particularly in institutional buildings where steam demand varies substantially depending on time of year and occupancy, a boiler can operate at 50 percent or less of its rating, generally referred to as the boiler maximum continuous rating, or MCR.

For example, if a 6MW boiler has an average output of 3MW, standing losses will increase from two to six percent when considering the true operating efficiency. Even a small reduction in these losses can result in a worthwhile saving. However, the best saving will result from selecting a boiler that matches the load as closely as possible.

In some situations, periods of low demand exist. In this case, consideration should be given to reducing boiler pressure, which will reduce standing losses.

Combustion losses

Combustion losses occur during the combustion process and are represented by the energy that goes out of the chimney rather than into the steam.

In most cases, more air than is required has to be delivered to the process to ensure that all the fuel is properly burnt. This excess air means hot flue gases are increased and losses take place. While this cannot be eliminated, it can be minimised by properly setting or tuning a boiler and carrying out regular combustion checks.

Monitoring the oxygen (O_2) content of the flue gases provides a reliable indication of the level of excess air. The O_2 content should be in the range of two to four percent for natural gas, six to eight percent for coal and three to five percent for oil.

Figures higher than these indicate too much excess air and increased losses, while lower figures are a warning that incomplete combustion may be taking place. The sensing of the O_2 content can be used to automatically trim the air-fuel mix to minimise excess air.

Variable speed drives (VSD) on forced- and induced-draught fans can be used to control combustion air rather than using dampers. Used in combination with O_2 trim, one hospital was able to save $55,000 annually in coal fuel costs by fitting VSDs on the boiler fans, with a payback of under three years.

The use of Programmable Logic Controllers (PLCs) to control the steam generation process is now common in boiler plant, particularly in limited and unattended plant. This, coupled with data logging, enables the boiler manager to analyse boiler operation closely and to identify opportunities for efficiency improvements.

Case Study:

Goodman Fielder's Meadow Fresh processing plant in Christchurch handles approximately 100 million litres of milk a year. The site's largest energy cost is the light fuel oil (LFO) which is used to produce steam from the two boilers, at a cost of $3.6 million per year. The steam generated is in turn used for pasteurising and milk sterilising.

Given that the boilers were new, commissioned in 2004, the boiler tuning carried out in 2009 yielded surprising results. For a job that took two-three hours of an engineer's time, the tune-up resulted in an improved net efficiency that translated into energy savings of $45,000 per year.

Even in situations of perfect combustion, flue gases contain heat. It is possible to recover some of this heat by fitting economisers, located just after the point where flue gases leave the boiler. In the economiser, flue gases are used to preheat feedwater before it enters the boiler, reducing the amount of work the boiler must do.

Another potential saving measure is to use flue gases (via a heat exchanger) or other waste heat sources such as air compressors to heat the air delivered to the boiler for combustion purposes. These measures will typically improve efficiency by two to six percent.

Historically, economisers have only been economically viable on large installations. However, several companies have recently started to manufacture packaged economiser units for small plants, improving the feasibility of economisers on these sites.

Blowdown

Blowdown, an essential feature of good boiler operational practice, involves draining off water in the boiler to dispose of dissolved solids which will have accumulated.

These solids naturally occur in water supplies and are usually carbonates and sulphates of calcium and magnesium. As water evaporates into steam, the concentration of these solids increases the risk of scale deposits.

While appropriate water treatment will reduce the problem, blowdown is essential if the concentration of solids is to be kept within a desirable range. The concentration of solids is referred to as the total dissolved solids (TDS) and is measured as parts per million.

Blowdown involves draining off hot water from the boiler and is a loss of energy. For example, the typical blowdown rate for a 6MW (10,000kg/hr steam output) boiler is likely to be in the order of 1,000kg/hr. Assuming an operating pressure of 10 bar, this represents a loss of over 5,000GJ annually or around three percent of boiler output.

The first step is to minimise the amount of blowdown through effective water treatment to minimise TDS. Maximising condensate recovery will also help by minimising make-up water.

A second step is to consider automating the blowdown process through continuous monitoring of TDS and blowing down only the amount necessary. By automating continuous blowdown, this reduces the total blowdown rate.

Case Study:

Colgate Palmolive Ltd. achieved a less than two-year payback by improving the control of blowdown on its three boilers.

It replaced the original continuous blowdown system with intermittent valves controlled by a microprocessor sampling water conductivity at timed intervals.

This reduced the amount of continuous blowdown from 50kg per hour, which was set for peak operation, to less than 25kg per hour on average. It cost $4,400 to install and saved $2,400 per year in water, chemicals and gas.

The final step is to consider recovering heat from the blowdown process through one of two commonly used methods.

The first uses blowdown water to preheat makeup water before it enters the feed tank. The second uses flash steam by taking it back to the de-aerator or hot well for direct contact heating of the feedwater. Using either method can recover up to 50 percent of the energy in the blowdown.

Boiler feedwater treatment

To avoid problems with downstream components, boiler feedwater must first be treated to remove heavy contaminants, dissolved gases and correct the pH so the water is alkaline with a pH of 9.0 or higher. Not providing proper feedwater treatment can lead to some major inefficiencies in the boiler system and can dramatically reduce the life of the boiler:

1. Removing dissolved salts from the boiler makeup can improve the efficiency of boiler operation and increase the life of the boiler and associated equipment. Non-volatile impurities that remain in the makeup water concentrate up in the boiler once the water is turned into steam. This increase in salt concentration can lead to scale and requires blowing down the boiler to remove it. Increased blowdown and tube scale directly result in increased energy consumption, and scale can lead to premature boiler failure.
2. Corrosive contaminants such as O_2 and CO_2 gases which are dissolved in the feedwater must be removed. O_2 gas is usually removed by the use of a deaerator. Without removing this gas prior to entering the boiler, the O_2 gases will attack the metal piping, forming oxides (rust), and can severely damage the boiler. The CO_2 gas is usually removed via the reduction of carbonate alkalinity entering the boiler. Preventing air in-leakage through the pump gland and other areas also helps reduce the CO_2 content. Without removing CO_2 gas before entering the boiler, the gas combines with water to form carbonic acid, which causes further corrosion.
3. Before being used, the feedwater must first be alkalised to a pH of 9.0 or greater. Alkalising the water further reduces oxidation and can support the formation of a stable layer of magnetite (a form of iron oxide) on the water side of the boiler, providing further protection.

Boiler feedwater treatment costs can be significant, and must be accounted for when undertaking a boiler system assessment. Often, the most cost-effective way to reduce these treatment costs is to maximise the amount of pre-treated condensate recovered.

In some cases, steam is directly used in the process and is contaminated. In these situations, a high percentage of fresh boiler feedwater is unavoidable, in which case feedwater treatment becomes inherently important. New technologies such as reverse osmosis (RO) are being used to provide a high quality of feedwater, which can result in higher system efficiencies through decreased blow-down and higher heat transfer efficiencies, as well as reducing chemical costs. RO technologies are particularly applicable on larger sites and/or sites with high water dissolved solids content.

Boiler plant operation

Good boiler plant operating practice can result in energy savings, often with minimal investment. Some examples include:

- In multi-boiler installations, it is much more efficient to have one boiler operating at close to capacity rather than two boilers at 50 percent capacity.
- Good water treatment not only reduces the risk of corrosion, but also reduces scale buildup on boiler heat transfer surfaces, which can reduce heat transfer effectiveness. This can also occur in steam-using equipment, where scale formation can inhibit the transfer of heat from steam.
- Switching off boilers, either manually or automatically, when not in use is recommended.

Fuels

Fuels commonly used in New Zealand for steam generation include:

- Natural gas
- LPG
- Coal
- Oil
- Wood waste
- Electricity.

In the case of solid fuels, well-designed storage facilities are very important as wet fuel does not heat effectively. There is often potential to significantly reduce steam system operational costs through changing the type of fuel used. As this is not technically an efficiency improvement, it falls outside the scope of this document. More information on the benefits of changing fuel types, as well as several case studies on fuel changing, can be found on the EECA Business website (www.eecabusiness.govt.nz).

4 Measuring performance

If a steam plant is to operate efficiently, it is essential to measure and analyse its performance as a comparison with industry benchmarks. Where industry benchmarks are unavailable, internal benchmarks can be adopted, such as fuel consumption per unit output, and used to set improvement targets.

Metering fuel used and steam produced is a useful starting point. Data from these meters allows easy calculation of steam generation plant efficiency as set out below:

$$\text{Thermal efficiency percent} = \frac{\text{Energy in steam produced}}{\text{Energy in fuel consumed}}$$

Metering of gas and oil fuels is also easily done, but the metering of solid fuels such as coal and wood-waste can be more difficult. An automatic weighing system could be considered.

In such circumstances, the boiler operator should use records of O_2 or CO_2 measurements and flue gas temperatures to estimate combustion efficiency. This will be useful information, but be aware that this will not include standing or blowdown losses.

Some caution is required with steam meters, as many are only accurate over a certain range. It is important to establish this range, along with any likely errors if operating outside the range. This may be a problem if a boiler operates over a wide range of outputs.

In medium-sized (4MW) installations and larger, feedwater should be metered and temperature recorded, as this provides a useful check on steam meter calibration. It also refines the efficiency calculation by adjusting the energy in steam to allow for energy in the feedwater:

$$\text{Net energy in steam} = (\text{Energy in steam} - \text{Energy in feedwater})$$

Makeup water, i.e. water required to compensate for blowdown and condensate that is lost, should be metered as this provides a good indicator of how much is lost in the system. Any increase in makeup water could provide early warning of a new loss.

Note: The above methods of estimating thermal efficiency are appropriate for day-to-day energy monitoring. In situations where an accurate measurement of efficiency is required, such as in new boiler acceptance trials or as part of a boiler purchase process, a formal efficiency test should be conducted as set out in an appropriate code such as the ASME Boiler Code or BS 845-2:1987.

The thermal efficiency of a boiler that will be achieved in day-to-day operations will depend on a number of variables, including:

- Boiler type (e.g. water or fire tube)
- Fuel
- Load factor
- Size of plant.

For example, large industrial boilers operating at high load factors can be expected to have higher efficiencies than small boilers serving institutional buildings with widely varying loads.

The efficiency of coal- and oil-fired boilers is likely to reduce over time, as the use of coal and oil can result in soot deposits.

Target figures below are based on data from the references given in this guide and through discussion with boiler manufacturers and operators. As noted above, the higher figures tend to relate to industrial users:

- Gas-fired boilers: 78-83 percent
- Oil-fired boilers: 78-84 percent
- Coal-fired boilers: 76-81 percent
- Steam generators: 75 percent

Boiler tune-ups can be expected to improve efficiencies by two to five percent.

Metering of steam at other points in the distribution system is worthwhile, particularly in larger systems serving multiple load points. This enables the energy manager to identify where and how the steam is being used and also to establish losses in the distribution system. It also leads to early detection of unexpected changes in steam flows, which can often indicate a problem with the system.

5 Useful resources

1) **EECA Business:** www.eecabusiness.govt.nz
   - Case studies, technical notes, project funding information
2) **Spirax Sarco Resource Centre:** www.spiraxsarco.com
   - Steam engineering tutorials, steam tables, software tools
3) **U.S. Department of Energy:** www.1.eere.energy.gov
   - Software tools, technical publications, case studies
4) **Armstrong International:** www.armstronginternational.com
   - System assessment tools, online calculators
5) **Chartered Institution of Building Services Engineers (CIBSE):** www.cibse.org
   - Guide books and other useful publications

Appendices

Appendix i: introduction to steam

Steam is an extremely useful energy form and is used in a number of industries in New Zealand.

Sixty percent of energy use in New Zealand (excluding transport) is process heating using temperatures below 300°C. Most of this is in the form of steam. Steam is also commonly used in hospitals as a sterilising agent and for cooking.

Steam – a simple guide to thermodynamics

Steam is water in a gaseous state and is normally produced by heating water.

Figure 8 shows the process of producing steam at atmospheric pressure. In the first part of the process, water is heated from a typical ambient temperature of 20°C to 100°C. The amount of heat energy required is 335 kilojoules (kJ) per kg. This heat is known as sensible heat because it can be felt or sensed.

In the second part of the process, heat continues to be added. The temperature remains at 100°C and water changes to steam. This heat is known as the latent heat of vaporisation, or more commonly, latent heat. To convert 1kg of water to 1kg of steam, with no change in temperature, requires 2,257kJ.

The total heat required to convert the water at 20°C to steam at 100°C is therefore 2,592kJ.

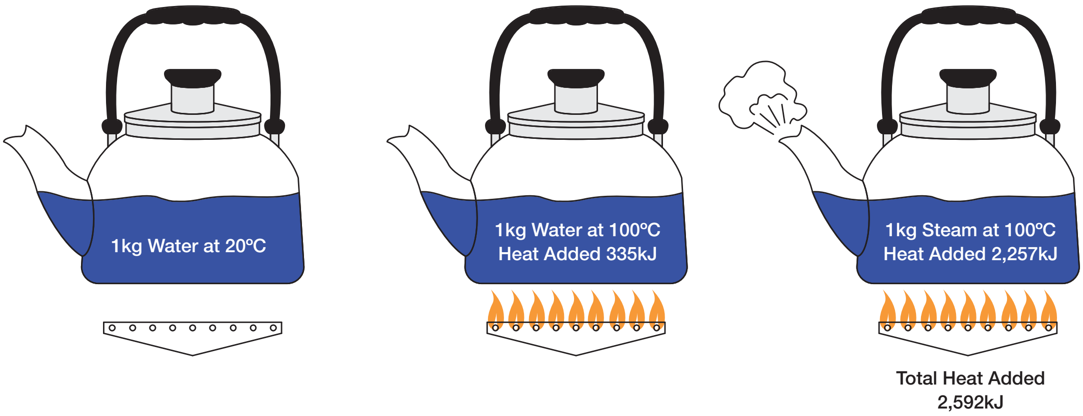

Figure 8: Steam Generation at Atmospheric Pressure

If these processes take place in a sealed or fixed-volume space and steam cannot vent to the atmosphere (as in the case above), the process changes, as shown in Figure 9.

Starting with 1kg of water at 20°C and adding heat, if the steam formed cannot escape, pressure will increase. When pressure reaches 1,000kPa, the temperature of the water will have increased to 185°C and the sensible heat added will be 700kJ.

If the valve on the boiler is opened at this point, latent heat will need to be added to the water at 185°C to convert it to steam at 185°C. At this temperature and pressure, the latent heat required is 2,000kJ. Total heat required to generate this steam from water at 20°C is therefore 2,700kJ, which is just over 100kJ more than was the case with steam at atmospheric pressure.

If steam is allowed to cool, the process is reversed. The steam condenses back to water, releasing the latent heat and, if allowed to continue cooling back to 20°C, releasing sensible heat.

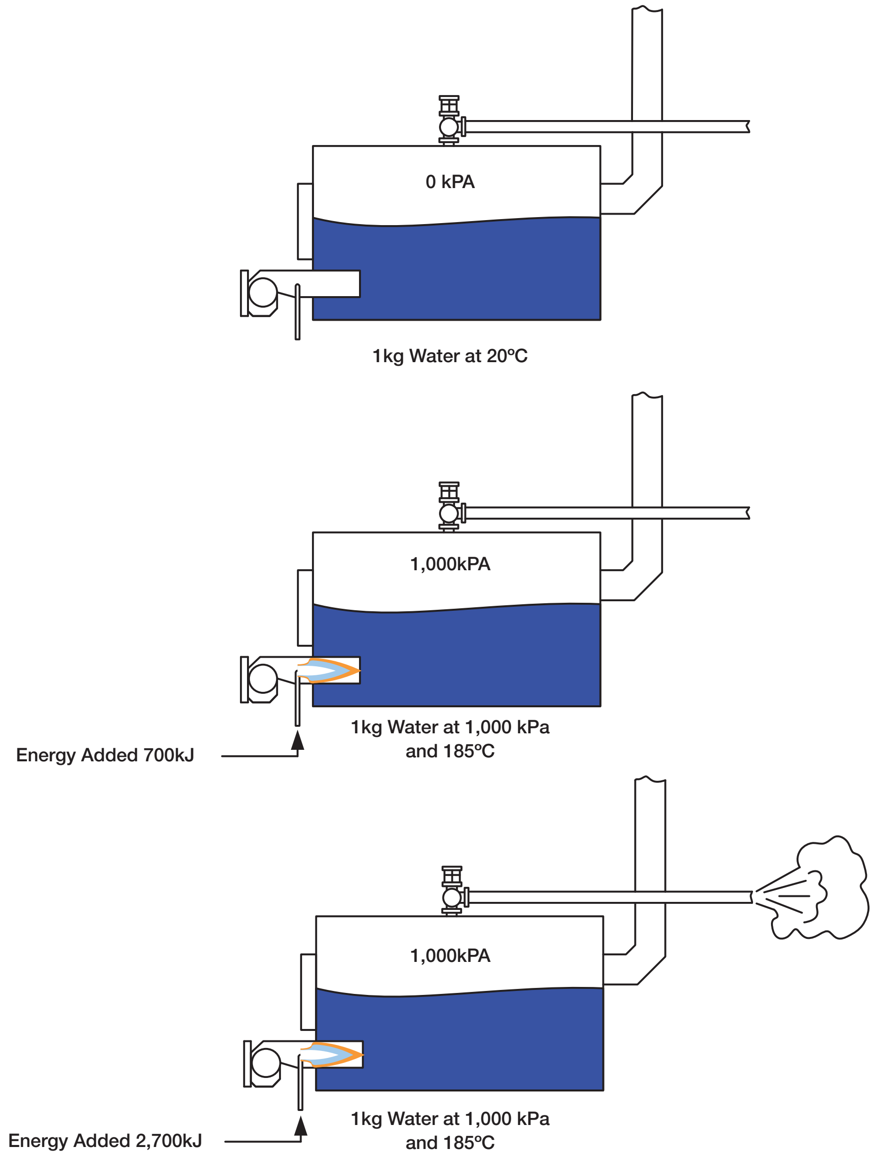

Figure 9: Steam Generation under Pressure

There is a direct relationship between steam pressure and temperature. The higher the pressure, the higher the temperature. For example, if pressure is increased from 1,000kPa to 2,000kPa, steam temperature will increase to 215°C. This is referred to as saturation temperature.

The saturation temperature is boiling temperature for pressure at which water and steam is held and, as more heat is applied, saturation temperature will increase, along with pressure in accordance with the saturation curve.

This demonstrates a number of important characteristics:

- As steam pressure increases, temperature increases.
- As steam pressure increases, more energy is required to generate each kilogram of steam, i.e. the higher the pressure, the higher the energy content.
- The energy content includes about 70 percent latent heat at 1,000kPa pressure. As pressure increases, the amount of latent heat decreases.

Where steam is produced in direct contact with water, the temperature and pressure relationship mentioned above is maintained.

If steam is taken out of the main body of a boiler and further heated, the temperature will increase beyond saturation temperature. This is known as superheating and is commonly used in power generation. It is not a common practice in typical industrial steam installations. For this reason, superheated steam is not covered in this guide.

Why is steam used?

Steam has several characteristics which make it useful:

- It is readily transportable from a central point of production through a simple piping system to one or more points of use.
- It contains a lot of energy, as heat and pressure, in comparison with competing forms of energy. For example, 1kg of steam at 10 bar contains 2,785kJ, whereas 1kg of pressurized hot water at 125°C only contains 525kJ.
- Expanding on the above, to transport 2,785kW (kJ/second) in the form of steam at 10 bar over 100 metres could be achieved with an 80mm diameter pipe with a condensate return of 50mm diameter. To transport the equivalent as hot water at 125°C with a temperature drop of 25°C will typically require flow and return lines of 125mm diameter.
- The raw material – water – is cheap and does not create a major pollution risk if released.
- It is relatively simple to produce and transport, and technology is well established.

Steam is most commonly used where heat energy is required for an industrial process such as drying, curing or cooking. The most common applications are found in the dairy, timber and food processing industries. In hospitals, steam is still the most commonly used sterilising medium and is also used in hospital kitchens for cooking. Laundries and dry-cleaners are also steam users.

There is a demand for both steam and electricity in some industries, such as the timber processing and dairy industries. Where demands are well matched, this provides an opportunity to consider co-generation, where the steam is first used to generate electricity and, after passing through a generator turbine or steam engine, exhaust steam is used for processing.

Why is steam not used more often?

The simple answer to this question is that, for many applications, there are more cost-effective means of transporting the same quantity of energy to a point of use.

Steam is effectively a hot, pressurised gas and thus presents a potential hazard. Steam-production plant, distribution pipework and steam-using equipment must be constructed, operated and maintained to a high standard.

In New Zealand, the Department of Labour, in administering the Health and Safety in Employment Act, has implemented a series of regulations and codes of practice governing the construction and operation of steam systems.

Compliance with these regulations and codes, along with the good practice and maintenance required to ensure a safe system, is costly. As a consequence, steam systems are relatively expensive to install and run.

High temperatures and pressures involved in a steam system increase potential for energy losses, either in the form of heat losses from pipes and equipment or through steam leaks. Steam is unforgiving of poor maintenance, for example a small leak at a joint inevitably becomes bigger if neglected.

In comparison to other competing forms of energy, steam is definitely in the high-maintenance class.

Appendix ii: units

In this guide, a number of units are used. These are as follows:

Temperature:

Degrees Celsius: °C

Pressure:

Bar: bar

Kilopascal: kPa

Notes:

1. *In the text, "bar" is used when referring to operating pressures, whereas when discussing steam properties, "kPa" is used. This reflects customary usage in the industry. 1 bar = 100 kPa.*
2. *Gauge pressure, rather than absolute pressure, is used throughout.*

Energy (or heat content):

Joule: J

Notes:

1. *kJ = 1,000 J, MJ = 10^6 J, GJ = 10^9J.*
2. *GJ is used in the context of energy cost, as commercial and industrial gas tariffs are typically priced per GJ.*
3. *Sometimes, kWh (kilowatt-hours) is used as the energy unit for gas, particularly in the case of small commercial and domestic tariffs. 1 kWh = 3.6 MJ.*

Mass:

Kilogram: kg

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