Boiler optimisation

This infosheet contains information about:

- different boiler applications;
- optimising the performance of boilers; and
- efficient steam systems.

A new steam trapping system resulted in immediate fuel savings of around $160 000 per year for a major milk powder producer.

INTRODUCTION

Optimising the performance of a boiler and its associated steam distribution system reduces running costs and improves site operations. Steam is used extensively in industry as a heat transfer fluid and as a source of energy to power mechanical plant and equipment. As a heat transfer fluid, steam has an advantage over fluids such as hot water and oil. It is able to store very large quantities of heat, which can be given up at constant temperature as the steam condenses.

Unfortunately more energy is lost in industry through steam wastage than through any other medium. Research studies by industry experts in the early 1990s suggested that losses from steam systems make up approximately 35% of all identified potential energy savings.

BOILER APPLICATIONS

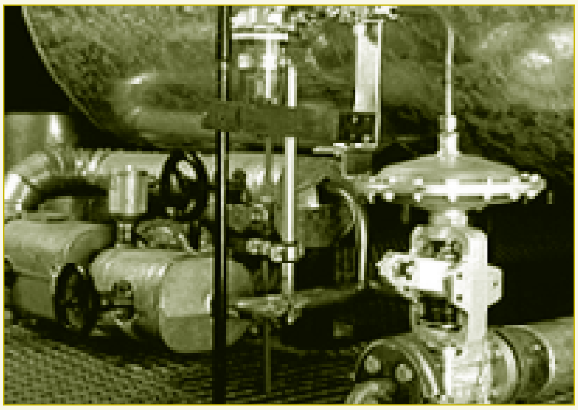
Steam is produced in two types of boilers.

Water tube boilers

Water tube boilers are usually used in large industrial and power generation situations where extremely high heat transfer rates are required to produce large quantities of steam. The water is heated in tubes and the fire (combustion process) is contained in the space around the tubes.

Fire tube boilers

Fire tube boilers are used in the more typical industrial and commercial boilers, which generally require lower steam generation or have limited space. In this case the fire, or the hot combustion gases, are contained inside tubes within the boiler and the water is circulated around these tubes.



The steam generated by boilers can be used in two ways:

- at high pressure (> 4200 kPa) to drive turbines or reciprocating engines; and
- at low pressure (700–1400 kPa) to supply heat to heating coils etc., or by direct injection into fluid.

In some plants, a combination of these uses is employed. The resulting high-pressure superheated steam is used to drive a turbine for the generation of electricity, and the turbine exhaust steam is used for heat transfer applications. In these systems the condensate is generally returned to the boiler for re-use, and the overall efficiency is almost 80%.

In most industrial and commercial plants, steam is only used for process and environmental heating. It is important to optimise the efficiency of each part of such systems through proper selection, sizing, operation and maintenance.

Steam should be distributed to the end-use locations at the highest practical pressures to minimise pipe sizes and subsequent heat losses. At the same time, however, it should be used at the lowest possible pressures to take advantage of the greater latent heat available at lower pressures. This minimises the formation of flash steam from the discharged condensate.

In industrial processes, the decision to use either heating coils/jackets or direct steam injection is determined by the:

- required rate of heat transfer;
- agitation of solutions;
- nature of the product;
- operating temperatures; and
- cost of feed-water treatment.

A typical steam system (see Figure 1) uses the steam for direct process heating in the injection vessel, and for indirect heating through the indirect heating coil.

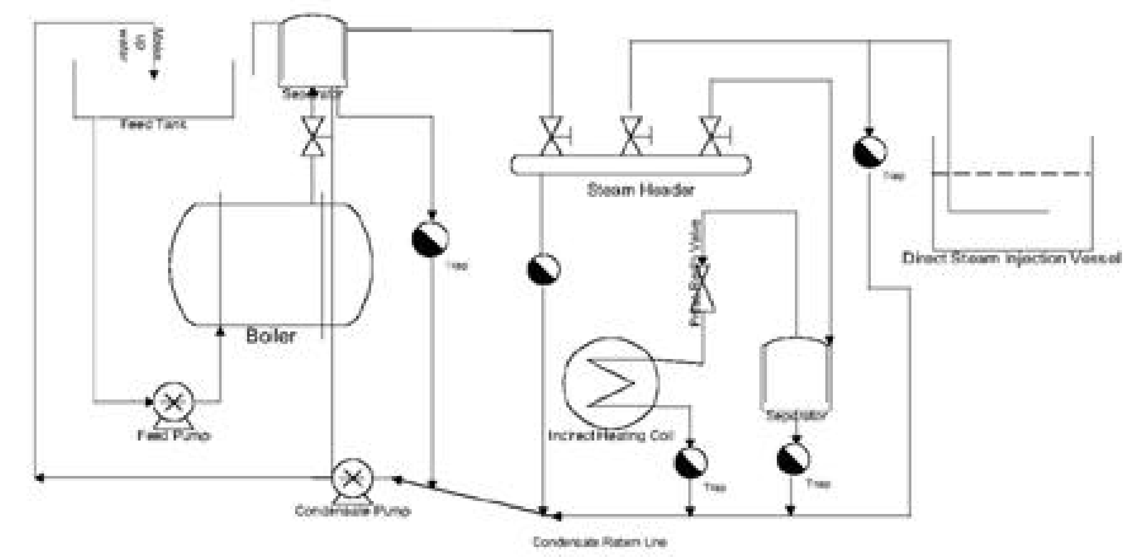


Figure 1: Simple industrial steam system

EFFICIENT OPERATION

For boiler optimisation it is important to address both the combustion system, and the steam and feed-water systems.

Combustion efficiency

Combustion efficiency indicates the flue gas loss. Boiler efficiency also includes the blowdown and stand-by losses. Whether comparing new or existing boilers, their most efficient operating point is usually somewhere between 60% and 90% load.

Stable combustion requires three inputs—fuel, oxygen and a source of ignition. If the combustibles can provide this third element as they burn, the source of ignition can be turned off. In complete combustion a number of things happen:

- carbon in the fuel is converted to carbon dioxide;
- hydrogen in the fuel is converted to water vapour; and
- sulfur and nitrogen in the fuel, and in the air supplied for combustion, are converted to their oxides.

In theory, there is a precise and predictable amount of oxygen needed to completely burn a given amount of fuel. This is called stoichiometric air. In practice, however, burning conditions are never ideal and more air must, therefore, be supplied to completely burn the fuel. The amount of air above the theoretical requirement is referred to as 'excess air'.

If insufficient air is supplied to the burners, unburned fuel—soot and smoke, and carbon monoxide (the incomplete conversion to carbon dioxide)—appear in the exhaust from the boiler stack. These can result in:

- the heat transfer surface fouling;
- pollution;
- lower combustion efficiency;
- flame instability (i.e. the flame blows out); and
- the potential for an explosion.

Operating boilers at excess air levels provides:

- protection from costly and potentially unsafe conditions;
- operating protection from an insufficient oxygen condition caused by variations in fuel composition; and
- 'operating slop' in the fuel/air control system on the boiler.

Flue gas loss (100% minus combustion efficiency) is usually the largest factor in reducing a boiler's efficiency. Stack temperature and O_2 levels are the main factors that determine combustion efficiency. Most boilers lose between 15% and 20% of their fuel energy input up the stack. A gradual decrease in boiler efficiency often indicates the need for one, or a combination, of the following:

- minor adjustments or repairs in the control linkages, fuel valve or air damper;
- the replacement of a worn burner tip or control cam; and
- the cleaning of stack surfaces (heat transfer effectiveness is reduced when the surface becomes 'fouled' by a coating of insulating material—soot on the gas-side, or scale on the water or steam side).

An insufficient air-to-burner ratio can be dangerous. On the other hand, air flows greater than those needed for stable flame propagation and complete fuel combustion needlessly increase flue gas flow and consequent heat losses, and thereby lower boiler efficiency. Minimising these losses requires monitoring and periodic tuning. Ideally, the fuel–air ratio is automatically controlled based on the percentage of O_2 in the stack, and on an unburned hydrocarbons indication. These automated systems are called O_2 trim packages. They will minimise the level of excess air and, therefore, reduce the flue gas losses. Savings in fuel economy may exceed 2%, which on a 5 MW size boiler is significant, and a payback period of one to three years can be achieved.

Flue gas recirculation

One of the many ways to reduce NOx emissions is to use flue gas recirculation, a method that recycles some of the exhaust gases back to the burner. Flue gas recirculation has the following effects.

- The heat content of the exhaust air contributes to heat recovery.
- The reduced oxygen content of the exhaust gases lowers the flame temperature in the combustion zone, thereby reducing NOx formation.
- The reduced flame temperature lowers heat transfer, potentially limiting the maximum heating capacity of the unit. (It would not be unusual for a boiler retrofitted with flue gas recirculation to produce a 10% reduction in maximum steam generating capacity.)

Gas-side fouling

The easiest fouling condition to correct is normally the gas-side deposits. Natural gas generally does not produce significant gas-side deposits if the burner is functioning properly. Fuel oil combustion deposits consist predominately of soft, black soot and are easily removed with brushing. Lower grade fuel oil may contain large quantities of alkaline sulfates and vanadium pentoxide that cause more serious gas-side deposits.

These compounds have low fusion temperatures causing them to slag and become deposited on convection surfaces. Solid fuels, including coal and wood, produce deposits that contain ash-based slag and soot.

Boiler gas-side temperatures are so high that ash deposits on convection surfaces (that could have been easily removed as they formed using a 'soot blower') can become 'sintered', or melted, into glass-like masses known as 'enamel'. Any type of tube fouling acts as an insulator between the flue gas and convection surface, reducing the efficiency of the boiler or heater.

The cost of poorly maintained boiler tubes can be estimated from the increase in stack temperature compared to 'clean' conditions.

The loss of boiler efficiency is approximately 1% for every 4.5°C increase in stack temperature above baseline conditions.

Table 1: Required cleaning for boilers

Type of boiler	Cleaning required
Small fire tube boilers	Manual brushing on the gas-side surface
Boilers using distillate fuel oil	Monthly brushing
Fire tube units burning solid fuel	Weekly, or even daily, cleaning needed to prevent ash deposits from becoming sintered and difficult to remove
Water tube boilers using low quality fuel	Large deposits can be removed automatically with a high-pressure blast Soot blowing may be needed as often as once per shift

STEAM DISTRIBUTION EFFICIENCY

Heat recovery

There are a number of ways to recover heat.

Process product heat recovery

In applications where steam is used for direct process heating, and the steam is lost to the process and vented to the atmosphere, it is difficult to recover the liberated condensate economically. In these situations it may still be possible to capture the waste heat from the process through the installation of a heat recovery system which uses the process liquid to pre-heat the feed-water makeup. This can be achieved by the insertion of a shell and tube heat recovery system as shown in Figure 2.

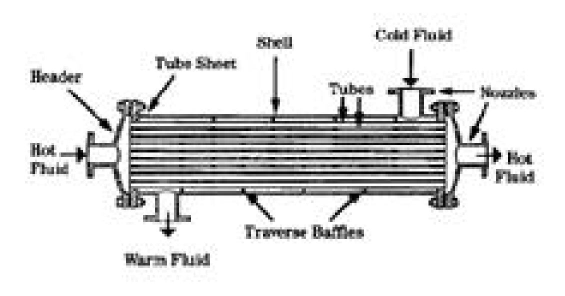


Figure 2: Heat tube recovery system

In this situation the boiler makeup water would be passed through the cold fluid line and the process fluid would be passed through the hot fluid line. The energy performance of the shell and tube type of heat exchanger depends on the application, but may be as high as 80–90%. Shell and tube heat recovery units can be designed to manage most operating conditions and temperatures up to 500°C.

Blowdown heat recovery

Blowdown heat recovery (generally applicable to larger boilers) is simple and effective at preheating incoming feed-water. Blowdown rates typically range from 4–8% of total steam generated, but can be as high as 10% if incoming water has high solids content. In any case, this water has significant heat content that can easily be recovered. For example, if a 150 psig saturated steam boiler generates 4550 kg/h of steam and has a blowdown rate of 10%, the heat recovery potential is ~0.22 GJ per hour. At a fuel cost of $4/GJ, and 80% combustion efficiency, an annual saving of about $8400 could be achieved. 'Demineralising' this feed-water may also reduce blowdown requirements.

Leaks and losses

Stand-by losses

About 1.5–2.0% of the rated boiler fuel input is lost to the engine room. While this loss is small when boilers operate at or near their rated capacity, it can be significant where boilers operate frequently at low loads. For example, imagine a boiler rated at 10 GJ/hr fuel input but operating at a 2 GJ/hr level.

The stand-by loss of 2% of 10 GJ/hr is 200 MJ/hr. This is the reason why plants with large seasonal variations in steam-use install small boilers to operate during the summer rather than operate large boilers year round.

Steam leaks

On its journey through the distribution system, steam will lose energy in many ways. These losses are difficult to avoid, but must be kept to a minimum. Leaking steam is the most obvious and serious of all losses. These losses occur through faulty valves, joints and steam traps. Even a small leak can result in considerable steam and, consequently, energy loss. For example, a 1 mm diameter hole on a steam line at 700 kPa will result in an annual energy loss equivalent to 3000 litres of fuel oil or 4300 m^3 (166 GJ or around $1000) of natural gas per year.

Figure 3 provides a quick guide for estimating the quantity of steam that is lost through leaks simply by measuring the length of the steam plume emanating from a leak.

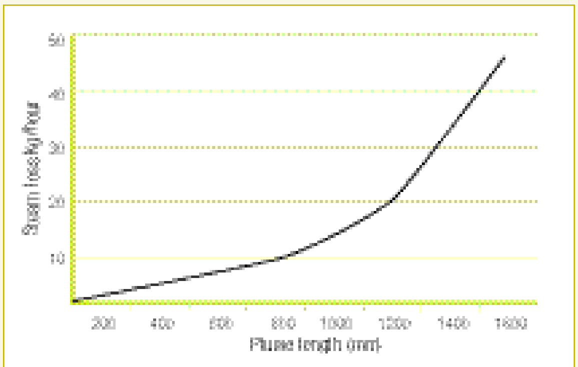


Figure 3: A quick guide for estimating the quantity of steam lost through leaks

Pipe losses

Steam pipes can be a major source of concern due to direct heat transfer losses. Adequate insulation is essential. For example, a one metre length of uninsulated steam pipe carrying steam at 700 kPa will loose heat at an annual rate equivalent to 1000 litres of fuel oil or 650 m^3 (25 GJ or around $150) of natural gas per year.

Although lagging of pipes is common practice in most plants, lagging of flanges, valves and other pipeline fittings is not. The heat loss from an uninsulated flange is equivalent to the loss from 600 mm of uninsulated pipe. A glove valve can loose heat at the rate equivalent to a five metre length of pipe. While these flanges and fittings are usually not insulated (to allow ease of maintenance access), the amount of energy lost outweighs any maintenance time saving.

Figure 4 provides a guide to heat losses from a one metre length of uninsulated pipe of varying internal diameters for different pipe temperatures

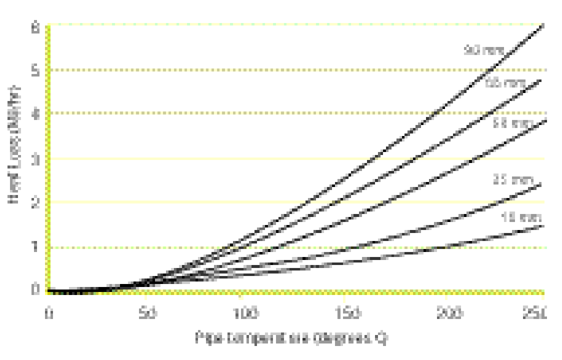


Figure 4: Heat losses from a one metre length of uninsulated pipe

Insulation of process vessels

Adequate insulation of process vessels is necessary to reduce heat loss from walls, ends and fittings. Clearly vessels, with their great surface areas, present significant potential losses. For example, with steam at 700 kPa, 1 m^2 of uninsulated surface will lose approximately 0.225 GJ through a 24-hour period, equating to approximately 81 GJ per year of natural gas or 2 tonnes of fuel oil.

Steam traps

Removing heat from saturated steam results in condensation. If condensate is allowed to remain in the steam system it will present a barrier to the efficient transfer of heat from the steam. Steam traps are used to selectively remove condensate (without removing steam) and to remove air and other non-condensable gases from the steam system.

All steam traps operate on the same basic principle. The trap collects air, other non-condensables and steam within a container and then discharges them in a controlled manner. This can be discharged either to the atmosphere or to a closed loop system such as the condensate return system (see Figure 1).

There are four groups of traps:

- mechanical;
- thermostatic;
- thermodynamic; and
- miscellaneous.

Condensate return

Condensate discharged from process plant may contain up to 25% of the heat added in the boiler and in addition will be chemically treated water. Any sensible heat still left in the condensate should be returned to the feed tank. This water is free of impurities and every 5°C increase in the feed-water temperature will save approximately 1% of the fuel used to raise steam. Again, to maximise the recovery of sensible heat, condensate lines should be insulated.

Waterside fouling

Chemical deposits or scaling on the waterside can significantly reduce efficiency. A more serious side effect is that these deposits are very good insulators; since they reduce the heat transfer and increase the gas-side metal temperature, this can result in premature tube failure. Even a thin layer of scale causes a marked increase in tube temperature and an accompanying decrease in expected life. Chemical compounds found in raw water cause waterside deposits. The tendency to form scale deposits can be controlled through an active water treatment program prescribed by specialists. A program such as this, if strictly followed, will prevent efficiency loss and premature equipment failure.

Mineral impurities in boiler water can also cause other operating problems, for example foaming and the consequent moisture carry over into the steam line. Most processes specify dry steam because the moisture carried over contains mineral impurities that cause fouling of downstream steam heating equipment.

Flue gas heat recovery

Economisers and/or air pre-heaters are the most common heat exchangers used to capture waste heat from the flue gas. Economisers transfer heat to boiler feed-water, and air pre-heaters to combustion air. These heat exchangers are usually installed directly in the boiler stack, or are ordered integral to new boilers as part of the design. They normally produce simple payback periods of one to two years on retrofitted applications. While boilers burning natural gas and No.2 fuel oil can easily be retrofitted, recovering heat from No.6 fuel oil, or any sulfur-bearing fuel, can be challenging.

In these cases, the designer has to be especially concerned about acid attack on heat exchanger surfaces. In all cases, be sure the water fed to the economiser comes from the de-aerator so the incoming water is not cold. Even though cold water would enhance the amount of heat recovered from the stack, acid attack problems are almost always associated with cold water entering the economiser.

Economisers

Economisers are usually the best choice for retrofitting very large boilers that operate at significant loads all year round.

For example, a boiler operating at 1035 kPa saturated steam and generating 9100 kg/hr could typically save 2.4 GJ/hr using an economiser to reduce its flue gas temperature from 288°C to 150°C.

CHECKLIST

Use the checklist below to ensure that a boiler and steam distribution system is optimised.

- ☐ Utilise flash (waste) steam recovery systems.
- ☐ Repair leaking joints and glands, leaking valves and safety valves.
- ☐ Insulate all steam and condensate pipes, flanges and valves.
- ☐ Ensure process temperatures are correctly controlled.
- ☐ Maintain lowest acceptable process steam pressures.
- ☐ Reduce hot water wastage to drain.
- ☐ Remove or blank off all redundant steam piping.
- ☐ Ensure condensate is returned or re-used in the process.
- ☐ Preheat boiler feed-water.
- ☐ Recover boiler blowdown.
- ☐ Improve burner design, combustion control and instrumentation.
- ☐ Heat recovery from the flue gases may save boiler fuel input even at lower stack temperatures.
- ☐ Check operation of steam traps.
- ☐ Check feed-water chemical control to minimise waterside build-up and improve scale control.
- ☐ Recover heat from condensate—preheat feed-water through heat exchanger fitted after feed-water pumps.

CONCLUSION

There are many ways to ensure that boiler and steam distribution systems operate at optimum efficiency.

Checking each of the areas identified as potential problems will help achieve a system that runs as efficiently as possible. Addressing the issues can produce substantial savings as well as reduce greenhouse gas emissions.