Efficient Steam System Design

The word ‘Efficient’ is often used to describe the general performance of a system. However it is important to distinguish between efficiency and effectiveness. Efficiency is a measure of the energy in versus the energy out where as effectiveness is a measure of how well a system performs in terms of achieving the required results.

For example a heat exchanger can be very efficient even if it is half flooded. The majority of the energy that is fed into the heat exchanger goes into the process. However due to the fact that it is flooded it’s output capacity is reduced and it therefore not effective.

What we really want is an efficient and effective system.

A steam and condensate system is a mixture of four balances, a temperature balance, a pressure balance, an energy balance and a mass balance. For a system to work well it must be designed so that all four balances are satisfied simultaneously.

The steam pressure affects the temperature, the temperature balance affects the energy transfer and the energy balance demands a mass flow. All the pipework, valves, pumps, tanks etc must be designed to keep the system in balance but often under varying operating conditions. Not impossible just not that easy.

Effectiveness

A big mistake when designing steam system equipment such as heat exchangers is to oversize the equipment. It may seem a good idea on paper just to add extra surface area but it this can have an adverse affect on the operation of the equipment in the field.

For example if a heat exchanger related to a reboiler is designed for operating at 30 psi (this example is used because they are often designed to operate with low steam pressures) but the heat exchanger area is oversized then the final operating pressure maybe be 5 psi. If the condensate from the heat exchanger feeds into a flash recover vessel at 10 psi then the unit will become flooded. If there is some instability in the system then the level of condensate will rise and fall in the heat exchanger and can cause erosion and corrosion problems around the surface of the condensate. Too low a steam pressure can also result in excessive corrosion of the tubes at the entrance to the heat exchanger due to the high velocities connected with the low density steam.

So the first point is to correctly size the steam equipment and not to oversize it.

Another factor that will adversely affect the performance of a unit is excessive superheat. Although superheated steam is hotter than saturated steam (for the same pressure), the presence of superheat will actually reduce the heat output. Saturated steam has a very high heat transfer coefficient because the moment it comes into contact with the cooler heat exchanger surface it condenses and transfers the large quantity of latent heat into the process flow. In the case of superheated steam it is just a hot gas and the heat transfer from the gas to the process flow is greatly reduced compared with the condensing heat transfer.

If there is only slight amount of superheat (4 or 5 ^{o}C) then the steam will quickly lose the superheat and move to the condensing phase. If there is excessive amounts of superheat the hot steam can also have an adverse affect on the product and result in rapid fouling of the heat transfer surface.

Excessive levels of superheat also make process control more difficult. One of the great benefits of saturated steam is that when the pressure is reduced the temperature reduces so the output reduces. When there is a large superheat component to the steam the ability to control the process by regulating the steam pressure is reduced.

For the majority of heating applications the recommendation is to use saturated steam.

If the steam is generated with superheat, e.g. discharge from a steam turbine, then the steam should be conditioned with a desuperheater before distributing it to site. A very good desuperheater will control down to 5^{o}C above saturation but 10^{o}C is usually satisfactory. If the level of superheat is reduced to too close to the saturation temperature then large amounts of condensate will be injected into the steam will little effective. This can result in problems of water hammer in the steam distribution system.

Remember that when a desuperheater is used to condition the steam, the condensate that is injected into the desuperheater is converted to steam. So if it is important to know the flow rates or mass balance of a process this quantity of condensate has to be added to the inlet steam flow. A flow meter should be located downstream of the desuperheater so that it measures the total steam flow including the steam generated in the desuperheater.

Steam Traps

Another factor affecting the performance of a heat exchanger is the steam trap. What often happens is that mechanical traps are oversized. They are sized to two or three times the running load to allow for the start up load and when the correct trap size has been determined one size bigger is selected for ‘safe measure’. The result is a trap with a capacity several times greater than necessary and poor system performance.

When the oversized trap opens the flow through the trap is far greater than the condensate being formed. The condensate surges through the unit and the trap and the oversized trap invariably passes a significant amount of steam. This drops the pressure in the heat exchanger so the control valve opens to compensate. The trap closes but now the unit over-pressurizes adversely affecting the control stability of the process. The instability in the condensate flow also reduces the overall heat transfer coefficient.

Hydrodynamic traps are a much better solution for process applications because the flow through the traps is continuous. There is not surging of condensate or steam so the process control is much better and the stable condensate flow results in an improved heat transfer coefficient. Often a great deal of investment is made in the control valve and positioned to improve the process stability but on the outlet of the heat exchanger there is a very crude float of inverted bucket contraption that defies attempts to stabilize the steam flow. So, hydrodynamic traps are a must for effective system performance.

When measuring the performance of the steam trap for a process application it is necessary to know four temperatures and pressures, before the control valve, after the control valve, before the steam trap and after the steam trap, particularly if it is a high pressure application with a large turndown. If for example the steam supply pressure is 20 Bar but the unit is running at 5 Bar then the steam temperature after the control valve will be 180^{o}C but the saturation temperature 160 ^{o}C. If the trap is working well then the temperature measured before the trap should be 160 ^{o}C too and the temperature after the trap related to the back pressure. If the process is critical it is advised to install a temperature transmitter before the trap to monitor the trap operation but it is important to interpret the results based on the operating conditions.

System Efficiency

Flash Recovery

It is a good idea to try and recover the large amount of sensible heat in high pressure condensate. When the condensate passes across a steam trap or control valve the drop in pressure converts some of the condensate back to steam to maintain the energy balance. This ‘flash’ steam can be used in the process to reduce the amount of ‘live’ steam.

However care has to be taken to correctly design a flash recovery system.

One example is where process air is heated with a flash steam coil followed by a live steam coil. The condensate from the live steam coil goes to a flash tank which feeds the flash steam coil. However it is critical that a pressure reducing valve is used that has sufficient capacity to supply all the load of the flash steam coil. Without the correctly sized pressure reducing coil it is possible for the system to cycle. The pressure in the live steam coil will increase to achieve set point. As the pressure and flow in the live steam coil increases the quantity of flash steam increases so there more heating capacity and the system overshoots the set point. The system responds by closing the live steam coil but this also reduces the flash steam and the system doesn’t have a enough heat available and drops below set point.

A flash steam system should be designed so that amount of flash steam generated is always lower than the demand for the low pressure steam. This way there will always be some make-up of live steam and the system will remain stable.

Another mistake with flash systems is to recover flash at each pressure stage. For example if a plant uses 25 Bar, 12 Bar, 5 Bar and 2 Bar steam it is often the case that condensate from 25 Bar processes goes to a 12 Bar tank, 12 to 5 and 5 to 2. However there is relatively little flash generated between 25 and 12 or 5 to 2 and therefore, depending upon design loads the minimum stages should be used, e.g. 25, 12 and 5 all feed into a 2 Bar flash tank, or if not the 25 and 12 to 5 and only the 5 to 2 Bar.

It can be the case that there is no live steam make up to the lowest pressure supply (e.g. 2 Bar) because so many of the traps on the higher pressures are passing steam that 2 Bar steam is being maintained without make up steam. It therefore appears that all is well and there is little point in investing in steam trap maintenance. However steam traps are not only there to save energy, they also protect the associated process equipment.

The purpose of a steam trap is to pass condensate at the same rate it is forming without passing live steam. If a steam trap fails open or is rapid cycling then instead of having stagnant steam in the heat exchanger tubes there is now two phase flow. Two phase flow is highly corrosive and so it would only be a matter of time before the tubes and particularly the bends of the heat exchanger become eroded and fail.

So even if the overall plant efficiency is good because the lower pressure steam flows are being maintained without live steam it is still essential to carry out trap maintenance. The importance to the overall performance of a plant to maintaining traps in good working order is often overlooked.

Boilerhouse Operation

There are many articles written about the correct operation of boilers and a great deal of expertise in this area. This article is more related to the demand side than the production side. However the point that is worth rising if the effective use of the energy that is input into a boiler. There are some losses such as radiation and convection losses and blow down losses that can be considered fixed losses (although it is of course possible to recover the energy from the blow down) but the majority of the losses from the boiler are in the chimney.

The temperature of the combustion gases leaving the boiler are related to the temperature of the steam being generated. The combustion gases cannot be at a lower temperature than the steam and are normally at least 20^{o}C above. So the first point to consider is what pressure is required in the plant. Often the steam is generated at pressures much higher than required for historical reasons that are no longer relevant (previous use of steam turbines etc). If the pressure can be reduced then there is significant potential for energy savings. But before the pressure is reduced checks need to be made on the suitability of the boiler to run at lower pressures when designed for higher pressures.

But the key to efficient steam generation is to recover as much as possible of the energy that is being lost in the chimney. If we were to ignore the heat losses from the shell and the blow down losses then the closer the chimney temperature gets to the ambient air temperature the closer the boiler gets to being 100% efficient.

The normal place to start is to install an economizer to heat the condensate from the de-aerator to the boiler. This will reduce the amount of fuel needed to bring the condensate up from the de-aerator temperature to the boiling point temperature and directly reduce the amount of fuel required. A second step could be to install an air to air combustion air preheater. Care has to be taken regarding a potential increase in the NOx per ton of steam because of the slightly elevated air flame temperature but the reduced fuel consumption should compensate for this. Care should be taken not to heat the combustion air beyond the specified limits of the combustion fan and burner.

Even with both an economizer and air to air preheat the exhaust gas temperature in the boiler chimney is rarely below 110^{o}C. Normally the rule is not to drop the boiler chimney temperature below this due to the possibility of localized cooling (in slower moving pockets of gas) and the possibility of condensation forming. Any condensation will be mildly acidic if it is natural gas (with negligible sulphur content) or more acidic if the fuel contains sulphurs e.g. No.6 Oil.

However the Condex unit from Combustion and Energy Ltd is designed to operate below the due point of the chimney gases (typically around 70 ^{o}C). The final exit temperature of the gases will depend on the temperature of the water to be heated but typically a water temperature of 20 ^{o}C will result in a chimney exit temperature of between 45 and 50 ^{o}C. At this temperature a large proportion of the latent heat (due to the water that is a byproduct of combustion) in the combustion gas flow can be captured.

The fact that the gases will leave the boiler at temperatures less than 50 ^{o}C means that the boiler efficiency can be increased as high as 95%. However care has to be taken when assessing this saving because with economizers and air preheat the boiler will produce the same amount of steam with less fuel but in the case of the Condex the saving will be from using less gas because less steam is required.

See PES web site or www.combustionandenergy.com for more details on the Condex unit.

Thermocompressors or Injectors

Often in a process it is necessary to generate a pressure below atmospheric. This can be done with a condenser to collapse the condensable vapor component and a mechanical vacuum pump to remove non condensables. However vacuum pumps can be expensive to run and maintain.

An alternative is to use a thermocompressor or injector. These units use high pressure steam to create a low pressure in a venturi that sucks in the vapor flow creating a low pressure. The mix of the vapor flow and the steam are discharged at a higher pressure that can be condensed without the need for vacuum pumps.

The key with thermocompressors is that in general they can only double the pressure and this is measured in absolute pressure. So if it is required to generate a vacuum of -0.3 Bar g this equates to 0.7 Bara which means the maximum discharge pressure would be 1.4 Bara or 0.4 Bar g.

Heat Exchangers

As with boilers there is endless material available on heat exchanger design but in general for heating liquids the choice is between shell and tube or plate. In general shell and tube would be selected for more robust high pressure applications and plate for lower flows and lower pressures. But there are many specialist designs in each type.