# HEAT RECOVERY

**KIRK S. WESSELOWSKI, ZEECO, USA, DISCUSSES THE PROPER APPLICATION OF PREHEATERS AND OIL HEATERS FOR THERMAL OXIDISERS IN GAS PROCESSING FACILITIES.**

In order for gas plant operators to keep up with stringent environmental emissions regulations, operators are using thermal oxidisers to maintain environmental compliance as well as maximise plant efficiency through heat recovery. The majority of gas plants utilise regenerative chemical solvents in an absorption column to remove $CO_2$ and $H_2S$ from the process gas. These solvents are typically regenerated in a stripper with a reboiler, a process that requires an external source of heat. The off gas from the regenerator must often be burned in a thermal oxidiser to ensure environmental compliance, so recovering heat from the thermal oxidiser flue gas with a convection oil heater and using it in the reboilers is a beneficial approach for many applications.

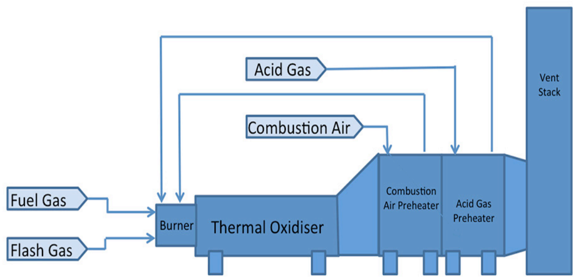


**Figure 1.** Acid gas thermal oxidiser system with preheaters.

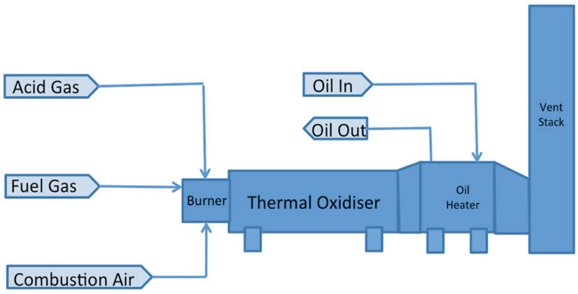


**Figure 2.** Acid gas thermal oxidiser system with hot oil heater.

However, in some plants sufficient heat for the reboilers and other consumers of process heating is available from other sources. In these cases, using the thermal oxidiser flue gas to preheat the streams fed to the unit can be an attractive design option. This article will illustrate the types of applications that can benefit from preheaters and oil heaters, and will give some advantages and potential pitfalls for each. With these insights, thermal oxidiser waste heat recovery systems in gas processing plants can be integrated into the plant design, significantly reducing operating costs while maintaining excellent reliability and long operating lifetimes.

## Thermal oxidisers

The purpose of a thermal oxidiser is simply to destroy combustibles in a waste stream that would be harmful to the environment and/or health and safety of people near the source of the waste stream. To completely oxidise the waste stream, it must be heated to a sufficient temperature, and held at that temperature for an appropriate time in an oxygen rich environment. By controlling the flow paths within the thermal oxidiser so that every part of the waste stream is exposed to these conditions, experienced combustion engineers can ensure that the combustibles will be completely oxidised to their relatively benign combustion products.

In a typical gas processing plant, the inlet gas may be 'sweetened' by removing the $H_2S$ and $CO_2$ using an amine unit, and/or dehydrated using a glycol contactor. The amine solution and the glycol solution each require a regenerator (a stripper with a reboiler) so they can be reused. These reboilers require heat input, usually by using heat transfer oil or sometimes steam. The vent stream generated by the amine (the 'acid gas') and the glycol reboiler off gas can each contain hydrogen sulfide, BTEX (benzene, toluene, ethylbenzene, and xylene), and hydrocarbons, which must all be oxidised in order to maintain environmental compliance for the plant. While flash gases and glycol reboiler off gasses often have significant hydrocarbon content, the acid gas is generally more than 95% $CO_2$ and water vapour, and requires significant external energy input in order for the low levels of combustibles in the acid gas to burn.

Another way to remove $CO_2$ from the processed gas is by using a permeable membrane separator. It may be difficult to achieve the required efficiency with a permeable membrane separator alone, so they are often used in conjunction with an amine unit. The membrane is more permeable to $CO_2$ than methane, leaving most of the methane in the residue gas. However, the membrane is not a perfect separator, so the permeate gas contains a significant amount of hydrocarbons, in addition to the $CO_2$. This makes the permeate gas a good source of energy, provided it can be burned effectively with a waste heat unit in place to recover the energy from the flue gas. The permeate gas is generally burned in a thermal oxidiser to meet the required emissions levels and to recover that energy.

When considering options for waste heat recovery from a thermal oxidiser, system designers must consider how much of the combustion energy will originate in the waste gas and how much will originate in any supplemental fuel that may be required. In thermal oxidiser design there is an important distinction between a waste gas that provides a net positive release of heat when burned at the required combustion temperature (an 'exothermic' waste) and one that requires external energy input in order to burn at the required temperature (an 'endothermic' waste).

In a gas processing plant, the amine acid gas is typically an endothermic waste gas, meaning that the thermal oxidiser requires additional fuel gas in order to achieve the combustion temperature. On the other hand, exothermic streams such as flash gases and permeate gases have sufficient hydrocarbon content such that they release more than enough energy when burned to achieve the required operating temperature.

## Heat recovery

There are two ways to approach improving the overall thermal efficiency of the plant. The first is by preheating the waste gas and/or combustion air to directly reduce fuel consumption of the thermal oxidiser. The second is by capturing heat generated by the destruction of waste gases in the thermal oxidiser that can then be used elsewhere in the plant. The principle is to take heat out of the thermal oxidiser flue gas and put it back into the process where it is needed. In the case of an endothermic waste stream, the flue gas heat can be used in a preheater, or captured by a steam boiler or oil heater. For an exothermic waste, there is no benefit to preheating the streams, so a waste heat steam boiler or oil heater would typically be used.

Preheaters can be used in conjunction with hot oil heaters if a gas processing plant generates an endothermic acid gas stream but only a fraction of the enthalpy in the flue gas

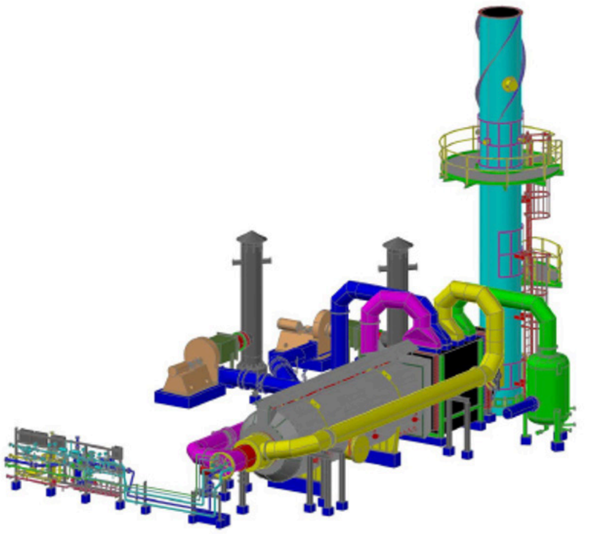

**Figure 3.** A thermal oxidiser with acid gas and combustion air preheaters.

needs to be captured for use elsewhere in the plant. In this manner, the thermal oxidiser heat recovery system can be tailored to reduce the overall plant fuel consumption by decreasing the thermal oxidiser fuel consumption while reducing (or perhaps eliminating) fuel consumption in a direct fired heater.

## Acid gas thermal oxidisers

A typical system will incorporate both a combustion air preheater and a waste gas preheater, as shown in Figure 1.

In previous decades, such a configuration was avoided because of the difficulty in designing gas-gas heat exchangers that would stand up to the extreme environment. The thermal oxidiser flue gas temperatures will typically be 800 °C - 950 °C. In order to maximise thermal efficiency, acid gas and combustion air preheater outlet temperatures often exceed 450 °C, resulting in heat transfer surfaces that can often surpass 600 °C, with the possibility of much higher temperatures during turndown conditions. While many metals have been proven sufficient at these temperatures, early iterations of waste gas preheaters were prone to failure because of uneven distribution of flue gas in the preheaters, especially at turndown flow conditions, and because of differential expansion between components of the preheaters.

These problems can be avoided by good engineering design of the thermal oxidiser system in general and preheaters in particular. Working with an experienced combustion company such as Zeeco can eliminate these concerns. Some specific design considerations include:

### *Co current preheater design*

Arranging the inlet cold combustion air or acid gas stream at the same end of the preheater as the inlet hot flue gas will reduce the maximum heat transfer surface temperature when compared to a counter current design. Although this results in a somewhat larger heat transfer area for a given duty, the increase in reliability and equipment lifetime makes this a beneficial trade off.

### *Preheater arrangement*

If both a combustion air preheater and an acid gas preheater are used, then the combustion air preheater is typically situated upstream of the acid gas preheater. Since combustion air will be flowing any time the thermal oxidiser is operating, the heat transfer surfaces will always be cooled by the combustion air, and surface temperatures will be less than the inlet flue gas temperature. However, the thermal oxidiser must operate without flowing acid gas at least part of the time, typically during the plant's startup. If acid gas is not flowing, then the heat transfer surfaces in the acid gas preheater will be at the flue gas temperatures, since there is almost no heat being removed by the cold side of the heat transfer surface. Therefore, the acid gas preheater is situated downstream of the combustion air preheater. The flue gases exiting the combustion air heater will be cooler than the thermal oxidiser operating temperature, mitigating the severity of the no acid gas flow condition.

### *Heat transfer surface design*

Preheaters must be carefully designed to allow for differential expansion of elements comprising the preheaters. Differences in thermal expansion can generate strong forces that will rip apart a heat exchanger that does not account for thermal growth. Tubular surfaces are preferred over plate heat exchangers because the design is typically more robust. Appropriate tube expansion bellows, prebent tubes, or U-tube designs will allow each row of tubes to grow individually, preventing large expansion forces from developing.

## Thermal oxidisers with oil heaters

If the waste heat captured from the thermal oxidiser flue gas can be used elsewhere in the plant, then a thermal oxidiser with an oil heater design may be a good choice. A typical arrangement of an acid gas thermal oxidiser with an oil heater is shown in Figure 2.

The oil heater is placed at the discharge of the thermal oxidiser, allowing a limited amount of control of the oil heater duty in this system. The thermal oxidiser operates at a specified furnace temperature in order to ensure good destruction efficiency, so the heat transfer rate in the oil heater is determined largely by the mass of flue gas. The mass of flue gas from the oxidiser is predominantly dictated by the acid gas rate, since sufficient air and fuel for combustion must be injected into the thermal oxidiser for a given acid gas flow rate. It is not possible to reduce the oil flow rate arbitrarily, since sufficient flow must be maintained in order to keep the oil below the maximum allowable film temperature specified by the heat transfer oil manufacturer. Consequently, for a given acid gas rate it will not be possible to reduce the oil heater duty below a specified minimum amount. The heat transfer oil system must have sufficient heat consumers, such as reboilers or air coolers, to remove the specified minimum amount of heat generated by the oil heater. On the other hand, the thermal oxidiser and oil heater system can be designed to fire additional fuel gas and combustion/quench air to enable higher flue gas flows than would be required simply to burn the acid gas. This overfiring of the thermal oxidiser will give the operators the flexibility to increase the oil heater duty when required.

**Figure 4.** A permeate and acid gas thermal oxidiser with a hot oil heater.

## Case studies

### Case 1: 80 million ft$^3$/d gas processing plant

A gas processing facility processes gas from an offshore facility and produces condensate, liquefied petroleum gas (LPG), and sales gas. The amine unit, which removes $CO_2$ and $H_2S$ from the natural gas, produces two waste gas streams, a large flow of endothermic acid gas stream that is 90% $CO_2$, and a smaller flow of exothermic flash gas. An ethylene glycol (MEG) dehydrator removes water from the natural gas, and the MEG regenerator off gas is a high BTEX stream that is exothermic at the thermal oxidiser operating conditions. The largest flow by mass is the acid gas stream, which requires a significant amount of energy to reach the thermal oxidiser operating temperature. The energy supplied by the flash gas and MEG off gas is not enough to eliminate fuel gas consumption at the thermal oxidiser operating temperature of 850 °C. Therefore, the thermal oxidiser shown in Figure 3 incorporates a combustion air preheater and acid gas preheater in order to reduce the fuel consumption by more than 75% during normal operation. The payout period for incorporating combustion air and acid gas preheaters into the design for this case and similar cases is generally less than two years.

By incorporating quench flow systems into the process design, the system is configured to handle a wide range of waste gas flow rates and compositions. The system can handle fully exothermic conditions when the flash gas and MEG off gas flows are high and the acid gas flow rate is low, as well as very endothermic conditions at the maximum acid gas rate and minimum flash gas rate. This is accomplished without using dampers or other moving parts in the hot flue gas stream, maximising reliability and reducing maintenance costs for long term operation.

### Case 2 : 100 million ft$^3$/d gas processing plant

This gas processing plant reduces the $CO_2$ in gas produced by several fields to less than 5% by volume, and maximises recovery of natural gas liquids. It uses both a permeable membrane separator and an amine unit to separate carbon dioxide from the inlet gas. Since the membrane is not a perfect separator, the permeate gas contains a significant amount of hydrocarbons in addition to the $CO_2$.

Although the permeate gas burned in the thermal oxidiser is 89% $CO_2$, it contains 9% methane, resulting in a lower heating value of approximately 21 500 kcal/kmol. This places the permeate gas in an intermediate range of heating values, much lower than methane at 191 700 kcal/kmol, but still a significant source of energy. The permeate gas lower heating value is too low for it to sustain combustion on its own, requiring a specialised thermal oxidiser design. This design uses assist fuel and staged air injection in order to enable the permeate stream to realise its full heat release with a minimum of assist fuel gas. The acid gas contains 91% $CO_2$ and 8% water vapour, resulting in a lower heating value of approximately 3000 kcal/kmol, so it is endothermic at the thermal oxidiser operating temperature of 815 °C.

When burned in the thermal oxidiser, the permeate gas releases 75 million kcal/hr and the acid gas achieves a heat release of 5 million kcal/hr. The total duty of the amine stripper reboiler and other preheaters and reboilers in the plant is 41 million kcal/hr. The thermal oxidiser has a hot oil waste heat recovery unit sized for 45 million kcal/hr, making it sufficient to provide all the heat necessary in the gas processing plant. The flue gas stack temperature is sufficiently above the sulfur dew point of the flue gas to avoid any corrosion problems.

The thermal oxidiser system is shown in Figure 4. Three fuel gas burners provide fuel gas as required to initiate and stabilise combustion, depending on the operating case. The thermal oxidiser is a horizontal cylindrical refractory lined vessel. Primary, secondary, and tertiary injectors add air into the thermal oxidiser at staging intervals that ensure proper control of the combustion process and complete combustion of the permeate and acid gas streams. Heat is recovered from the flue gas in the hot oil heater tubes before flue gas is discharged to the atmosphere via the vent stack.

## Conclusion

Thermal oxidisers play an important role in emissions control for gas processing plants. Direct oxidation of the waste gas streams is a simple and effective way to meet emissions requirements, but it often comes at the expense of fuel consumption in the form of assist gas. By capturing a portion of the heat energy used for waste gas destruction and using this to meet some, or all solvent regeneration needs, processing plants can enhance their efficiency and minimise their overall operating costs. If this energy is not needed elsewhere in the plant, then a waste gas and/or combustion air preheaters can be used to reduce the fuel consumption of the thermal oxidiser, thereby reducing the plant's operating costs. Through assessment of the total duty requirements of the plant, and proper understanding of the requirements of the thermal oxidiser process, heat recovery can be implemented in a thermal oxidiser system to positively impact plant economics, operational flexibility, and the environment.