

## **NEW APPROACHES TO SMELTER OFF-GAS HEAT RECOVERY**

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### **ABSTRACT**

Smelter processes generate significant off-gas flows at high temperatures, which represent a major heat loss from the process, so off-gas heat recovery is critical to minimizing energy consumption and reducing operating costs. Metallurgical process off-gas presents real challenges for heat recovery due to high dust loading, corrosive gas, and thermal cycling in batch processes. Waste heat boilers have been used for heat recovery on continuous smelting and converting processes. However, batch processes such as Peirce-Smith converting and other lower temperature applications have been largely overlooked for heat recovery.

The design and adaptation of novel heat recovery processes and technologies to smelter processes can provide a major step in reducing energy consumption, greenhouse gas emissions, and operating cost. This paper outlines the challenges faced in recovering heat in smelter processes and presents new approaches for heat recovery for batch processes and lower temperature applications.

## INTRODUCTION

Smelter processes generate significant off-gas flows at high temperatures, which represent a major heat loss from the process, so off-gas heat recovery is critical to minimizing energy consumption and reducing operating costs. Metallurgical process off-gas presents real challenges for heat recovery due to high dust loading, corrosive gas, and thermal cycling in batch processes. Waste heat boilers have been used for heat recovery on continuous smelting and converting processes. However, batch processes such as Peirce-Smith converting and other lower temperature applications have been largely overlooked for heat recovery.

## WASTE HEAT AVAILABLE IN SMELTER OFF-GAS

### Flash Furnaces

Flash furnaces are used extensively in sulfide smelters to smelt dried concentrate to a matte. The furnace operates continuously, with a feed system delivering a steady stream of concentrate to a burner, where it is reacted with oxygen to flash smelt the concentrate. The process generates a continuous, steady off-gas flow rate at 1000 to 1200°C. Off-gas flow rates are generally low due to the use of high overall oxygen enrichment in the burner process and fixed off-take which minimizes air infiltration.

Typically, waste heat boilers are close-coupled to the flash furnace to remove heat from the off-gas ahead of a hot ESP. The gas must be cooled below 400°C to be handled by the hot ESP, and the boiler uses the waste heat to produce saturated steam for miscellaneous process uses or superheated steam for local power generation. The boiler consists of a radiative section to cool the gas to about 700°C and then a convective section to cool the gas below 400°C.

Despite the significant amount of heat removed by the boiler, the off-gas still contains a large amount of sensible heat at the exit of the hot ESP, as shown in Figure 1 below.

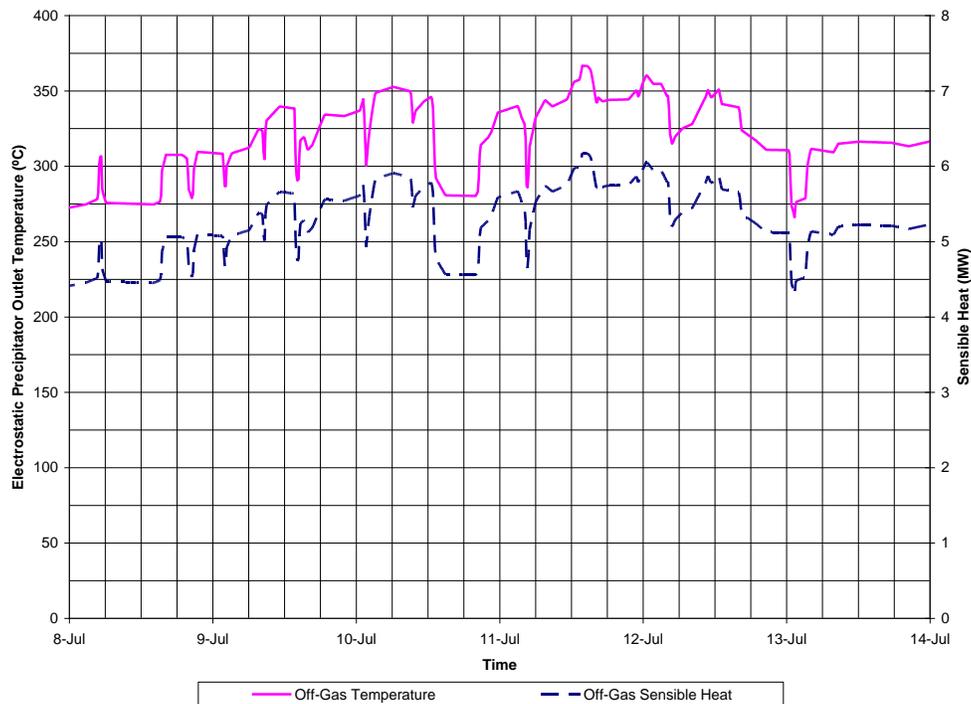


Figure 1 - Flash Furnace Off-Gas Temperature and Heat Content at Hot ESP Outlet  
40,000 Nm<sup>3</sup>/hr Off-Gas Flow Rate

Flash furnace off-gas at 40,000 Nm<sup>3</sup>/hr contains 5 to 6 MW of sensible heat at the ESP outlet and is relatively clean of dust. The off-gas is generally taken to an acid plant to produce sulfuric acid. This requires further cleaning and cooling in the acid plant's wet gas cleaning section. The gas is saturated with water through scrubbing and then cooled in a packed gas cooling tower or in shell and tube coolers. The heat removal therefore becomes the duty of the water cooling tower that is supplying the gas cooling units. Therefore, the remaining heat after the hot ESP is wasted in the wet gas cleaning plant, which has an operating cost to remove this heat.

If, alternatively, the hot ESP outlet gas could be further cooled through a heat recovery unit, additional heat recovery could be achieved. In addition, the cooling duty on the wet gas cleaning plant's water cooling tower would be reduced. This dual effect could provide major operating cost savings.

## Converters

Converters are used extensively in sulfide smelters to convert smelted matte to blister. Most converters operate in a batch process, with each batch, or cycle, generally lasting about 6 hours. The cycle consists of an initial slag blow of about 1 hour, followed by about 30 minutes idle where the vessel is slag skimmed and then charged with more matte. A second slag blow of about 1 hour occurs followed by about 30 minutes idle where the vessel is again slag skimmed and charged with matte, reverts, and other material. The vessel then blows steadily for about 3 hours in the copper blow. After completing a cycle, a converter vessel typically sits idle for 6 hours in hot standby mode while another converter vessel is brought online. Most modern Peirce-Smith converter smelters have two converters blowing and a third in hot standby. Often, a fourth converter is off-line for repair or rebuild.

Process gas flow rate exiting a blowing vessel is generally equal to the blowing rate during copper blow and slightly less than the blowing rate during slag blow. Process gas temperature is typically 1100 to 1200°C. The gas is captured by a primary hood, which typically allows 100 to 120% infiltration air into the hood (if the gas is going to an acid plant), effectively doubling the off-gas flow rate. The gas is then cooled by evaporative cooling or radiative cooling to below 400°C to enter a hot ESP. Instead of spray cooling or radiative cooling, some converter smelters have applied waste heat boilers or gas-to-air heat exchangers to converter off-gas with mixed success.

Despite cooling the off-gas below 400°C for the hot ESP, the off-gas still contains a large amount of sensible heat at the exit of the hot ESP, as shown in Figure 2 below.

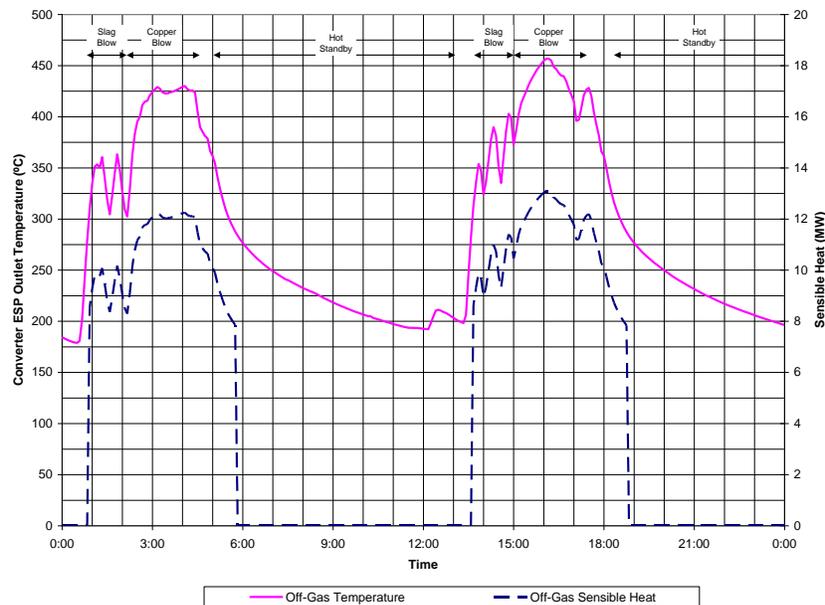


Figure 2 - Converter Off-Gas Temperature and Heat Content at Hot ESP Outlet  
30,000 Nm<sup>3</sup>/hr Blowing Rate

Converter off-gas at a 30,000 Nm<sup>3</sup>/hr blowing rate contains 8 to 12 MW of sensible heat at the ESP outlet per blowing converter, and is relatively clean of dust. The off-gas is generally taken to an acid plant to produce sulfuric acid. Like the flash furnace off-gas, this requires further cleaning and cooling in the acid plant's wet gas cleaning section. The heat removal therefore becomes the duty of the water cooling tower that is supplying the gas cooling units. Therefore, the remaining heat after the hot ESP is wasted in the wet gas cleaning plant, which has an operating cost associated with it to remove this heat.

If, alternatively, the hot ESP outlet gas could be further cooled through a heat recovery unit, additional heat recovery could be achieved, and the cooling duty on the wet gas cleaning plant's water cooling tower would be reduced, yielding major operating cost savings.

### **Anode Furnaces**

Anode furnaces are used in sulfide smelters to refine blister copper for anode casting. Anode furnaces operate in a batch process, with each batch, or cycle, generally lasting about 3 or more hours. The cycle consists of an initial oxidation stage of about 1 hour, followed by a reduction stage of about 2 hours. The oxidation stage may take a few hours longer if processing high-sulfur copper from continuous converting. After completing a cycle, a vessel typically sits idle for several hours in hot standby mode. Most modern smelters have two or three anode furnaces, with one or two operating at a time.

Process gas flow rate exiting a vessel is generally less than 10,000 Nm<sup>3</sup>/hr at a gas temperature of 1100 to 1200°C. The gas is captured by a primary hood, which allows significant infiltration air into the hood. During the reduction stage, the process gas can contain up to 25% combustibles (CO and H<sub>2</sub>), which must combust before entering a baghouse and fan. The air ingress at the primary hood combusts and dilutes the reduction stage process gas. In the oxidation stage, it simply dilutes the process gas. The gas is then typically cooled by evaporative cooling to about 200°C and then sent to a baghouse for particulate removal before being discharged to atmosphere via fan and stack. Some smelters also scrub the gas to remove SO<sub>2</sub> downstream of the baghouse.

Despite cooling the off-gas below 200°C for the baghouse, the off-gas exiting the baghouse still contains about 4.5 MW of sensible heat. That heat is currently discharged to atmosphere.

### **Electric Furnaces**

Electric furnaces are used to smelt lateritic nickel calcine and platinum group metal concentrate as well as for slag cleaning applications in sulfide smelting. The furnace operation is a continuous process, with a steady off-gas flow rate and temperature of 500 to 1000°C. Smelting furnace off-gas is typically cooled with evaporative cooling, mixed with secondary ventilation gases for dilution, and sent to a baghouse for particulate removal at 200 to 250°C. Slag cleaning furnace off-gas is typically sent to a scrubber.

Electric smelting furnace primary off-gas typically contains 12 to 25 MW of sensible heat. Normally the gas is cooled through evaporative cooling. If the primary gas were instead sent through a heat recovery device such as a waste heat boiler or air to gas heat exchanger, approximately 6 to 18 MW of thermal energy could be recovered. Alternatively, the primary off-gas could be sent directly to a dryer or kiln, allowing for full recovery of the off-gas sensible heat.

Even after primary cooling, the off-gas still contains a significant amount of heat, especially if it is then mixed with secondary ventilation gases containing some heat. Figure 3 below shows the baghouse outlet conditions for a typical electric smelting furnace.

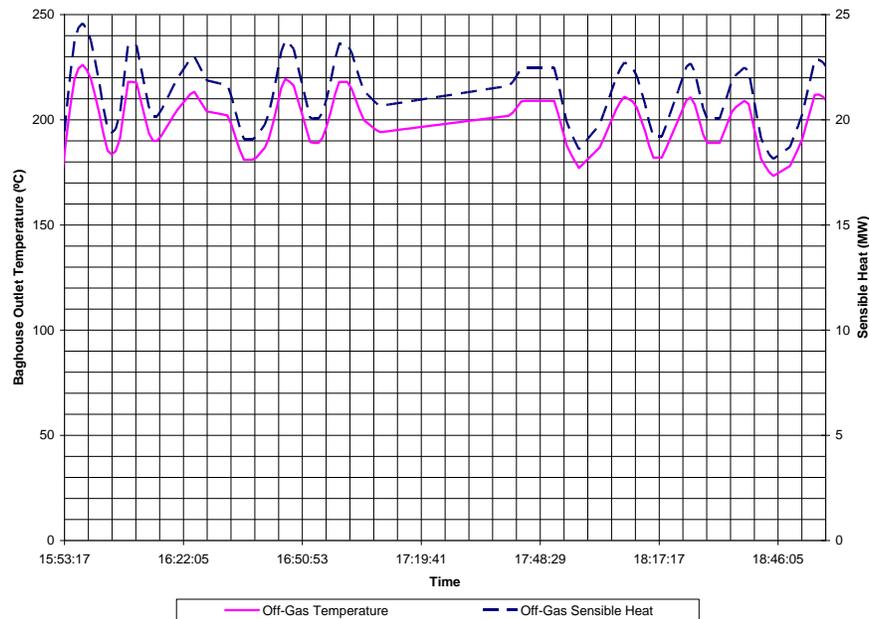


Figure 3 - Electric Smelting Furnace Off-Gas Temperature and Heat Content at Baghouse Outlet  
310,000 Nm<sup>3</sup>/hr Off-Gas Flow Rate

Electric smelting furnace off-gas at 310,000 Nm<sup>3</sup>/hr contains 19 to 24 MW of sensible heat at the baghouse outlet. This clean, continuous off-gas stream is normally discharged to atmosphere, wasting this energy. If the baghouse outlet gas could be sent to a heat recovery unit, additional heat recovery could be achieved.

## COMMON HEAT RECOVERY TECHNOLOGIES IN USE

### Waste Heat Boilers

Waste heat boilers are well proven in handling continuous hot, dirty, and potentially corrosive gas streams in the metallurgical industry. They are standard gas conditioning equipment on flash furnaces and top submerged lance smelting and converting vessels. Process off-gas waste heat boilers typically consist of a radiative section followed by a convective section. The radiative section cools the gas to about 700°C entering the convective section, which further cools the gas to 350 to 400°C. For other process gases with temperatures below 800°C, a convective section alone could be used to cool the gas. Boilers can produce about 0.66 kg of steam per Nm<sup>3</sup> of off-gas, or about 1560 kg/hr of steam per MW of heat removal.

Waste heat boilers can be designed to produce saturated steam or superheated steam. Superheated steam can be used to produce power through a steam turbine. Saturated steam from a boiler can be used for process steam or be superheated in a separate boiler to produce power through a turbine. Thus, waste heat boilers make the most sense where sufficient quantities of process steam could be used or where there is infrastructure in place to produce power through a steam turbine. Other facilities that do not produce power locally and do not use significant quantities of steam in their process will find waste heat boilers less useful, though they could still install a dedicated steam turbine for the system.

Batch processes, such as Peirce-Smith converting, generally do not use waste heat boilers, though some do. The thermal cycling of the batch process causes some issues with boilers. First, the thermal cycling of the system, which is hot when a vessel is operating and then cools down when not operating, causes regular expansion and contraction which can fatigue the equipment and develop cracks and other leakage points over time. Also, process gases containing high SO<sub>2</sub> can present acid condensation issues when the vessel is taken off-line and cools down.

## **Air-to-Gas Heat Exchangers**

Air-to-gas heat exchangers, or recuperators, are used in many metallurgical applications to recover heat from off-gas. These are generally shell-and-tube type heat exchangers. They are low capital cost units and can handle dirty gases. The heat is recovered in the form of preheated air, which can be used in other processes, such as dryers, kilns, or other processes requiring air input. Heat recovery savings is limited to the air demand by the available end users. The heat recovered is generally a low grade heat (less than 400°C) and therefore has limited other use.

Like waste heat boilers, air-to-gas heat exchangers are subject to the detrimental impacts of thermal cycling, including fatigue, cracking, leakage, and corrosion. Air-to-gas heat exchangers are an ideal option for continuous processes where there is a demand for preheated air but have limited other applications for heat recovery.

## **CHALLENGES FACED IN RECOVERING WASTE HEAT**

Waste heat recovery presents a number of design, operational, and maintenance challenges which must be addressed for effective long term performance of the system.

### **Fouling and Plugging**

Most waste heat recovery applications handle dirty gas, which presents a high probability of fouling and plugging. Sticky dust in smelting operations is a particular problem. Fouling and plugging reduce heat transfer, increase pressure loss, and can reduce fume capture efficiency at the source. In addition, dust buildup can contribute to localized corrosion.

Heat recovery units need to be designed to allow streamlined gas flow through the unit to avoid dropout or impingement onto the heat transfer surfaces. In addition, it is often necessary to incorporate rappers or sonic horns to periodically knock accumulated dust off of the surfaces. In sulfide smelting, it is preferable to add sulfatizing air to the off-gas in order to oxidize sulfide dusts to sulfates to reduce their stickiness. Heat recovery options that can be installed downstream of gas cleaning equipment, such as a baghouse or ESP, should also be investigated.

### **Corrosion**

Corrosion is another concern for heat recovery units. Heat removal from the gas stream can cool the gas to the point where water or acid condenses on the surfaces. Corrosion can be brought on by thermal cycling, fouling, or poor process control. Corrosion reduces the life of the equipment.

In order to avoid corrosion, it is critical to understand the water and acid dew points of the gas stream for the full range of expected operating conditions. It is also important to understand the surface temperature profile throughout the heat recovery unit. Finally, effective process control must be put in place in order to maintain gas and surface temperatures above the dew point to prevent condensation and corrosion. Minimizing thermal cycling from batch processes is also key.

### **Thermal Cycling**

Thermal cycling is a concern for variable processes and particularly for batch processes. It can cause condensation and corrosion as temperature decreases. The regular expansion and contraction of the equipment due to the thermal cycling can also cause material fatigue, cracking, and leakage. This can greatly increase air infiltration into the system, reducing process gas capacity and potentially causing corrosion due to the dilution cooling effect.

Heat recovery units should be designed with appropriate expansion allowance. The units should also be regularly maintained to minimize leakage and maintain the integrity of the equipment. Where possible, the process should be controlled to minimize the range of thermal cycling.

## **Equipment Cost**

Waste heat recovery generally must be expected to achieve 20 to 33% simple ROI to be implemented. Therefore, it is critical to minimize the equipment cost to provide a favorable return. Equipment cost can increase substantially when handling higher temperature or corrosive gases that require higher grade materials. For boiler applications, the high pressure rating of the vessel adds to the cost, as does steam handling and distribution. It is imperative to maintain effective heat transfer so that equipment size is not excessive.

In most heat transfer applications, the most efficient and cost effective heat recovery is the initial cooling of the gas in the first section of heat transfer. As the gas gets cooler, the heat transfer temperature gradient is reduced, and heat transfer becomes less efficient. Therefore, it takes more heat transfer area and thus higher equipment cost to remove each additional kW of energy. This higher marginal cost leads to diminishing returns on the investment, offsetting the cost benefits of economy of scale. Therefore, the most optimal heat recovery design might not be the one that provides the maximum amount of heat recovery, but rather the one that provides the lowest average cost.

## **Parasitic Loads**

Heat recovery systems include parasitic loads which add operating costs and off-set some of the heat recovery savings. Often, heat recovery units add pressure drop to the off-gas system, increasing ID fan power consumption. There is also additional motive power required to supply and circulate the heat recovery fluid using pumps and/or fans. Some applications may also require air or water cooling condensers or cooling towers, which consume power. Selection and design of a heat recovery system should aim to minimize these parasitic loads by minimizing pressure losses and maximizing equipment efficiency.

Heat recovery systems also require regular maintenance on the heat exchanger, motive equipment, turbines, and distribution systems, which add costs and off-set some of the heat recovery savings. Therefore, it is beneficial to simplify the system design, minimize the amount of equipment required, handle cleaner gases and fluids where possible, and perform proper preventative maintenance.

Parasitic loads and the associated added operating and maintenance costs must be considered along with capital cost and heat recovery savings when selecting and designing a successful heat recovery system.

## **Batch Processes**

Batch processes present several issues for heat recovery. As discussed above, batch processes are particularly susceptible to thermal cycling, which can lead to fatigue, corrosion, and leakage. In addition, batch processes tend to have variable off-gas conditions when operating, which can lead to inconsistent heat recovery. This can have a detrimental impact on power generation or preheated air availability.

The heat exchanger has to be designed to handle the peak gas conditions, even though real annual heat recovery savings will be based on average operating conditions. Batch processes tend to have a higher differential between peak and average operating conditions than continuous processes, so the return on investment (ROI) would tend to be lower for a batch process than for a similar continuous process. Most importantly, batch processes typically operate far fewer hours per year than continuous processes. Therefore, dedicated heat recovery equipment on a batch process would realize much lower annual heat recovery savings than a continuous process, dramatically reducing the ROI for the unit.

There are two potential mitigating options for handling variable heat recovery from batch processes: thermal storage and common heat exchangers. With thermal storage, the heat recovered from the process is stored in the form of a thermal medium, such as oil. The level of stored heat would rise and fall with the operation, while a constant stream of heat (less than operating heat recovery rate) would be bled from the storage system to produce power or preheated air. This would allow the downstream power generation equipment or processes using preheated air to see a constant load, providing a more stable and efficient process and reducing the size of that heat recovery equipment.

Common heat exchangers are another mitigating option for batch processes. Copper smelters, for example, typically have three or four converters, which each cycle through operating and standby modes as well as rebuilds. Most of these smelters blow two converters at any one time to maintain a steady flow of gas and SO<sub>2</sub> to the acid plant. In a four-converter smelter, each converter operates about 45% of the time. Therefore, putting a dedicated heat exchanger on each converter would be very difficult to justify because of the reduced annual heat recovery savings. However, if the heat exchanger could be installed after the converter off-gas ducts combine, that heat exchanger would operate with a relatively steady flow of two blowing converters more than 90% of the time. This would greatly increase the ROI of the system.

Batch processes do provide a couple of additional advantages over continuous processes. For one, the reduced operating hours and process flexibility provide more opportunities to optimize the design and performance of the unit or to make repairs or clean out a unit. In addition, there is less likelihood of reduced process availability due to a heat exchanger, since the unit can be maintained during normal downtime for the vessel while the smelter continues to operate.

### **Low Grade Heat**

Low grade heat, with gas temperatures between 50 and 300°C, has historically been very difficult to recover economically. Temperatures are not high enough to effectively boil water to produce good quality steam, and air preheat is limited to less than the inlet gas temperature. In addition, the cost of recovering the heat is high due to the lower temperature gradient between the off-gas and the heat transfer fluid. As a result, more heat transfer area is required per unit of energy, and the equipment cost is therefore more expensive. Conventional waste heat boilers and air-to-gas heat exchangers are generally not suitable for recovering low grade heat.

### **Availability and Maintenance Requirements**

Heat recovery systems add multiple components that must be maintained. Motive equipment, such as pumps and fans for the heat recovery fluid, as well as instrumentation and valves must be maintained regularly. Plugging or fouling can occur in the unit. If the heat exchanger unit is the only path for the off-gas, maintenance of that equipment may reduce overall system availability.

Maintenance requirements and availability must be considered in selecting and designing a suitable heat recovery system for a given application. The system should be as simplified as practical. In more critical applications, it may be best to have the heat recovery unit installed in parallel with a spray chamber or have a bypass so that the process can continue to operate even when the heat exchanger must be taken off-line for maintenance.

## **POTENTIAL NEW HEAT RECOVERY TECHNOLOGY APPLICATIONS IN SMELTERS**

### **Organic Rankine Cycle Heat Recovery and Power Generation**

Organic Rankine Cycle (ORC) heat recovery is well established for low-grade heat recovery in other applications, but it has not been widely used in smelting applications. ORC uses a similar concept as a boiler producing steam from water, except the fluid used is a low-boiling point organic fluid as the heat transfer medium. For a metallurgical off-gas application, the hot off-gas would pass through a shell-and-tube heat exchanger with the organic fluid on the other side. Heat in the off-gas is transferred to the organic fluid, vaporizing the organic fluid. The vaporized organic fluid is then passed through a gas turbo-expander or turbine with a generator to produce electricity. The fluid would then be cooled and condensed back to liquid and then pumped back to the heat exchanger, completing the cycle. The organic fluid circuit is a closed circuit. Figure 4 shows a schematic of a typical ORC heat recovery system.

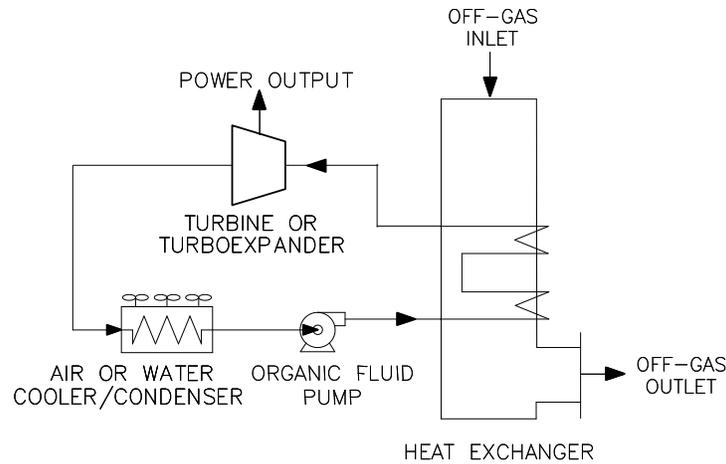


Figure 4 – Typical ORC Heat Recovery System

ORC heat recovery has been used for many years in geothermal applications with low temperatures as well as hydrocarbon processing facilities with higher temperatures and lower flow rates. ORC offers the distinct advantage of being able to recover much lower grade heat than a boiler or traditional heat exchanger to produce power. ORC units work well with inlet gas temperatures above 175°C. This makes them suitable for handling gases downstream of baghouses and electrostatic precipitators (ESPs). This allows them to handle clean gases, greatly reducing the risk of fouling and plugging and reducing maintenance. ORC units could be used on smelter primary gases downstream of ESPs or baghouses, including smelting furnaces, converters, and anode furnaces. This includes systems which already have boilers or air-to-gas heat exchangers upstream, increasing total heat recovery.

The lower temperature operations reduce the magnitude of thermal cycling of the equipment, and the ability to install downstream of converter ESPs allows the unit to see a more continuous flow and temperature from the converter set. ORC units can typically produce enough power to be used to directly drive the ID fans of a system as well as some additional equipment. This results in lower installation, distribution, and metering requirements than would be required to put the power back on the grid. Figure 5 below shows the normalized heat recovery potential (kWt/Nm<sup>3</sup>/hr) versus inlet gas temperature for various outlet temperature targets.

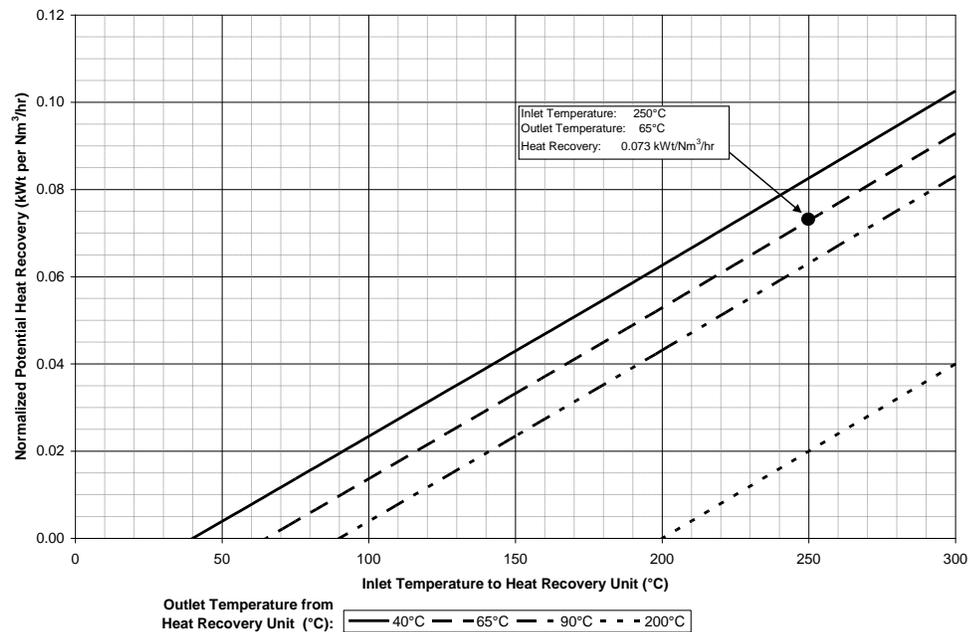


Figure 5 – Normalized Heat Recovery Potential for ORC Applications

Figure 5 above shows that off-gas entering at 250°C and exiting at 65°C could yield heat recovery of 0.073 kWt per Nm<sup>3</sup>/hr of off-gas. An off-gas flow rate of 300,000 Nm<sup>3</sup>/hr would thus allow 21,900 kWt (21.9MWt) of heat to be recovered.

Sulfide smelting is a new application for ORC and thus requires some development. The power generation side of the system is well defined and would be no different than previous well proven installations. The off-gas heat exchanger would be the main area of new application. ORC systems in smelting applications are expected to have a capital cost in the range of \$2000 to \$3000 per kW of power production. Net energy recovery to power (including parasitic loads) is estimated to be 10 to 20% of thermal energy recovered. Figure 6 below shows the opportunity envelope for a typical ORC system in terms of Return on Investment (ROI) versus electricity costs.

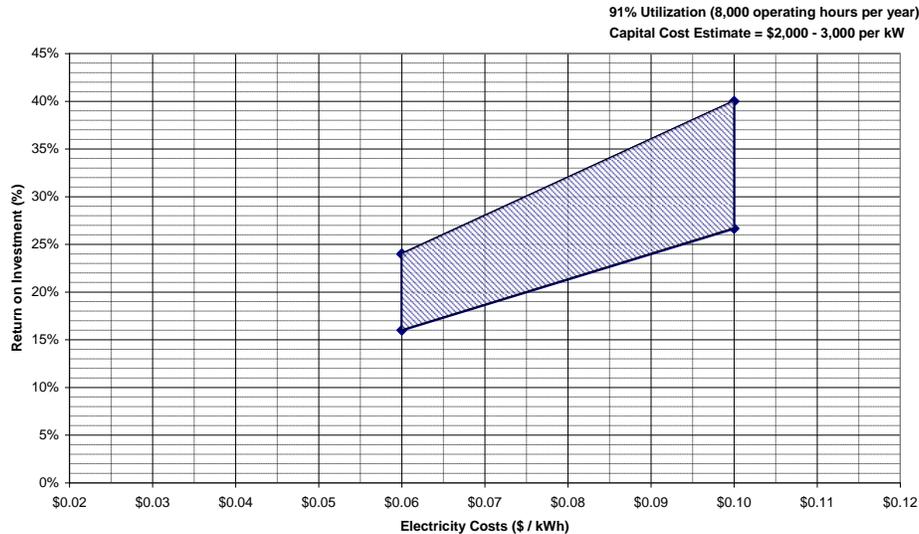


Figure 6 – Typical ORC Return on Investment Opportunity Envelope

Key design issues for ORC applications include:

- Selection of ORC working fluid
- Heat exchanger design and materials of construction
- Air-cooling or water-cooling
- Power generation setup
- Optimization of heat recovery

Various working fluids can be used for the ORC system. Typical fluids include low density hydrocarbons such as propane and butane as well as numerous refrigerants and ammonia. The various fluids offer a range of boiling points and heats of vaporization. Fluid selection criteria also include flammability and safety concerns, corrosiveness, environmental and health impact, stability, and cost and availability.

Heat exchanger design must include an assessment of potential abrasion, corrosion, fouling, and plugging. Materials should be selected to handle the expected gas inlet temperature, composition, and dust loading. The design must also consider the acceptable pressure drop and available size and footprint.

Following the turbo-expander or turbine, the ORC fluid must be cooled and condensed for pumping back to the heat exchanger. This duty can be performed using air-cooling or water-cooling. Air-cooling requires a larger footprint, while water-cooling requires cooling water availability and infrastructure. Key criteria to assess in selecting the cooling method include ambient temperature and humidity, availability of cooling water and infrastructure, and available space.

Power generation can be achieved using a turbo-expander or turbine technology. A single unit or multiple units could be used in parallel, and the process can be a single stage or two stage process. Selection of the most suitable equipment and configuration will depend on expected power generation rate, fluid selection, cost, and efficiency.

### Thermal Oil Heat Recovery

Thermal oil heat recovery is a developed technology in other industries that could be applied to metallurgical applications. Thermal oil units are typically constructed like waste heat boilers but using liquid oil instead of water and steam as the heat transfer medium. The oil can typically be heated up to about 350°C. Thermal oil has been used in food preparation ovens as well as for heat recovery on pulp and paper firing applications. Figure 7 shows a schematic of a typical thermal oil heat recovery system.

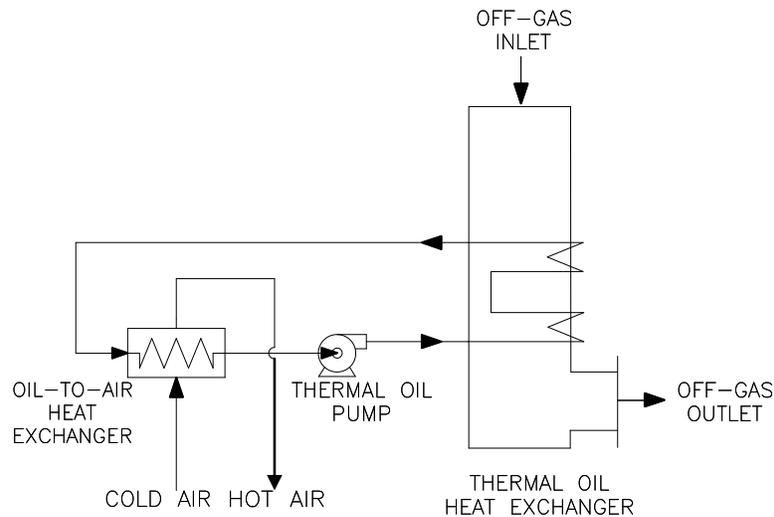


Figure 7 – Typical Thermal Oil Heat Recovery System

Thermal oil heat recovery in metallurgical applications would best be used to preheat air for process operations. This would require a primary heat exchanger to recover heat from the off-gas into the thermal oil and a secondary heat exchanger to transfer heat from the oil to the preheat air or other medium.

A variety of natural and synthetic oils can be used in thermal oil heat recovery. Key factors in selecting the oil include:

- cost,
- expected operating range,
- quantities required, and
- availability

There can be significant variation in the availability and costs between various oils, and some oils can operate at much higher temperatures without degradation. Proper selection of oil is highly dependent on the specific application requirements.

Thermal oil applications in non-ferrous smelters would include typical waste heat boiler applications but where steam is not of use and other heating, like air preheating, is of use. This would include furnace and top submerged lance vessel off-gas. Thermal oil is better suited for preheating air without condensate losses, and the heat exchanger typically would not require boiler certification or high pressure rating. The main disadvantages of the thermal oil concept include higher capital cost, particularly if a higher-cost oil is selected, the need for a second heat exchanger to preheat air, which reduces overall efficiency, and the flammability of the oil, which requires proper handling and safeguards.

## Thermal Storage and Power Generation

The ability to store heat recovered from a process would enable many batch processes to have economically feasible heat recovery options. Thermal storage decouples the heat recovery process from the end user of the recovered heat. This enables the end user to operate more steadily without the variability of the batch process heat load. This is critical for the efficiency and productivity of many end users, such as turbines and continuous processes using air preheated from a heat recovery unit. Thermal fluids have been used for thermal storage in many applications, including solar power generation. Figure 8 shows a schematic of a typical thermal storage heat recovery system.

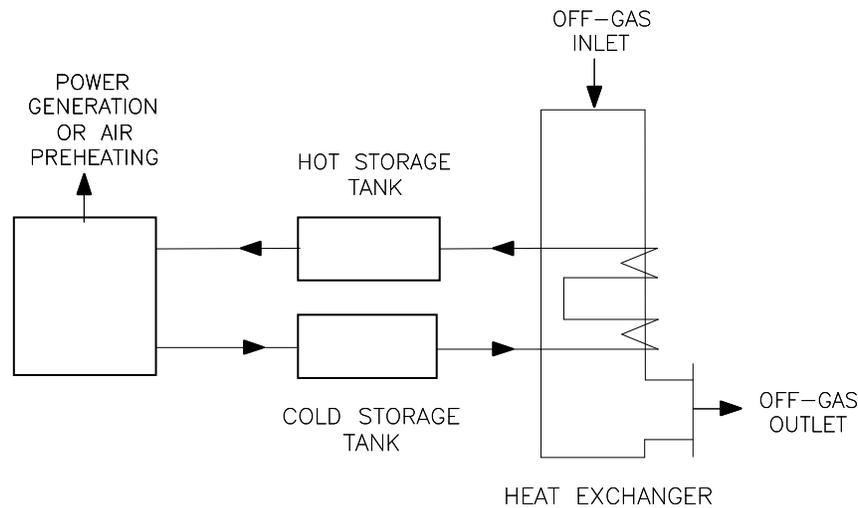


Figure 8 – Typical Thermal Storage Heat Recovery System

Thermal storage works by transferring heat to a thermal fluid in a heat exchanger and then collecting the heated fluid in an insulated hot storage tank. The heated fluid accumulates in the hot storage tank when the process is operating and is drawn down when the process is not operating (between cycles). A constant stream of heated thermal fluid is drawn off the hot storage tank to boil water for power generation or to preheat air for another process. The cooled thermal fluid is then returned to a cold storage tank to be recirculated back through the heat recovery unit.

### BENEFITS OF PROCESS OFF-GAS HEAT RECOVERY

Heat recovery provides many direct and indirect benefits. It reduces energy consumption and the associated operating costs. If production is limited by energy availability, heat recovery can even allow for increased production. Heat recovery also reduces greenhouse gas emissions by reducing consumption of fuels for processes or power production. Finally, heat recovery helps contribute toward achieving sustainability for an operation, while also promoting corporate responsibility and improving public image.

The ability to generate consistent electric power from heat recovery is a significant opportunity to reduce or contain operating costs as electricity costs are expected to increase significantly in the future to cover the costs of modernizing power plants and reducing their emissions.

Current and future regulations on CO<sub>2</sub> emissions will increase the cost of using fossil fuels and most electric power. Cap-and-Trade programs are in place in some countries and are expected to be adopted in the United States and elsewhere in the future. There is uncertainty in what the effective cost of CO<sub>2</sub> emissions will be, however, it is generally expected that costs will be in the range of \$10 to \$30 per ton in the near term and will likely increase significantly beyond that. Therefore, reducing consumption of electricity and fossil fuels and therefore reducing CO<sub>2</sub> emissions will produce significant operating cost savings where CO<sub>2</sub> emissions are regulated. Figure 9 below shows the estimated annual savings per MW of electricity use reduction for 8,000 hr/yr operation.

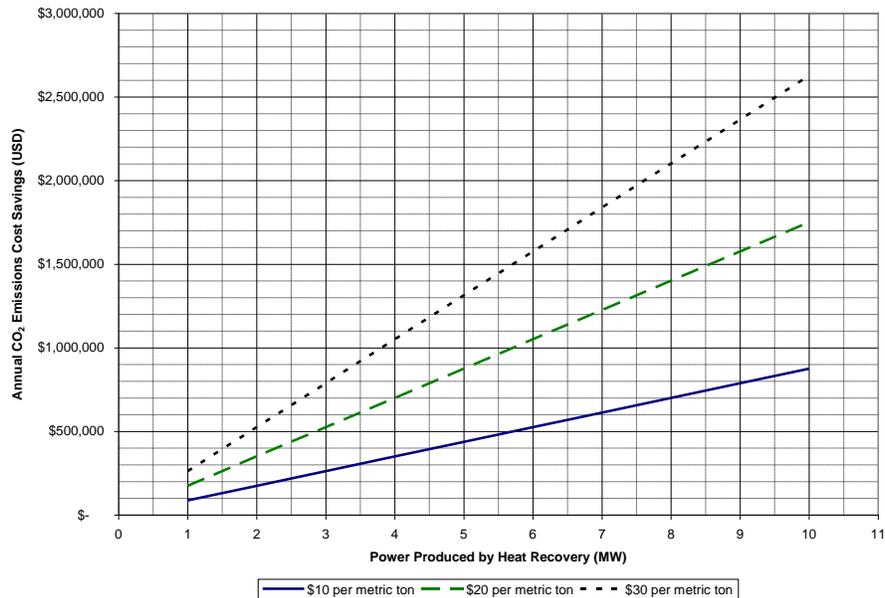


Figure 9 – Potential Annual CO<sub>2</sub> Emissions Cost Savings from Heat Recovery Power Production

As Figure 9 above shows, significant cost savings can be achieved by reducing CO<sub>2</sub> emissions through heat recovery power production in places where CO<sub>2</sub> emissions are or will be regulated. At costs of \$10 to \$30 per ton, CO<sub>2</sub> emissions cost savings can add up to 15% to the ROI of an ORC heat recovery system.

### CONCLUSIONS

A large quantity of process energy is lost to off-gas in metallurgical smelter applications. Some technologies have been used for years to recover heat from process off-gas with mixed success. Even when heat recovery is applied using conventional technologies, the outlet gas still contains a significant amount of lower grade heat that is lost. Also, continuous processes have historically been the main target for heat recovery, with batch processes largely ignored.

New technology applications can enable smelters to recover heat from lower grade sources and from batch processes, presenting many new opportunities for heat recovery. These technologies can complement the heat recovery already achieved by conventional technologies in higher temperature, continuous applications.

Smelters today face increasing fuel and power costs, as well as new or tighter regulations on greenhouse gas emissions and demands for sustainability. Successful heat recovery applications are an important part of the solution for all of these issues.