

Heat Recovery and Energy Optimization in Smelter Gas Cleaning

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ABSTRACT

Drying, smelting, converting, and refining processes generate significant off-gas flows. The process off-gas contains a significant portion of the energy input into and generated from the smelter processes. The ability to recover heat from the off-gas and to optimize energy usage in the process and gas cleaning system is critical to driving down operating costs.

Process gas presents real challenges for heat recovery due to high abrasive dust loading, potentially corrosive gas, and thermal cycling in batch processes. Waste heat boilers have been used extensively for heat recovery on continuous processes such as flash smelting and continuous converting. However, batch processes such as Peirce-Smith converting and lower temperature applications have been largely ignored for heat recovery.

The design and adaptation of heat recovery and energy optimization processes and technologies can provide a valuable next step in reducing energy consumption, recovering heat, and reducing greenhouse gas emissions.

This paper outlines the challenges faced in recovering heat and optimizing energy consumption in smelter processes and presents new approaches for heat recovery and energy optimization for batch processes and lower temperature applications.

INTRODUCTION

Copper Smelter processes generate significant off-gas flows at high temperatures. This typically represents a major source of heat loss from the process; therefore, 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 along with various lower temperature processes 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 boiler consists of a radiative section to cool the gas to about 700°C and then a convective section to cool the gas to below 400°C, suitable for entry into a hot ESP. The boiler uses the waste heat to produce saturated steam for miscellaneous process uses or superheated steam for local power generation.

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.

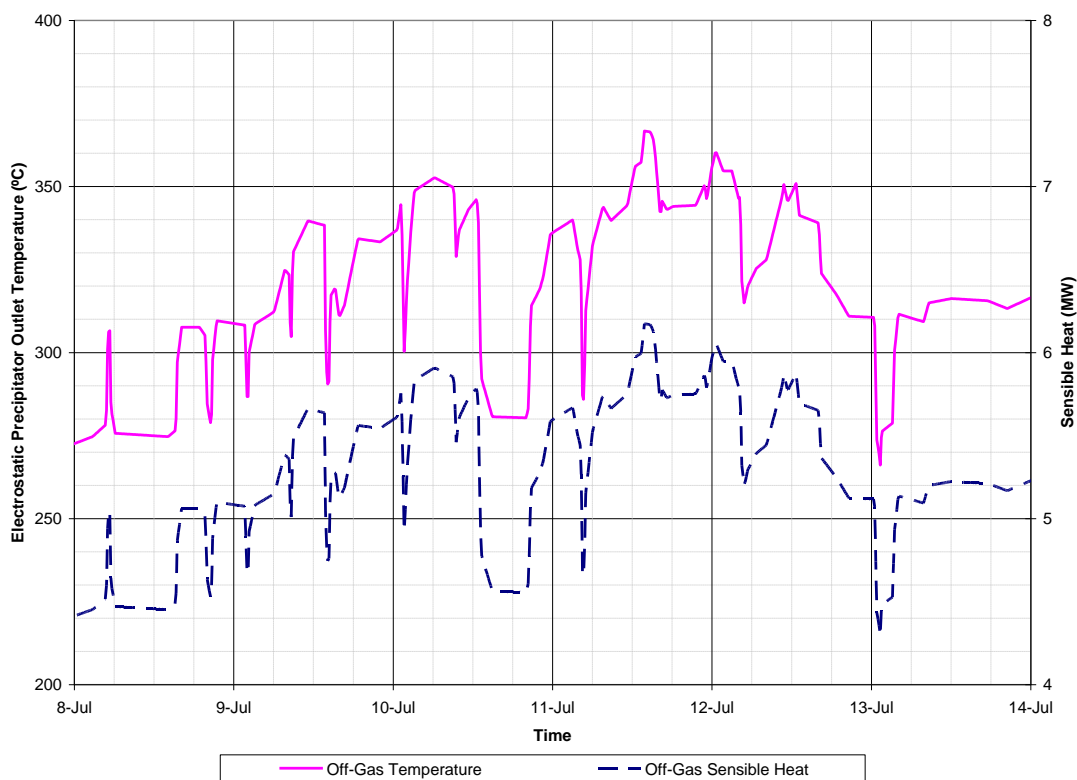


Figure 1 - Flash Furnace Off-Gas Temperature and Heat Content at Hot ESP Outlet (40,000 Nm³/hr Off-Gas Flow Rate)

Typical flash furnace off-gas at 40,000 Nm³/hr contains approximately 4.5 to 6 MW of sensible heat at the ESP outlet and is relatively clean of dust. The off-gas is generally further cooled and cleaned and taken to an acid plant to produce sulfuric acid. During this gas conditioning step, 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 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 associated operating cost to remove this heat.

If, alternatively, the hot ESP outlet gas could be further cooled through a heat recovery unit, this low grade waste heat can be recovered. This would also allow the cooling duty on the wet gas cleaning plant's water cooling tower to 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 phase 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 phase. 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 to 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.

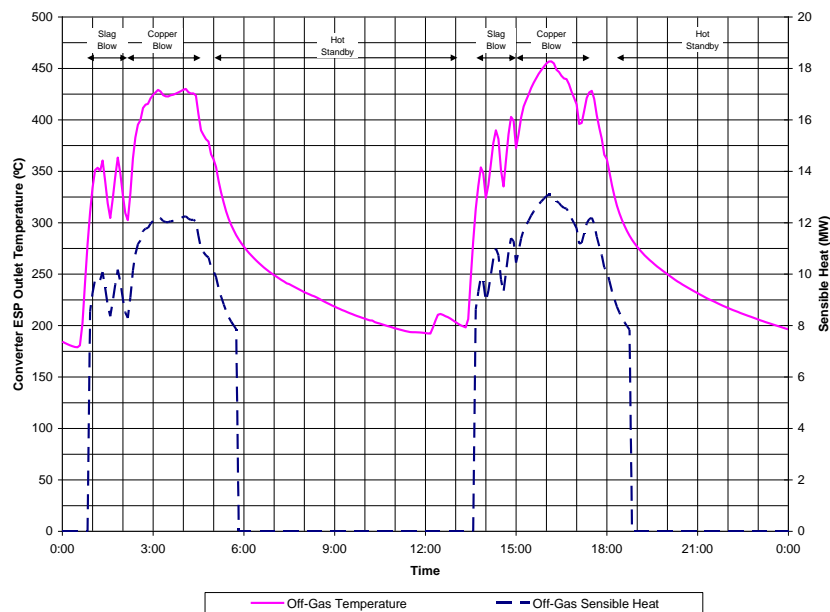


Figure 2 - Converter Off-Gas Temperature and Heat Content at Hot ESP Outlet
30,000 Nm³/hr Blowing Rate

Converter off-gas at a 30,000 Nm³/hr blowing rate contains approximately 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 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.

TSL Furnaces

Top Submerged Lance (TSL) smelting, such as the Ausmelt and Isasmelt processes, are used to smelt wet copper concentrate to matte. Copper converting from matte to blister using the TSL process is also possible, but not yet wide spread. Both the smelting and converting operations using TSL are continuous processes, with a steady off-gas flow rate and temperature of 1100 to 1200°C. Furnace off-gas flow rates are typically higher than flash smelting due to the higher moisture content of the feed and the use of lower oxygen enrichment.

The furnace off-gas is typically handled in a similar manner to flash smelting, using a close-coupled waste heat boiler and hot ESP. The gas is then sent to an acid plant for further conditioning and sulfuric acid production before venting to atmosphere.

As with flash smelting, a heat recovery unit could be used to recover the remaining waste heat in the off-gas downstream of the hot ESP.

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 Nm³/hr at a gas temperature of 1100 to 1200°C. During the reduction stage, the process gas can contain up to 25% combustibles (CO and H₂). The gas is captured by a primary hood which allows sufficient infiltration air to ensure combustion of CO and H₂. Often, there is significant additional air infiltration into the primary hood which further dilutes the process gas. In the oxidation stage, all of this air infiltration 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 SO₂ downstream of the baghouse.

Despite cooling the off-gas to below 200°C for the baghouse, the off-gas exiting the baghouse can still contain up to 3.5 MW of sensible heat. That heat is currently discharged to atmosphere.

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.

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.

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 SO₂ 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.

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 Nm³ 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 is typically used for power generation via a steam turbine while saturated steam can be used for other process applications. Saturated steam can also be sent through additional heat recovery units to produce superheated steam for power generation. 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. Facilities that do not produce power locally or 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 although there have been attempts for such applications with some degree of success. The thermal cycling of the batch process, i.e. hot when vessel is operating then cools down when not operating, results in regular expansion and contraction which can fatigue the equipment, developing cracks and other leakage points over time. Also, process gases containing high SO₂ 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.

POTENTIAL NEW HEAT RECOVERY TECHNOLOGY APPLICATIONS IN SMELTERS

Thermal Oil Heat Recovery

Heat recovery using thermal oil heat exchangers is a developed technology in other industries that could be applied to sulfide smelting applications. Thermal oil has been used in food preparation ovens as well as for heat recovery on pulp and paper firing applications. There are currently also several iron foundries using thermal heat exchangers to recover heat from cupola furnace off-gas.

Thermal oil units are similar in construction to waste heat boilers but use liquid oil instead of water and steam as the heat transfer medium. The oil can typically be heated up to about 350°C. Figure 3 shows a schematic of a typical thermal oil heat recovery system.

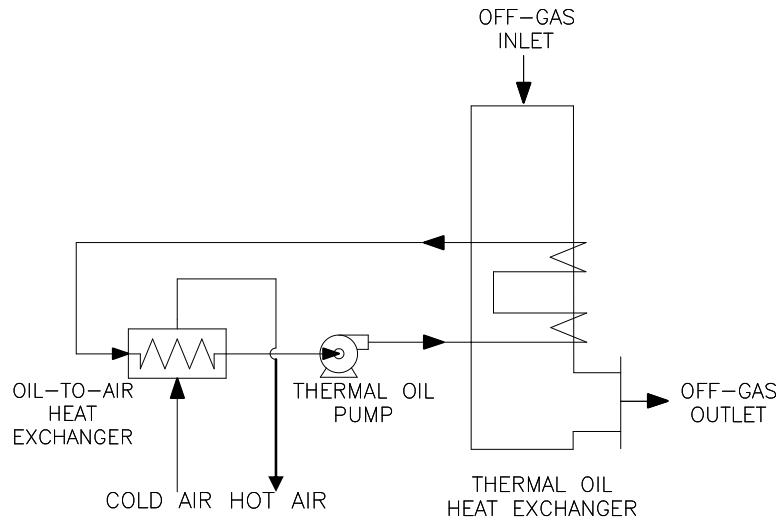


Figure 3 – Typical Thermal Oil Heat Recovery System

Thermal oil applications in sulfide smelting would include typical waste heat boiler applications but where steam is not of use and other heating, like air preheating, is of use. Thermal oil heat exchangers can also be used to recover lower grade heat from the off-gas exiting a primary waste-heat recovery technology such as a waste-heat boiler

Potential uses for thermal oil heat recovery in sulfide smelting applications include preheating 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. 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.

Alternatively, the oil could be sent to an Organic Rankine Cycle heat recovery system for power generation.

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. Therefore, proper selection of oil is highly dependent on the specific application requirements.

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 is a thermodynamic cycle which converts heat into work. The working principle of the organic Rankine cycle is the same as that of the traditional Rankine cycle involving water and steam; however, the organic Rankine cycle uses a low boiling point organic fluid in place of water. Fluids typically used as ORC working fluids include standard commercial refrigerants as well as low boiling point hydrocarbons. The lower boiling point allows heat recovery from lower temperature heat sources such as industrial waste heat, geothermal heat, solar ponds, etc. where steam generation is not practical.

The basic organic Rankine cycle system consists of a boiler, a turbine or turbo-expander with generator, a condenser, and a pump. The working fluid is pumped as a liquid to a boiler where it is evaporated through indirect contact with a hot heat transfer medium. The vaporized organic fluid leaving the boiler then passes through the turbine or turbo-expander. The gas expansion that occurs as the gas passes through the turbine generates shaft power which produces electricity in a coupled generator. The organic fluid exiting the turbine passes to a cooler/condenser which discharges the remaining heat and condenses the working fluid, which is collected in a receiver. The cooler/condenser can be air-cooled or water-cooled. Finally, the pump recirculates the condensed fluid back to the boiler to complete the cycle.

Heat is transferred to the ORC working fluid, either directly (one heat exchanger between waste heat and working fluid) or indirectly (one heat exchanger between the waste heat and an intermediate heat transfer medium such as thermal oil, and a second heat exchanger between the intermediate medium and the ORC fluid) – depending upon the characteristics of the waste heat source and other constraints. Typically, direct heat transfer configurations would be preferred for lower temperature clean gas streams with steady process flow conditions. Indirect heat transfer configurations would be preferred for higher temperature dirty gas streams, where gas conditions are variable, or where multiple heat sources could be tied to a single ORC system. Direct systems can achieve gas outlet temperatures of 40 to 85°C while indirect systems using thermal oil as the intermediate heat transfer medium can achieve outlet gas temperatures of 150 to 220°F.

In the majority of smelting applications, the heat exchanger would be located downstream of a hot ESP, therefore making direct heat exchange possible. In some batch processes an indirect heat exchanger loop may still be applied in order to smooth the variability gas stream. In the case of direct exchange, the heat source is simply connected to the ORC which converts part of the heat into electricity, as previously described. Figure 4 shows a schematic of a typical ORC heat recovery system utilizing direct heat exchange.

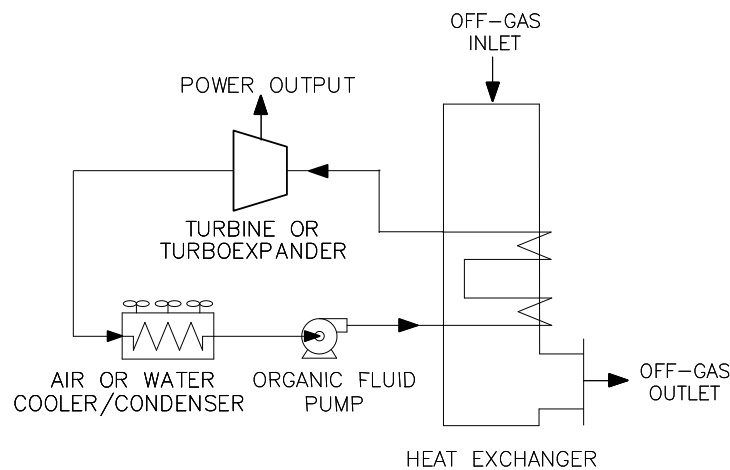


Figure 4 – Typical ORC Heat Recovery System

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 that 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. Typical fluids include low density hydrocarbons such as propane and butane as well as numerous refrigerants and ammonia.

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 of the system.

The ORC fluid must be cooled and condensed after leaving the turbo-expander or turbine to be pumped 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.

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 ($\text{kWt/Nm}^3/\text{hr}$) versus inlet gas temperature for various outlet temperature targets.

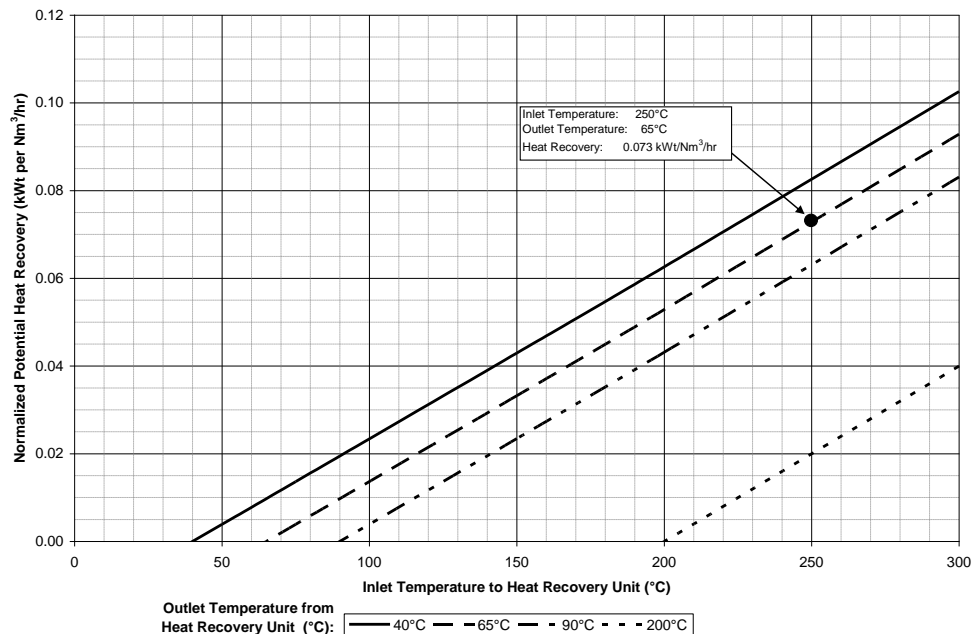


Figure 5 – Normalized Heat Recovery Potential for ORC Applications

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 Nm³/hr of off-gas. An off-gas flow rate of 300,000 Nm³/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. However, the ORC power generation equipment in this application would be the same standard equipment used for other applications, which has been well proven over many years. The primary equipment that will be specific to the sulfide smelting application will be the heat exchanger design to recover heat from the waste gas stream into the ORC fluid or intermediate heat transfer fluid. ORC systems in smelting applications are expected to have a capital cost in the range of \$3000 to \$4000 per kW of power production. Net energy recovery to power (including parasitic loads) is estimated to be 10 to 20% of thermal energy recovered. Higher efficiencies could potentially be achieved for higher off-gas temperature applications. Figure 6 below shows the opportunity envelope for a typical ORC system in terms of Return on Investment (ROI) versus electricity costs.

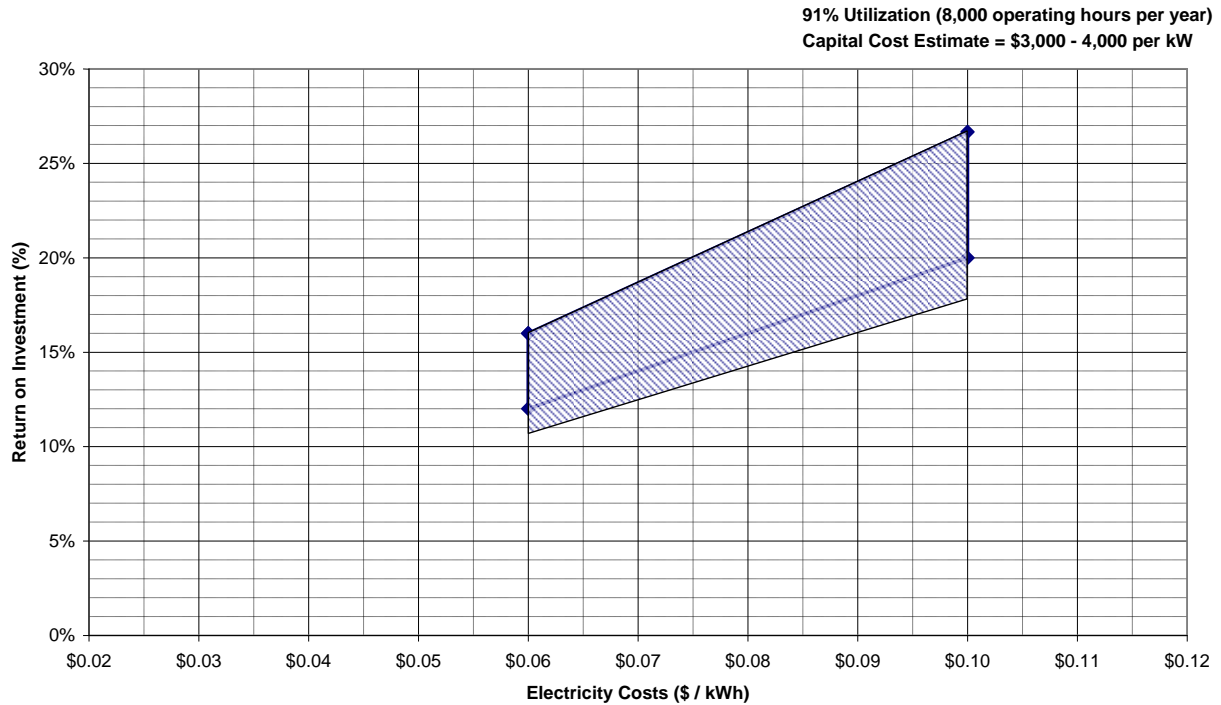


Figure 6 – Typical ORC Return on Investment Opportunity Envelope

ORC offers the distinct advantage of being able to recover much lower grade heat than a boiler or traditional heat exchanger to produce power. This makes ORC suitable for handling gases downstream of a baghouse or hot ESP allowing it to handle clean gases, greatly reducing the risk of fouling and plugging and reducing maintenance. This includes systems which already have boilers or air-to-gas heat exchangers upstream, increasing total heat recovery.

Thermal Storage and Power Generation

Historically, heat recovery options on batch processes have been limited due to the variability in the waste gas stream heat load. However, the ability to store the 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, allowing 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 7 shows a schematic of a typical thermal storage heat recovery system.

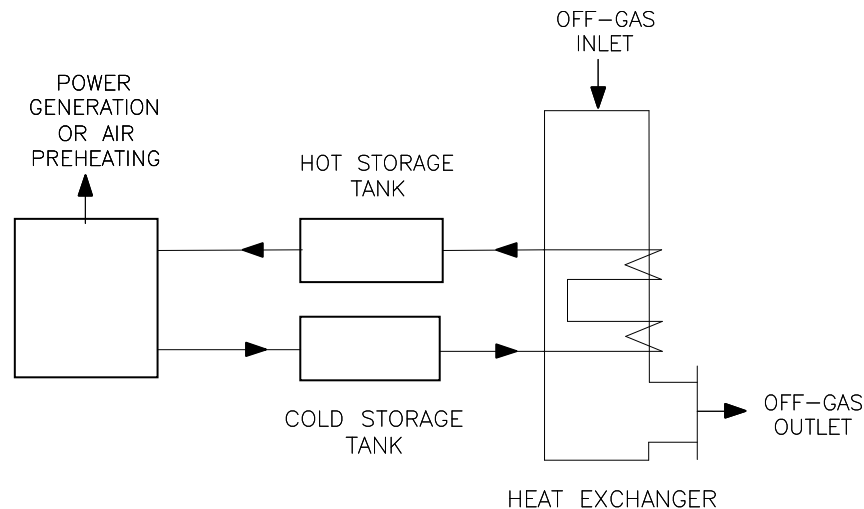


Figure 7 – Typical Thermal Storage Heat Recovery System

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 the direct benefit of reducing both the energy consumption and the associated operating costs of a process. 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.

Heat recovery also provides a number of indirect benefits. For example, if production is limited by energy availability, heat recovery can 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.

Current and future regulations on CO₂ 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 near future. There is uncertainty in what the effective cost of CO₂ 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 CO₂ emissions will produce significant operating cost savings where CO₂ emissions are regulated. Figure 8 below shows the estimated annual savings per MW of electricity use reduction for 8,000 hr/yr operation.

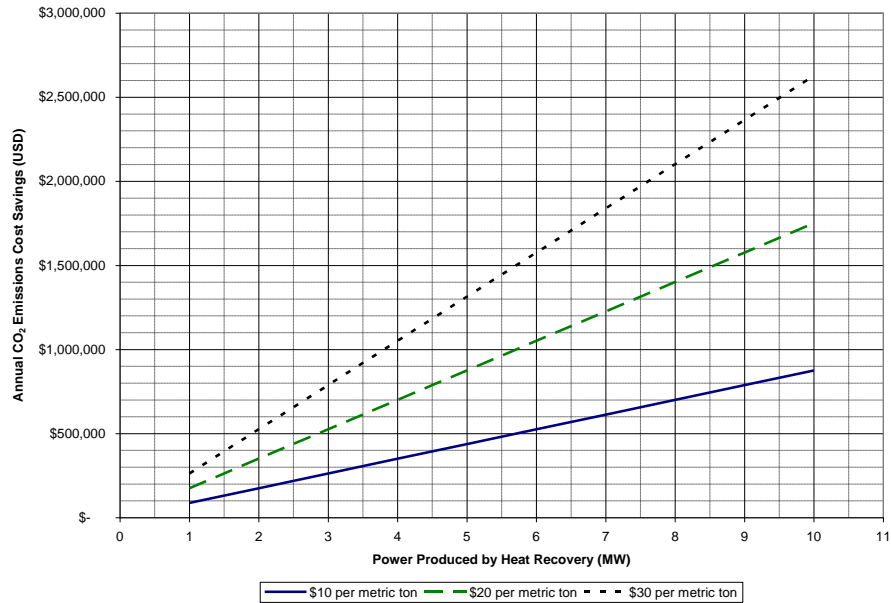


Figure 8 – Potential Annual CO₂ Emissions Cost Savings from Heat Recovery Power Production

As Figure 8 above shows, significant cost savings can be achieved by reducing CO₂ emissions through heat recovery power production in places where CO₂ emissions are or will be regulated. At costs of \$10 to \$30 per ton, CO₂ emissions cost savings can add up to 15% to the ROI of an ORC heat recovery system.

CONCLUSIONS

A large quantity of the energy input into the various sulfide smelting processes is currently lost to the off-gas. Continuous processes such as flash smelting and TSL smelting have largely been the focus of heat recovery applications in the past, however, even when heat recovery is applied using conventional technologies, the outlet gas still contains a significant amount of lower grade heat that is lost. Opportunities to recover heat from batch processes have largely been ignored due to the difficulty in effectively utilizing the variable heat load of the waste gas stream.

New heat recovery technology applications can enable smelters to recover heat from both lower grade sources and batch processes. These technologies can be used to take advantage of many untapped heat recovery opportunities and can be used to complement the heat recovery already achieved by conventional technologies in higher temperature, continuous applications.

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

ACKNOWLEDGMENTS

Safe, Paykan and Russell, Matt, “New Approaches to Smelter Off-Gas Heat Recovery”, Conference of Metallurgists 2009 Proceedings.