ENERGY CONSERVATION AND RECOVERY IN NON-FERROUS METALLURGICAL PLANT OFF-GAS SYSTEMS

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ABSTRACT

As the metallurgical industry continues to increase in competitiveness, producers look to traditionally less explored avenues to reduce production costs and improve efficiency. Off-gas systems can consume a significant portion of the plant's energy and are often overlooked as an area that impacts the efficiency of the furnace operation. Modifications to the off-gas system can significantly reduce electrical consumption and energy losses from the process vessels.

This paper will discuss the modifications in existing facilities and design of new off-gas systems to reduce energy consumption and energy losses through the off-gas system.

Keywords: energy recovery, energy conservation, off-gas system, electric furnace, waste heat

INTRODUCTION

The off-gas system is often overlooked as an area for improving furnace production rate and one for potential energy recovery and conservation. A typical electric smelting furnace collects the process gas, conditions them, removes particulate from them, and vents them to the atmosphere. Often the process gas contains a significant amount of sensible and calorific heat that could be useful at other locations of the smelter if it can be recovered or converted.

This paper will focus primarily on the electric smelting furnace and its off-gas system. The electric smelting furnace off-gas system is composed of:

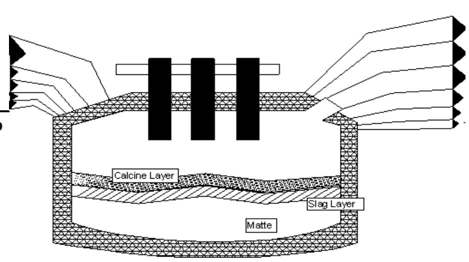
- process gas collection by direct evacuation or hooding,
- combustion of CO and H_2 in a combustion chamber,
- conditioning by water-cooled duct, evaporative cooling, or a waste heat boiler
- cleaning by a baghouse or ESP,
- discharge through a stack.

The process gas is collected by one or more off-take ducts directly off of the top of the furnace. Off-take duct is usually refractory-lined or water-cooled due to the relatively high gas temperature. The process gas contains carbon monoxide (CO) and hydrogen gas (H_2), so combustion of the gas is required to minimize explosion risks. A combustion chamber located close to the electric furnace allows the combustion air and process gas to mix and fully combust the CO and H_2. The process gas is then conditioned (cooled) by either water-cooled duct, evaporative cooling, or a waste heat boiler. Once the gas is cooled, it can be mixed with secondary fumes and cleaned in a cleaning device such as a baghouse or electrostatic precipitator (ESP) and then discharged to the environment by a stack.

ELECTRIC SMELTING FURNACE ENERGY BALANCE

Figure 1 shows an energy balance for a typical nickel electric smelting furnace.

Input	kWh/t	%
Electrical	449	60%
Calcine Feed	226	30%
Chemical Reactions	72	10%
Electrode Consumption	1	0%
	748	**100%**



Output	kWh/t	%
Metal	17	2%
Slag	594	79%
Off-Gas	52	7%
Reduction	46	6%
Sidewalls/Roof Losses	39	5%
	748	**100%**

Figure 1 - Typical Nickel Electric Smelting Furnace Energy Balance

The off-gas conditions in a ferro-nickel electric smelting furnace vary based on calcine carbon and LOI content but are relatively constant and summarized below:

- Flow rate: 25,000 to 70,000 Nm^3/hr
- Specific Flow Rate 170 to 490 Nm^3/tonne calcine
- Temperature: 700 to 800ºC (after post-combustion)
- Heat Content: 8 to 20 MW

ENERGY RECOVERY

Recovery of a portion of the energy contained in the off-gas can potentially reduce fuel or electrical costs in another area of the smelter or increase production rate depending on the recovery method selected. Selection of the energy recovery method requires an understanding of the energy available in the off-gas and the energy requirements of the other operations.

The layout of the smelter and individual operations in the smelting process dictate the feasible energy recovery options. Some possible energy recovery strategies could include:

- Using the electric furnace off-gas as secondary air in the nickel smelter reduction kiln
- Using the electric furnace off-gas as secondary combustion air in the drying kiln
- Recovering the electric furnace off-gas energy in a waste heat boiler to produce steam

Each option must be evaluated for potential cost savings, cost of implementation, feasibility, and risks. Examination of similar energy recovery strategies in other metallurgical operations (copper, lead, steel) will also help to determine the most cost-effective alternative.

Electric Furnace Off-Gas as Reduction Kiln Secondary Combustion Air

This option directs all or part of the electric furnace off-gas to either a single or multiple reduction kiln secondary air inlets. With this arrangement the electric furnace would have to be drafted by the reduction kiln fans or a new booster fan. Using a booster fan on the hot, dirty gas stream would require an expensive booster fan with relatively high maintenance requirements. For this reason, using the reduction kiln main fans to draft the electric furnace is more attractive.

One of the key issues with this alternative is coupling the furnace and the kiln process. A reduction kiln is an integral part of the plant production and is more sensitive to process upsets compared to the other unit operations. Other issues that must be resolved before this option could be considered include:

- Determine the impact of process disturbances in the electric furnace on the performance of the reduction kiln.

- Predict the change, if any, in the reduction kiln performance with the new source of secondary air.
- Determine the required changes, if any, in the reduction kiln main fan for this option.
- Determine the required changes to the reduction kiln off-gas cleaning system due to the introduction of fine electric furnace dust to the system.
- Address the potential for dust buildup in the connecting duct between the electric furnace and reduction kiln.

<u>Electric Furnace Off-Gas as Drying Kiln Air</u>

This arrangement has been implemented at the Hyuga Smelter in Japan. The electric furnace off-gas is mixed with pulverized coal combustion products to provide a drying gas at 800ºC (T. Kohga, et al., 1).

This option would direct all or part of the electric furnace off-gas to the combustion chamber for the drying kiln. As with the previous option, the electric furnace would have to be drafted by the kiln main fan or with a new booster fan. This option has significantly lower process risk compard to the previous alternative since an ore dryer is more forgiving to process upsets.

<u>Electric Furnace Off-Gas Energy Recovery with a Waste Heat Boiler</u>

Copper smelting facilities with flash furnaces and converters commonly use waste heat boilers to produce steam from the process gases. Flash furnaces produce a continuous, high heat-content off-gas that makes a waste heat boiler practical. Ferro-nickel smelting electric furnaces also produce a continuous off-gas with relatively high heat content. Under certain circumstances a waste heat boiler may be practical for this operation.

Sumitomo's Toyo Smelter uses a waste heat boiler to recover energy from its Peirce Smith converter off-gas. The Toyo smelter's waste heat boiler includes both a radiant and convective section. The steam generated at the converters is combined with the flash furnace waste heat boiler steam and sent to a turbine to generate electricity. (H. Kurokawa, et al., 2).

The electric furnace off-gas would be combusted in a combustion chamber and then directed through the waste heat boiler. The waste heat boiler would include only a convection section since the off-gas temperature exiting the combustion chamber is typically limited to below 800ºC. The arrangement of the waste heat boiler (vertical or horizontal) will be determined by layout restrictions although horizontal is most common.

Based on the electric furnace gas conditions listed above, the estimated steam generation rate from the waste heat boiler is 15 to 20 tonnes per hour (tph) per electric furnace. Possible uses for the steam include:

- Feed to a turbine to drive motors for the off-gas system fans or other motors

- Process heating in various areas of plant
- Supplement or replace steam requirement in the plant
- Feed to a turbine to generate electricity

The technical issues to be resolved before using a waste heat boiler for energy recovery include:

- Design and protection against acid dew point issues at the gas handling system
- Feasibility evaluation based on waste heat boiler application in similar industries
- Dust accumulation and handling based on the selected waste heat boiler configuration
- Explosion risks and protection due to potentially combustible off-gas conditions
- Use and handling of steam to various downstream consumers
- Use and handling of the electric power generated from the steam turbine

Figure 2 shows process flow diagrams for each of the energy recovery options. Table I summarizes the advantages and disadvantages of each of the energy recovery options examined.

The design basis for Table I is summarized below:

- Electric Furnace Off-Gas Conditions
  - Flow Rate: 74,000 Nm^3/hr per electric furnace
  - Temperature: 720ºC
  - Heat Content: 21MW per electric furnace
- Oil cost: US$30 / bbl
- Operating time: 350 days per year, 24 hours per day
- Electrical Power Cost: US$50/MW-hr

Table I - Summary of Energy Recovery Option Advantages and Disadvantages

	EF Off-gas Energy Recovery to Kilns	**EF Off-gas Energy Recovery to Dryers**	**EF Off-gas Energy Recovery to Waste Heat Boiler**
Advantages	• Savings estimated at $2,000,000/yr. • Most efficient energy utilization. • Without booster fan, minimal equipment installation (one duct, one damper) fast to implement. • Potential savings in overall gas cleaning configuration.	• Savings estimated at $2,500,000/yr. • Minimal to no impact on process metallurgy. • Most efficient energy utilization.	• Savings estimated at $1,250,000/yr. • No coupling of process units. • Potentially increases EF production through auxiliary power generation. • Steam production operation known.
Disadvantages	• Coupled process disturbances and variation. • Potential chemistry issues in kiln • Potential ringing of the kiln without booster fan. • Need to re-size the Kiln ESP fan without booster fan. • Kiln ESP/Scrubbers may not be capable to capture fine dust particles from EF. • Dust accumulation potential in interconnecting ducting. • Burner cooling may be required.	• Coupled process disturbances and variation. • High temperature booster fan required – high maintenance. • Dryer ESP may not be capable to capture dust particles from EF. • Additional heat losses in long ducting runs. • Dust accumulation in ducting. • Very high capital cost	• Convection section only due to low gas temperatures. • Potential dust problems in WHB • Highest capital cost • More equipment required. • Requires use and handling of small auxiliary power source.
Risk	• Coupling of the process units. • Slight variation to the present kiln historical operating conditions. • Emissions limits may not be achieved with ESP.	• Less impact from coupling of the process units. • Emissions limits may not be achieved with ESP. • Booster fan may be serious maintenance/downtime issue	• Not proven technology for ferro-nickel smelting EF. • Heavy dust load may impact performance. • Risk of combustibles entering boiler and downstream vessels.
Cost	• Lowest capital and operating cost.	• Higher capital cost. • Higher maintenance costs.	• Highest capital costs. • Highest in operating cost.

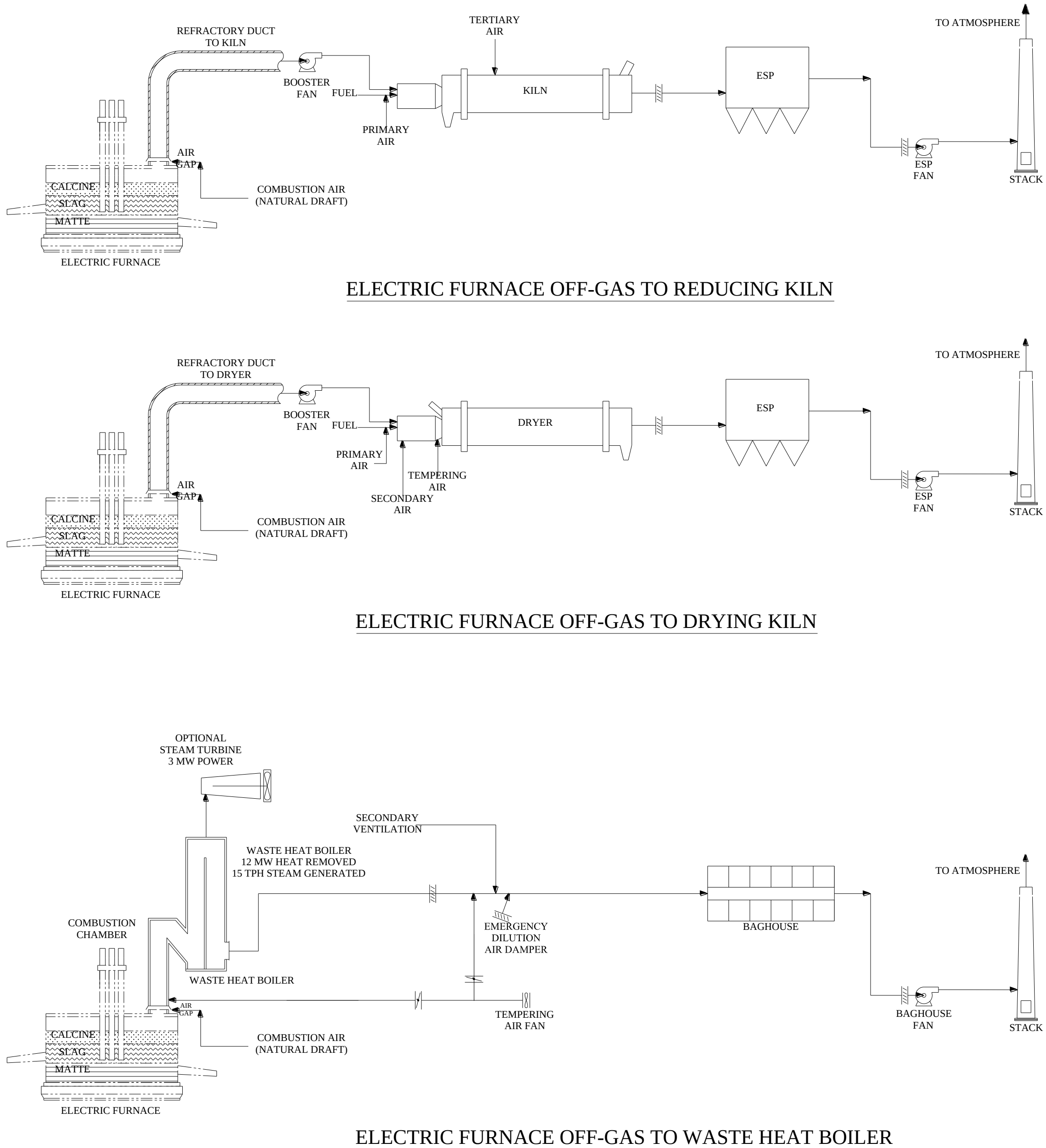


Figure 2 – Flow Diagrams for Energy Recovery Options

ENERGY CONSERVATION

Conserving Energy By Proper Design of the Off-Gas System

In the design phase of a new off-gas system, several design and control strategies should be considered to minimize energy losses to the off-gas system:

- Minimize total area of openings in the furnace.
- Include instrumentation for furnace pressure measurement and control.
- Minimize requirements for gas cooling by dilution air, or use secondary fume collection sources as dilution air.
- Where possible, take advantage of variability of the process gas flow rate.

Minimizing the total area of furnace openings is important since furnaces operate under negative pressure and openings provide opportunities for tramp air to enter the furnace. The air is heated up and exits the furnace usually with little or no benefit to the furnace. Heating air from 38ºC to 1,600ºC requires approximately 0.65 kW-hr/Nm^3. Assuming an air infiltration rate of 10,000 Nm^3/hr and 6,000 annual furnace operating hours, the total energy loss due to air infiltration is 39,000 MW-hr per furnace per year. Assuming an electrical power cost of US$50/MW-hr, the annual cost of heating the infiltration air is US$2 million.

Measurement and control of furnace pressure makes it possible to minimize the amount of air infiltration into the furnace and total energy losses through the off-gas system. Typical furnace pressure setpoints are in the range of -0.75 to -3 mm H_2O. Ideally the furnace pressure is controlled by a draft control damper located in the ductwork downstream of the furnace. Maintaining a constant pressure in the electric furnace can also reduce electrode consumption since the infiltration air provides oxygen which combusts the electrode carbon. Also it is desirable to operate the furnace at a freeboard temperature higher than the calcine temperature to realize some heat transfer benefits.

If dilution air is required to reach acceptable temperatures for a fan or pollution control device, consider using fumes collected from a secondary source instead of from ambient air. For example, use fumes from a tapping hood or canopy hood to cool furnace process gases. This strategy improves conditions in the furnace area and also cools the process gas to the desired temperature.

Processes with variable off-gas flow rates are potential applications for using I.D. fans with variable-speed drive motors. Where feasible, the fan RPM can be varied to achieve the furnace pressure setpoint. Significant electrical power consumption can be realized if the fan RPM can be reduced during portions of the operation where fume generation is low.

Conserving Energy By Continuous Monitoring and Control of the Off-Gas System

One of the significant barriers to continuous energy optimization in furnaces is an understanding of the furnace energy balance and how it changes over time. Furnace operators are primarily concerned with production goals and understanding the effect of the control parameters on production rate and product quality.

GCT has developed a real-time furnace energy feedback tool for operators, engineers, and managers called the Smart-Gas system. The system is made up of:

- Inexpensive, low-maintenance instrumentation,
- process and off-gas system models,
- a comprehensive historical database, and
- feedback via an HMI including the real-time off-gas energy loss rate.

Figure 3 shows the off-gas system measurements and predictions performed by the Smart-Gas system. The system uses the measurements to determine the total energy exiting the furnace by:

- Measure off-gas flow rate, composition, & temperature at end of water-cooled duct or spray chamber
- Calculate off-gas heat content
- Add spray chamber or waste heat boiler heat removal rate to heat content
- Add water-cooled duct heat removal rate to heat content

Smart-Gas alerts the operator when energy utilization is outside normal operating ranges. The Smart-Gas System was originally developed for steel-making electric arc furnaces, but will be equally valuable to non-ferrous electric smelting furnaces. The Smart-Gas system is able to provide real-time feedback on energy utilization and help the furnace operator recognize changes in:

- furnace infiltration area
- feed characteristics (%C and LOI content)
- calcine and slag level as they impact the furnace off-gas heat content

The off-gas flow rate and total energy losses will increase as furnace infiltration area increases. The Smart-Gas system alerts the operator when flow rates are outside normal ranges. The heat content in the furnace off-gas is directly impacted by the feed characteristics. Often the calcine feed characteristics (%C, LOI) are analyzed once per shift or once per day. The Smart-Gas system can help the operator recognize changes in the feed characteristics before laboratory tests are completed. The calcine bed depth, calcine distribution, and slag depth also impact the furnace energy balance. The system helps the operator recognize and react to changes in furnace behavior more quickly.

The historical database also makes it possible to detect changes in raw material characteristics, poor furnace electrical efficiency, and energy efficiency differences between furnace operators.

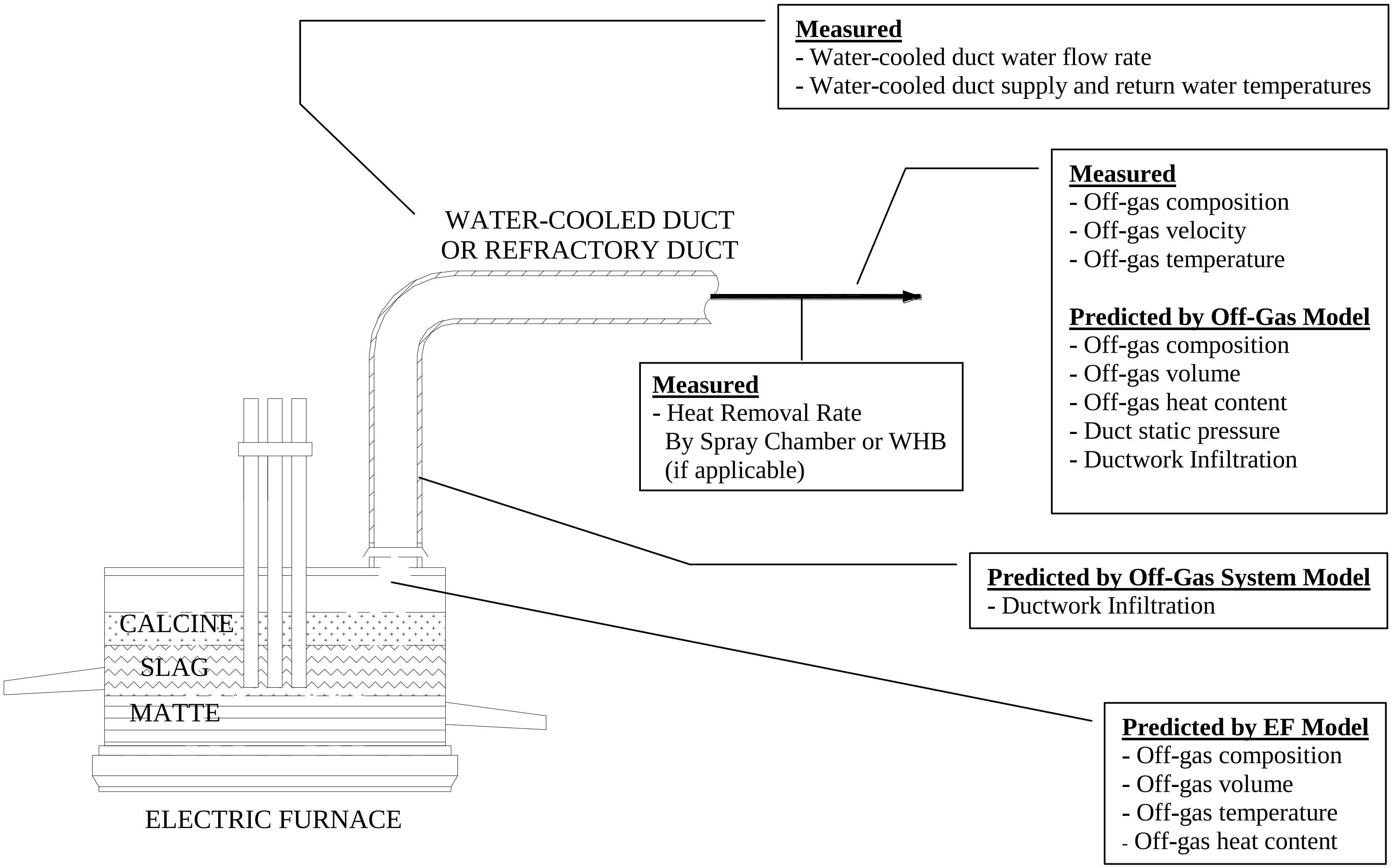


Figure 3 – Smart-Gas System Measurements & Predictions in the Off-Gas System

The Smart-Gas system includes off-line reporting tools in order to summarize the furnace energy balance daily, weekly, monthly, or for any other reporting period. The system can also be combined with continuous emissions monitors (CEMs) to provide an understanding of the interaction of furnace operation with emissions to the environment.

CONCLUSIONS

Although energy loss from the smelting process is inevitable, it is possible to recover or reduce the amount lost by coupling different operations where practical. Recovering energy from an electric smelting furnace seems to be a viable alternative, however, it is plant specific and the potential use of energy has to be carefully evaluated.

Through continuous measurement of the off-gas conditions, a reliable on-line heat and mass balance can be developed which is critical for a consistent furnace operation. This will allow the operator to optimize the furnace operation to meet the growing energy concerns as well as meeting the environmental targets.

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