ASARCO LLC HAYDEN CONVERTER RETROFIT PROJECT – AN UPDATE

*M. Russell[1], P. Safe[1], A. Veek[2], A. Fernandez[2] and K. Parameswaran[3]

[1]Gas Cleaning Technologies LLC
4953 N. O'Connor Rd.
Irving, Texas 75062
(* corresponding author: russell@gcteng.com)

[2]ASARCO LLC Hayden Operations
866 North Hayden Avenue
Hayden, Arizona 85135

[3]tfgMM Strategic Consulting
34365 N. 96th Way, Scottsdale, AZ 85262

ABSTRACT

ASARCO LLC (Asarco) Hayden Copper smelter, in Hayden, Arizona, has operated continuously (except for minor labor and economic curtailments) since 1912. The current plant configuration comprises INCO flash smelting, Peirce Smith (P-S) converting and fire refining/anode casting. In order to comply with the U.S. Environmental Protection Agency (EPA) 1-hour National Ambient Air Quality Standards (NAAQS) for sulfur dioxide promulgated in June 2010, the Hayden smelter had to increase overall sulfur fixation from approximately 95 % to 99^+ %, requiring a retrofit of the existing converter department and upgrade of associated emissions controls systems. The Converter Retrofit Project (CRP) involved replacing the five existing 13' diameter Peirce-Smith converters (2 blowing, 2 hot standby) with three new 15' diameter Peirce-Smith converters (1 blowing, 1 hot standby) to allow for more effective process gas capture using the existing acid plant contact section. Significant upgrades were made to the acid plant wet gas cleaning section and converter primary gas handling system to improve capture performance, reliability, and sludge handling. In addition, a new tertiary gas capture system was installed to further minimize fugitive emissions from the converter aisle. The existing furnace tapping ventilation ESP was replaced with a new baghouse to enable at least 50% SO_2 removal using high-surface-area dry lime injection, which was also implemented on the existing converter secondary gas baghouse system. The first two converters and all gas handling system improvements were started up in April 2018, and the third converter was brought online in November 2018. This paper presents the regulatory context; genesis and rationale for CRP; detailed description of the project; challenges during commissioning; system improvements implemented, and design considerations made, and systems performance and process optimization achieved since startup.

KEYWORDS

Copper smelter, Emissions Control, Lime injection, Peirce-Smith Converters Process Optimization, National Ambient Air Quality Standards, State Implementation Plan.

INTRODUCTION

This paper updates information on the CRP presented at the 7th International Symposium on Advances in Sulfide Smelting at the Extraction 2018 conference in Vancouver, Canada in August 2018 (Parameswaran, Wilhelm, & Camorlinga, 2018).

Background

The ASARCO LLC (Asarco) Hayden copper smelter began operations in 1912 with reverberatory furnaces (reverbs) and converters. The Clean Air Act of 1970 spurred installation in 1971 of a sulfuric acid plant for sulfur dioxide capture from converter off-gas. Two anode furnaces and casting wheels were installed in 1973. The modernization of the smelter with the installation of an INCO Flash furnace to replace the reverbs in 1983 included replacement of the sulfuric acid plant with a new double-contact acid section and an installation of an oxygen plant. In the mid-1990s the flash furnace dry gas cleaning system was replaced with a wet gas cleaning system. In 2012, the anode furnace particulate emissions control was implemented with installation of hoods on each of the three anode furnaces to collect and route the anode furnace off-gas to a spray cooler, and then to a baghouse (Parameswaran et al., 2018; Ramos & Parameswaran, 2017; Fernandez, McPeak, & Russell 2013). This project was in response to the EPA revising the National Ambient Air Quality Standards (NAAQS) for lead from 1.5 $\mu g/m^3$ to 0.15 $\mu g/m^3$ in 2008.

At the time construction began on the Converter Retrofit Project (CRP), the smelter operated two fluid bed dryers, an INCO flash furnace, and five Peirce-Smith converters (2 blowing, 2 hot standby) to dry, smelt, and convert copper concentrate to blister copper. Three anode furnaces (2 hot) fire refine the blister copper to anode copper that is then cast on two anode casting wheels. Anode copper is shipped to Asarco's Amarillo Copper Refinery (ACR) for electrorefining to cathodes. The smelter is capable of processing 1725 Tpd (1900 tpd) of concentrate to produce approximately 455 Tpd (500 tpd) of copper anodes.

Concentrate dried in the fluid bed dryers is collected in the dryers' baghouses and discharged into bins for feeding the flash furnace. The flash furnace can process 90 Tph (100 tph) of feed with 16 Tph (18 tph) of oxygen with all four burners operating, producing a nominal matte grade of 58%. The furnace has its own wet gas cleaning system with a saturation tower, variable throat venturi scrubber and cyclonic separator, and a condenser-cooler with mist eliminator. The flash furnace process gas is exhausted by two ID fans (1 on/ 1 standby), which send the cleaned and cooled gas to the acid plant wet gas cleaning system.

A furnace tapping vent system provided ventilation for slag skimming and matte tapping operations as well as slag return from the converters back into the furnace. A booster fan drafts the tapping vent system to the R&R Cottrell, an electrostatic precipitator (ESP), where it mixes with gases from the two dryer product baghouses. The R&R Cottrell was drafted by stack draft from the 305m tall (1000 ft) smelter stack annulus.

The five existing converters were 4m diameter with varying lengths of 9.1, 10.1 and 10.7 m, and were designed for a blast air rate of up to 31,600 Nm^3/h (20,000 SCFM). Process gas from each converter was captured with a primary hood with a closed-coupled drop out box and then flowed through a long duct to a 3-cyclone multiclone set for initial dust removal. The individual converter gas streams combined in a common duct to three converter ID fans (2 on / 1 standby) and then discharged to the acid plant wet gas cleaning scrubber inlet. The combined process gases from the flash furnace and converters pass through the acid plant wet gas cleaning section and contact section and then discharge to the center of the smelter stack. The acid plant has a nominal capacity of 183,000 DNm^3/h (116,000 DSCFM) at 12% SO_2.

A secondary hood installed over the primary hood on each converter collected gases escaping the primary hood during blowing as well as gases from secondary activities. All gases captured by the secondary hoods reported to a secondary hood baghouse and then to the smelter stack annulus. The secondary baghouse used a lime injection system with a small quantity of conventional lime to protect the baghouse from potential acid condensation and corrosion but was not designed to provide any significant SO_2 emissions reduction.

The anode furnaces have dedicated off-gas ports, where off-gases leaving the vessel are captured by refractory lined hoods. The hoods are operated under draft to pull in air through the gap between the rotating vessel shell and the fixed hood to fully combust and temper the anode furnace gas. The gas from the two hot furnaces combine and report to an evaporative spray chamber, where the gases are cooled to 205°C (400°F) before being cleaned in a 195,000 m^3/h (115,000 ACFM) 4-compartment pulse jet baghouse. An ID fan pulls the off-gas through the baghouse system.

REGULATORY CONTEXT: PROMULGATION OF REVISED SULFUR DIOXIDE NAAQS

On June 22, 2010, EPA established a new 1-hour NAAQS for sulfur dioxide at 75 parts per billion, replacing the prior 140 parts per billion 24-hour standards. The form of the new NAAQS is the 99^{th} percentile of the 1-hour daily maximum sulfur dioxide concentrations, averaged over 3 years.

On August 5, 2013, the Environmental Protection Agency (EPA) officially designated the Hayden area as non-attainment for the 2010 sulfur dioxide NAAQS. This designation started the clock for the Arizona Department of Environmental Quality (ADEQ) to develop a State Implementation Plan (SIP) that would describe how the Hayden area would attain the NAAQS. Since the Asarco Hayden Smelter was the major contributing source to the non-attainment designation, ADEQ reached out to Asarco to collaborate in developing the SIP to address the Hayden area non-attainment designation. At this time Asarco had already retained Gas Cleaning Technologies (GCT) to conduct a benchmarking exercise and begin the preliminary engineering efforts for the converter retrofit project (CRP). The CRP was designed to reduce the overall SO_2 emissions from the Hayden Smelter and allow the Hayden area to attain the sulfur dioxide NAAQS. Before the retrofit, the Hayden Smelter's overall sulfur fixation was estimated at 95% and post-retrofit the overall sulfur fixation rate was projected to be 99^{+}%. Along with improved SO_2 capture and control, particulate and metal emissions are expected to be reduced as a result of the CRP.

In the ensuing years, ADEQ and Asarco worked collaboratively to develop the sulfur dioxide SIP which included: new rulemaking, a modeling demonstration, and determination of new SO_2 emission limits for the Hayden Smelter. ADEQ's completed SIP was submitted to EPA for review and final approval on April 6, 2017. Since then, Asarco has assisted ADEQ in responding to EPA's comments and questions regarding the submitted documentation and currently all outstanding EPA questions have been addressed. The CRP regulatory timeline is outlined below:

- August 5, 2013 (effective on October 4, 2013): EPA officially designates the Hayden Area as Non-Attainment of the 2010 SO_2 NAAQS.
- April 23, 2014: EPA published the Guidance for 1-Hour SO_2 Nonattainment Area SIP Submissions.
- 2014-2015 Asarco worked with ADEQ on SO_2 SIP Modeling Demonstration of Attainment – CRP primary control project.
- 2015-2016 Asarco began an analysis to establish new emissions limits post-retrofit based on EPA Guidance procedures.
- January 19, 2016: Asarco received the air quality permit revision to construct the CRP
- 2016 Asarco assisted ADEQ in drafting the rules and SIP document.
- November 29, 2016: ADEQ published the Proposed SIP and Rules for the Hayden SO_2 SIP.
- April 6, 2017: ADEQ Submitted Final Hayden Non-Attainment Area SIP to EPA for review and approval.
- April 7, 2017: ADEQ submitted the Final Rulemaking to Arizona Governor's Regulatory Review Committee (GRCC) that included a revised SO_2 SIP that incorporated public comments.
- 2017-2018: Asarco assisted ADEQ in addressing EPA's comments on the submitted SIP documentation including several revisions to the SO2 SIP modeling demonstration.
- EPA approval of SIP is pending.

KEY LIMITATIONS OF PRE-RETROFIT SMELTER CONFIGURATION IN MEETING THE REVISED SULFUR DIOXIDE NAAQS

The existing smelter had several limitations that would need to be addressed to meet the new SO_2 NAAQS. First, the long individual converter ducts with no gas cooling were susceptible to more thermal cycling and air infiltration due to the higher gas temperatures when blowing, greater duct surface area, and more potential for SO_2 to SO_3 conversion leading to acid condensation and corrosion.

With two converters blowing, the acid plant does not have enough flow capacity to effectively ventilate two converters as well as the flash furnace process gases, resulting in reduced capture at the converter primary hoods. Insufficient acid cooling capacity also limited the acceptable gas strength that could be handled by the acid plant. The lack of effective draft control to each converter hood could also result in poor exhaust distribution between the two blowing converters, leaving one converter with poorer draft and capture efficiency.

The blowing gases escaping the primary hoods were mostly captured by the secondary hoods but reported to the secondary baghouse with minimal SO_2 removal. This represented by far the largest source of stack SO_2 emissions. In addition, any blowing or secondary activity gases escaping the primary and secondary hoods would report to the converter aisle roofline as fugitive emissions from the building roof monovents. This low-level emissions source was found to have a much larger impact on ambient air concentrations near the smelter than stack emissions from the smelter stack based on the air dispersion modeling.

Flux was fed to the converters via a ladle, requiring the converter to have to roll out to receive the flux and then roll back in to resume blowing. Roll-in and roll-out activities are commonly the largest source of blowing fugitive emissions for Peirce-Smith converters because the mouth is not well positioned under the primary hood for effective capture throughout most of the rolling range, but some blowing must occur during rolling to keep the tuyeres from plugging with molten material.

The wet gas cleaning section equipment was decades old and in need of replacement. Also, dust collected by the wet gas cleaning system was thickened via settling in cone settlers and then solar dried in ponds. The solar drying resulted in inconsistent drying time and final dryness of bagged material due to fluctuations in weather conditions.

Finally, the furnace tapping vent system reported to an electrostatic precipitator (ESP) and then to the smelter stack without any SO_2 controls. In addition, tapping capture could be improved by providing higher exhaust rates to the individual hoods, but this would require upsizing of the individual ducts and greater gas cleaning capacity dedicated to the tapping vent system.

ALTERNATIVE CONVERTING TECHNOLOGIES AND BENCHMARKING

Upon promulgation of the new sulfur dioxide NAAQS and identification of the existing smelter's limitations, there was some concern as to whether the new NAAQS standard could be achieved using Peirce-Smith batch converting, and what upgrades would be required to do so.

Several smelters around the world have employed continuous converting technologies over the last 25 years, including flash converting, top submerged lance (TSL) converting, and the Mitsubishi process. These processes generally require lower exhaust rates to effectively exhaust the converters than Peirce-Smith converters require, and smelters using them have achieved very high sulfur fixation exceeding 99%.

Based on this understanding, a conceptual study was performed to investigate the feasibility of using alternative continuous converting technologies to replace the Peirce-Smith converters at Asarco. The study showed that while the continuous converting processes have some logical advantages for new greenfield smelter, retrofitting a continuous converting process into the Asarco smelter to work with the existing INCO flash furnace and anode furnaces would be extremely costly and/or technically infeasible. More importantly, it was not clear whether the continuous converting would provide comparable if not superior impurity removal compared to P-S converting.

The continuous converting process would require either a matte granulation process upstream or a physical arrangement that would allow for gravity flow of molten matte by launder into the converting furnace. Similarly, gravity flow of blister copper via launder to the anode furnaces would be desired. Also, the anode furnaces would need to be able to accommodate a more continuous blister feed and be able to process a blister copper with significantly higher sulfur content and potentially higher impurity content.

Any retrofit would need to allow for the existing smelter to continue operating throughout the construction period. The layout of the existing furnace, converters, and anode furnaces would preclude the installation of an effective new equipment arrangement without extensive downtime and capital cost. In addition, continuous converting processes typically operate with higher matte grades than the INCO flash furnace at Asarco can produce at current throughput targets.

In parallel with the conceptual study of alternative converting technologies, Asarco and Gas Cleaning Technologies (GCT) conducted benchmarking of world-class smelters for SO_2 emissions control. This included visits to some smelters as well as a literature review. The benchmarking showed that in fact many of the world's lowest SO_2 emitting smelters use Peirce-Smith batch converting, including the Sumitomo Toyo smelter, Aurubis Hamburg, Boliden Ronnskar, and Atlantic Copper.

Based on the positive findings of the benchmarking effort and the conclusions from the alternative converting technology study, Asarco and GCT moved forward with developing a practical retrofit flowsheet for meeting the new sulfur dioxide NAAQS using an improved Peirce-Smith batch converting operation. Further benchmarking of emissions rates, furnace and converting operations, process gas handling, and secondary, tertiary, and fugitive emissions control measures were used to help in the design and operation of the new systems.

CONVERTER RETROFIT PROJECT

In order to attain the revised sulfur dioxide NAAQS requirements along with other emissions reduction measures associated with the negotiated consent decree, Asarco undertook the Converter Retrofit Project (CRP). The sections below outline the major modifications included in the CRP.

New Peirce-Smith Converters

One of the key conclusions of the engineering study work and benchmarking effort was that moving to a single converter blowing operation would yield significant gas handling advantages over the old two converters blowing operation while maintaining the same production rate. To achieve this, the existing five 4m diameter by 9.1 to 10.7m long converters (2 blowing, 2 hot standby) were replaced with three new 4.6m diameter x 10.7m long converters (1 blowing, 1 hot standby). The larger converters allow for a larger batch size and for blast air rates of up to 50,500 Nm^3/h (32,000 SCFM). The new converters were supplied along with electric variable frequency drives (VFD) and backup pneumatic drives. The converters were designed with 56 tuyeres, but generally, only 50 to 52 tuyeres are available on each converter due to restrictions on the punching car travel created by the existing building columns.

The converter mouth opening and apron plate dimensions were specified to provide a good fit with the new primary hoods and to accommodate in-stack flux and scrap feed systems. The mouth position relative to the tuyere line was also specified to optimize the mouth position centerline relative to the primary hood centerline during blowing, nominally 20° from vertical.

The existing crane rail in the 100+ year old converter aisle was relatively low compared to other copper smelters. To accommodate the new larger diameter converters, larger ladles, and suitable primary and secondary hoods, the floor of the converter aisle under the three new converters was lowered by nearly 1.75m (5.8 ft). This also brought the new tuyere punchers down to grade level, whereas they were previously on elevated platforms for the older converters.

The existing 5.7 m^3 (200 ft^3) matte ladles were replaced with new 7.9 m^3 (280 ft^3) ladles to reduce the number of ladle transfers and roll-in/roll-outs. The smaller ladles continue to be used for blister copper transfer to the anode furnaces. Sections of the crane rail were beefed up along with the overhead cranes (one upgraded, one replaced) to accommodate the larger ladle loads.

With the larger converters and deeper bath, the blast air pressure requirement has increased from 1.0 to 1.1 barg (14 to 16 psig) up to 1.2 to 1.4 barg (18 to 20 psig). The existing blast air blowers could not meet the higher pressure requirement. Therefore, two new 55,200 Nm^3/h (35,000 SCFM) at 1.6 barg (24 psig) blast air blowers (1 on / 1 standby) were installed in place of the two existing 30k blowers. The old 60k blower remains in place as an emergency backup.

A roll-in/roll-out blast air control strategy was implemented to minimize fugitive emissions from roll-in/roll-out. With the new control strategy, the blast air starts at a reduced rate only when the vessel reaches a partially rolled in position. Between that position and the fully rolled in (punching) position, the blast air flow rate is ramped up proportionally with converter position until it reaches full blast air flow at the fully rolled-in position. Similarly, on roll-out, the blast air flow rate is proportionally reduced as the vessel is rolled out to the partially rolled in position, where the blast air shuts off completely through the remainder of the roll-out. The partially rolled in position is established to maximize the positioning of the mouth under the primary hood while ensuring the tuyeres are safely out of the bath.

Dual mouth burners on a swivel arm were installed for holding each vessel hot and for refractory drying and vessel heat-up. The burner systems use natural gas with combustion air fans. Gas and combustion air supplies are variable to modulate the heat input based on need. The burners are rated for 3.5 MW (12 MMbtu/h) each, 7 MW (24 MMbtu/h) total per converter.

A flux and crushed revert feed system was installed to enable feeding of flux and crushed revert to the converter while in stack and blowing, increasing in-stack time and reducing the number of roll-ins and roll-outs. The feed system uses a series of conveyor belts, variable speed feeder, and a retractable chute that penetrates through a small door in the side of the primary hood to feed the converter. A front-end loader dumps flux or crushed revert into a screened hopper onto a feeder and conveyor belt that feeds the appropriate day bin via a diverter gate. Belt plows on the common conveyor divert the material to the correct blowing converter.

A scrap feed system was also installed to enable feeding of some scrap materials through a door on the side of the primary hood while in stack and blowing. The system uses boats that can hold bundles of anodes, cathodes, copper scrap, or frozen oxide slag cubes. The boats are lifted into place with the auxiliary hook of the overhead crane. Two hydraulic cylinders then push the boat up to the hood and then push the contents of the boat through the door into the converter mouth.

Asarco continues to use the Semtech OPC system assisting with slag blow and copper blow endpoint determination. The new primary hoods were designed with a special opening to allow the Semtech optical sensor to see the flame through the hood. Table 1 summarizes the typical converter cycle profile.

Table 1. Typical New Converter Cycle

Parameter	Value
Matte Charged:	272 T (300 t) - 12 ladles
Flux Added:	41 T (45 t)
Reverts Added:	18 T (20 t)
Copper Scrap Added:	18 T (20 t)
Blister Produced:	159 T (175 t)
Slag Blow Time:	2h:30m (2 slag blows)
Average Slag Blow Rate:	32,000 Nm^3/h (20,300 SCFM)
Copper Blow Time:	4h:05m
Average Copper Blow Rate:	35,500 Nm^3/h (22,500 SCFM)
Total Blowing Time:	6h:35m
Cycles per Day:	3
Blowing Hours per day:	19.8 (82.5% in-stack)

Process gas system

GCT designed and supplied new water-cooled primary hoods for each converter. The hoods provide effective process gas capture with a design hood air infiltration ratio of 1:1. The primary hoods use a common closed-loop water circulation system to provide heat removal and maintain hood integrity. The hood cooling circuit includes two pumps (1 on / 1 standby) with VFD drives and two heat exchangers (1 on/1 standby). The hood circuit includes a deaerator vessel on each hood's main return line to vent any entrained air or vapor bubbles as well as a common head tank to provide head to the circuit, thereby increasing the boiling point of the circulating water. A dedicated primary hood cooling tower provides indirect cooling of the hood water through the plate heat exchangers.

New horizontal evaporative spray chambers are close-coupled to the primary hoods for cooling the gases rapidly from 700°C (1300°F) down to a setpoint of 370°C (700°F), conditioning the gas for the downstream ESP and to minimize the potential for SO_3 formation that could cause acid condensation and corrosion downstream. The spray chamber uses 4 air-atomized water spray lances controlled by a dedicated valve skid to maintain the temperature setpoint. A common water storage tank and pump skid deliver the required spray water to the operating spray skid. Dedicated air compressors (1 on/1 standby) deliver atomizing air to the operating spray skid. Each spray chamber is also fitted with a drag chain conveyor, double dump valve, and tote bin for collecting the dust that drops out in the spray chamber. This dust is high in copper content and is sent to the bedding plant for recycle into the furnace feed.

A single common primary gas duct connects the spray chamber outlet ducts to the common 4-field ESP. The ESP provides primary dust removal from the converter primary gases. Each field has a hopper with drag chain conveyer, double dump valve, and tote bin. The independent dust collection for each field allows for segregation of the dust collected in the ESP. Dust from the first field is copper-rich and is sent to the bedding plant for recycling in the furnace feed. Dust from the last three fields have less copper and more impurities and are sent to the new sludge handling system for treatment and bagging as a byproduct bleed stream.

Each converter has a new secondary hood that sits over the primary hood to capture any blowing emissions escaping the primary hood as well as fume and dust from the secondary activities such as charging, slag skimming, and blister pouring. The blowing converter's secondary hood is exhausted at a reduced rate of 47,000 to 55,000 Nm^3/h (30,000 to 35,000 SCFM) by the converter primary gas ID fans and ties in with the primary gas downstream of the ESP and upstream of the ID fans. The secondary hood blowing exhaust provides the dilution required by the acid plant for SO_2 strength control while also enhancing sulfur fixation, since any SO_2 escaping the primary hood and captured by the secondary hood during blowing reports to the acid plant with the primary gases. The secondary blowing exhaust bypasses the ESP to avoid potential for acid condensation and corrosion in the ESP due to the low secondary gas temperature. The secondary blowing exhaust has very low dust loading, so it is not necessary to be cleaned prior to the acid plant wet gas cleaning section.

The ability to send the blowing converter's secondary exhaust to the acid plant is one of the main advantages of single converter blowing operation. The acid plant would not have the flow capacity to handle secondary blowing exhaust from two converters at once. By implementing this solution, SO_2 emissions from the secondary baghouse system were reduced by more than 95% and total stack SO_2 emissions by 90%.

Two converter primary gas ID fans (1 on / 1 standby) exhaust the primary gases through the ESP as well as the secondary blowing exhaust gas and send the gases under positive pressure of 2.5 to 3.5 kPag (+10 to 14 inwg) to the new wet gas cleaning venturi scrubber inlet, where it combines with the flash furnace process gas. Each ID fan has a VFD drive that modulates fan speed to maintain a draft setpoint at the spray chamber inlet. Desired balancing between the primary and secondary blowing exhaust is achieved by adjustment of balancing dampers at the spray chamber outlet and in the secondary blowing exhaust common duct. The ESP, primary ID fans, and duct from the ESP to the venturi scrubber are insulated to maintain temperatures above the acid dew point.

Another major advantage of single converter blowing operation is that draft of the blowing converter is much easier to maintain to ensure an effective capture. The primary and secondary hoods together provide greater than 99.7% capture of SO_2 generated during blowing. All of this SO_2 is sent to the acid plant for recovery as sulfuric acid. Figure 1 shows a photograph of the new converters and hoods and Figure 2 a photograph of the converter aisle.

Figure 1. Converter Retrofit Project – New Converter and Hoods

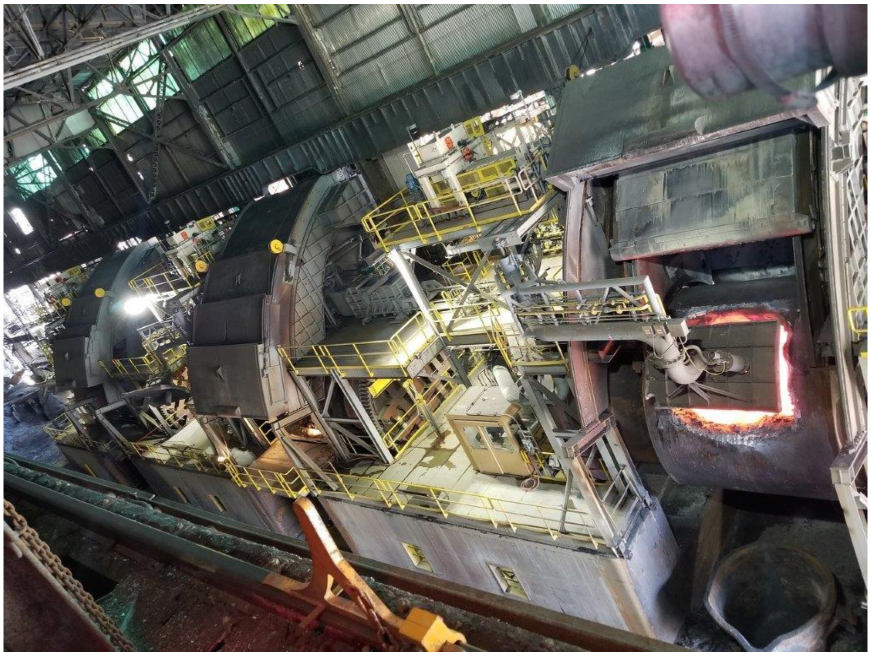

Figure 2. Converter Retrofit Project – Converter Aisle

Wet gas cleaning system and sludge processing

The original wet gas cleaning system consisted of an open tower scrubber, known as the 50% scrubber, followed by two small scrubbers and two packed gas cooling towers in parallel. Two stages of four wet ESPs provide final dust and mist removal before gases report to the contact section drying tower. The scrubbing and gas cooling equipment was decades old and would require major repair if not replaced to provide an additional 20 to 30 years of operation.

The sludge handling and processing from the scrubber blowdown and Wet ESP washdown as well as cleanout of the vessels with vacuum trucks consisted of settling the slurry in cone settlers followed by solar drying in ponds and then manually bagging the dried material for byproduct sale.

Given the age and condition of the scrubbing and gas cooling equipment and the inconsistency handling concerns of the sludge processing, a new wet gas cleaning train and sludge processing system was designed to replace the existing equipment.

A new wet venturi scrubber with cyclonic separator replaced the existing 50% scrubber and two small scrubbers. The single scrubbing vessel allows for greater pressure drop across it, enhancing cleaning performance. The venturi also incorporates a variable throat to maintain a pressure drop setpoint for more consistent cleaning and easier acid plant blower pressure control.

A new FRP packed gas cooling tower replaced the two brick-lined packed gas cooling towers. New heat exchangers were installed for the cooling tower liquor to provide more cooling capacity to accommodate the additional heat removal expected.

A new thickener, filter press, electric cake dryer, and semi-automatic bagging station were installed to process the dust sludge from the wet gas cleaning system, replacing the cone settlers and solar drying ponds. The new equipment allows for efficient dewatering, drying, and bagging of the dust sludge, which is a byproduct of the smelter. It also provides for more efficient and consistent production and byproduct quality while minimizing exposure and handling of the dust compared to the old solar drying and manual bagging operations.

Acid plant operation

The existing contact section of the acid plant was left largely unchanged with the Converter Retrofit Project. With the change to single converter blowing operation, the acid plant had enough flow and SO_2 capacity to handle operations with the improved capture and higher SO_2 load to the acid plant.

One issue the acid plant had been struggling with was effective absorbing acid cooling, especially during the summer months. A new 4,770 m^3/h (21,000 gpm) water cooling tower was installed to replace the old water-cooling tower, providing roughly 25% more cooling capacity to better handle maximum SO_2 reporting to the acid plant.

In the previous operation, ambient dilution air was introduced through a dilution air damper upstream of the drying tower that opened as required to limit drying tower inlet SO_2 concentration to 11.5% SO_2. With the new operation, most of the dilution air is now provided by the secondary blowing exhaust, which also helps enhance SO_2 and dust capture in the aisle.

A new large acid plant preheater was also installed for quicker heat up and to better maintain acid plant converter temperatures for effective SO_2 to SO_3 conversion at startup and at low inlet SO_2 conditions.

Converter secondary gas system

The existing converters' secondary hoods reported to the 510,000 m^3/h (300,000 ACFM) converter secondary gas baghouse for dust removal prior to discharge to the smelter stack annulus. With the Converter Retrofit Project, the existing secondary gas baghouse and fan were retained, and the new converter secondary hoods tie into this system for all non-blowing operations.

Slag return hoods capture fume when converter slag is returned to the INCO flash furnace via ladle and launder. The slag return hoods previously reported to the furnace vent tapping system. However, when operating, they consumed a significant portion of that system's capacity. With the Converter Retrofit project, there are fewer converter secondary hoods reporting to the secondary gas system, especially with the blowing converter's secondary hood being exhausted to the primary gas system. Therefore, the slag return hoods were modified to accommodate the new larger ladles and were re-routed to the converter secondary gas system to take advantage of its available capacity and to free up capacity in the furnace tapping vent system to dedicate the other tapping hoods.

With the converter secondary blowing exhaust reporting to the process gas system, the SO_2 reporting to the secondary hood baghouse has been reduced by more than 95%. This has made it practical to inject high-surface area lime into the baghouse inlet duct with the intent to dry scrub the gas and to further reduce baghouse SO_2 emissions by at least 50%. Since startup, the system has been achieving 60 to 65% efficiency in normal operation.

Converter Tertiary Gas System

A new 680,000 m^3/h (400,000 ACFM) converter tertiary gas system was installed as part of the CRP. The tertiary gas system consists of three canopy hoods above the new converters that capture any fumes escaping both the primary and secondary hoods during blowing and secondary activities and ladle transfers. Two ID fans (2 on, 0 standby) exhaust the tertiary hoods and discharge to the smelter stack annulus. The system includes no gas cleaning equipment since the dust loading and SO_2 content are extremely low. Instead, the purpose of the tertiary gas system is to minimize any low-level roofline fugitive emissions and to instead disperse the gas using the tall smelter stack, greatly minimizing its impact on ambient air concentrations.

The roof monovent sections above the converters were removed and the roof openings sealed, enclosing a total of seven bays. Vertical sheeting was installed on four of the roof trusses down to the top of the overhead crane to partition the roofline into three distinct canopy hoods, using the building side walls and roof as well to form the hoods. Dormer-style raised penthouses were built on the roof directly above each converter as a high point for the tertiary exhaust ducts to tie into. Each tertiary hood exhaust duct has a damper that can be positioned to adjust the exhaust distribution between the three hoods.

Sheeting was also installed along the two long east and west walls of the converter aisle to minimize cross-drafts that could blow fumes out from under the tertiary hoods and escape as fugitive emissions.

Flash furnace tapping ventilation and new baghouse

The flash furnace tapping vent system has a capacity of approximately 297,000 m^3/h (175,000 ACFM). By re-routing the slag return hoods, which could require as much as 119,000 m^3/h (70,000 ACFM) exhaust rate, to the converter secondary gas system, the exhaust rates to all the remaining tapping vent system hoods could be increased to improve capture efficiency and reduce fugitive emissions. In order to maximize their performance, several of the exhaust ducts were increased in diameter and/or re-routed to other artery ducts in the system to improve the pressure loss profile. A few additional hoods were also installed.

The tapping vent system is ventilated by a booster fan and then mixed with the gases from the two concentrate dryer baghouses. The combined gases previously reported to the R&R Cottrell, a decades-old electrostatic precipitator that was drafted solely by stack draft to the smelter stack annulus. As part of CRP, the R&R Cottrell was replaced with a new 637,000 m^3/h (375,000 ACFM) furnace vent baghouse with ID fan that still discharges to the smelter stack annulus.

Replacing the R&R Cottrell with a baghouse both reduced outlet dust emissions and enabled the addition of high-surface area lime injection to dry scrub the tapping vent gas to achieve at least 50% SO_2 removal. The new lime injection system for the furnace vent baghouse and secondary gas baghouse uses a common 100-ton lime silo with three discharge trains in its conical hopper. Each discharge train consists of a variable speed rotary valve to control lime feed rate and a second full speed rotary airlock to provide isolation from the conveying air. Each train has its own conveying air blower with air-to-air gas cooler to cooling the compressed conveying air to prevent stickiness in the lime. There are two air dryers that dry the inlet conveying air upstream of the blower. At any given time, one train is dedicated to each of the two baghouses and the third train is a standby backup train. The system is designed for a lime feed rate of up to 12 tons per day per baghouse. Currently, total consumption is 7 to 10 tons per day for each baghouse.

Engineering and construction schedule

The path from initial engineering studies to startup for the Converter Retrofit Project took nearly a decade. An initial process gas system study in 2009 led into the concept study for alternative converting technologies in 2010 on the heels of the new SO_2 NAAQS publication. Basic engineering was completed in 2011, and initial detailed engineering began in 2012. Detailed engineering was then suspended for a couple of years pending the negotiation and approval of a Consent Decree accepting the proposed modifications, which was finalized in December 2015. Detailed engineering for the wet gas cleaning system upgrades was started in the fall of 2015, and EPCM for the full CRP project started in January 2016.

Wet gas cleaning system construction began in July 2016, and the new system was commissioned coming out of a smelter outage in November 2016. Construction of the main CRP scope began immediately thereafter. A short smelter outage was taken in the summer of 2017, during which the new acid plant cooling tower was tied in and the old Converter 4 and Converter 5 were taken out of service.

Asarco continued to operate the smelter with existing Converters 1, 2, and 3 through the end of 2017 while constructing the new Converters 4 and 5 in the same locations where the old Converters 4 and 5 were. Converter 3 was taken out of service in January 2018, about 6 weeks before a smelter outage, leaving only existing Converters 1 and 2 operating during that 6-week period. Demolition of Converter 3 and construction of the new Converter 3 began immediately thereafter.

The new Converters 4 and 5 started up in April 2018 coming out of the smelter outage. The new converter process gas system, tertiary gas system, furnace vent baghouse system, and lime injection systems were all commissioned at the same time. Converters 1 and 2 were decommissioned and demolished.

Converter 3 systems construction continued into the fall of 2018, and Converter 3 was officially commissioned at the end of November 2018. The CRP project implementation was then complete. Figure 3 presents the new smelter gas handling flow diagram.

PROCESS OPTIMIZATION

Upon startup and commissioning of the new Converters 4 and 5 in April 2018, Asarco and GCT began process optimization efforts to optimize the performance, reliability, and efficiency of the various new systems. Numerous improvements have been made over the first year of operation. A couple areas of optimization are described below:

Blast air blowers

The converter blast air blowers were initially designed to provide direct blast air flow control to the converters since there was only one blower and one converter blowing at a given time. However, this resulted in control issues during slag blow, when slag buildup at the tuyeres would severely restrict flow, causing the blower to ramp up to try and meet the flow setpoint. This frequently resulted in the blower surge protection to activate, opening a blow-off valve and dropping flow and pressure to the converter.

The blast air blower controls were then modified to maintain a pressure setpoint in the blast air header, and the blast air flow control valve would modulate to maintain the blast air flow setpoint. With this new control, the blast air blower surge protection is triggered much less frequently, and a healthy blast air pressure is available at the converter from initial roll-in and throughout the blow. This steady pressure has helped bath agitation and reduced tuyere line wear. With the new controls, the blast air pressure setpoint was initially operated at 1.4 barg (20 psig). This has since be adjusted to 1.25 barg (18 psig) to ease splashing and buildup at the mouth.

Lime injection system performance

The two new dry lime injection systems are designed to provide at least 50% SO_2 removal efficiency for each baghouse. Significant effort has been put into ensuring each system reliably achieves this removal efficiency while avoiding excessive consumption of lime. The dust from both baghouses, which is mostly lime material, is recycled back to the bedding plant. Excessive lime consumption is therefore a concern for both the reagent cost as well as the furnace operation.

Trials of varying lime feed rates (rotary speeds), as well as baghouse cake thicknesses (indicated by dP) have been undertaken to optimize the SO_2 removal performance and lime consumption. This includes dynamic feed control where feed rate is increased or decreased based on the inlet SO_2 loading. The lime injection point on the furnace vent baghouse system has also been trialed. To date, the furnace vent baghouse has been achieving 50 to 60% removal efficiency when operating normally, and the secondary baghouse has been achieving 60 to 65% using 7 to 10 tons per day per system.

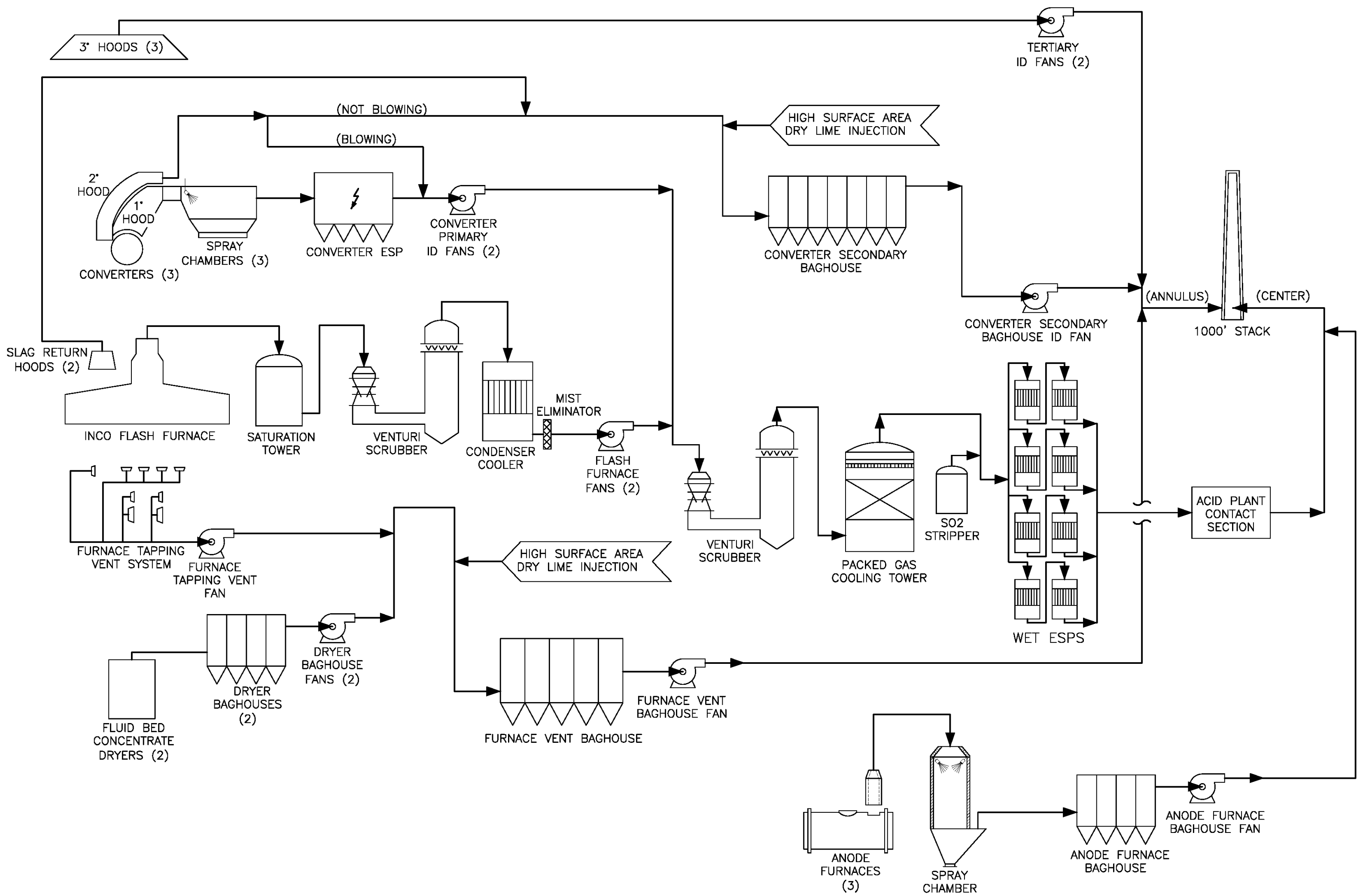

Figure 3. Converter Retrofit Project – New Smelter Gas Handling Flow Diagram

COMMISSIONING CHALLENGES

Commissioning the new converters to roll-in /roll-out turned out to be a big challenge mainly due to the getting up the learning curve with new process/equipment:

- The electrical drive consists of a VFD and electro hydro pneumatic thruster brake unit, the control of the VFD is done in the PLC and all interlocking is done via the PLC system. An algorithm was included to allow open and close the blast air valve depending of the Converter position to avoid send SO_2 gas outside (emissions) of the primary hood and several more interlocks such as: Healthy VFD status (electrical interlocks), Healthy UPS status, Healthy E-stop circuits, Tuyere punch not in operation, Pneumatic motor clutch not engaged, ID Fan running, ESP temperature normal, Blast air blower running, Acid Plant blowers running, and Roll up doors in position. Each one of the equipment included in the interlocks was commissioned prior to start-up of the converters.
- Operating personnel had to be trained on the new converter control philosophy. During the construction of the CRP the smelter was running at normal operation with three of the old converters and for the operators was a big change to switch to a new control technology with PLC's, Touch Screen Computers, etc.
- Operators had to adjust to change in process operation which is different at the flash furnace and converters. Previously, two small converters were blown at the same time with an off-gas system per Converter; now just one converter is blown at a time using one common off gas flue pipe, ESP, ID fan, silica and cold dope/reverts belts system for all the converters.
- The flash furnace operation changed in that the matte tapping and skimming schedule has changed, using new bigger ladles t (280 ft^3). This minimizes the crane trips between the flash furnace and converters to fill up the bigger converters, lowering the matte ladle SO_2 emissions.
- With all these changes, flash/converters operators took three or four months to fully adjust.
- Sulfur content of concentrates in recent months has increased from 32 to 34%, resulting in SO_2 concentration at the acid plant inlet, as a result of much lesser air infiltration at the converter primary and secondary hoods as well as higher SO_2 strengths in the Flash Furnace off-gas.
- Iron content in concentrates has also increased in recent months from 29% to 34–35%. This along with higher sulfur control has necessitated used of reverts to control the matte grade.

OUTLOOK

We anticipate undertaking the following tasks in the coming months: (1) Complete optimization of the off-gas handling system to maximize SO_2 capture and minimize fugitive emissions; (2) Optimize the cold dope/reverts generation at the smelter and usage of the copper scrap feeder system; (3) Improve the converters performance — 21 hours/day blowing time rolled hourly and (4) Improve converter tuyere line brick campaigns.

CONCLUSIONS

The Converter Retrofit Project at the Asarco Hayden smelter has been successfully completed and commissioned. The project has resulted in a more than 90% reduction in smelter SO_2 emissions, and overall sulfur fixation has increased from 95% to 99^{+}%.

REFERENCES

Fernandez, A., McPeak, K., & Russell, M. (2013). Asarco Hayden Anode Furnace Update. Presentation to SME Tucson Meeting, January 9, 2013.

Parameswaran, K, Wilhelm J., & Camorlinga, R. (2018). Sustainable Development Considerations in Primary Copper Smelting, B. Davis et al. (eds.), *Extraction 2018*, The Minerals, Metals & Materials Series, https://doi.org/10.1007/978-3-319-95022-8_19 .

Ramos, M. E., & Parameswaran, K. (2017a).,"Mining and Sustainable Development: Oxymoron or R_x for a Bright Future? -An Update. In Volume 1-Proceedings of Barrios International Symposium Non-ferrous Smelting and Hydro/Electrochemical Processing at 2017 Sustainable Industrial Processing Summit and Exhibition, Edited F. Kongoli, M. Palacios, T. Buenger, J.H. Meza, E. Delgado, M.C. Joudrie, T. Gonzales and N. Treand, FLOGEN 2017, pp. 133-160.