mechanical integrity best practice for sulfuric acid plants

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objectives

- acid plant hazards and risks
- mechanical integrity factors
- conclusions
Who is FM Global?

One of the world’s largest and oldest industrial property insurance and risk management organizations specializing in understanding and engineering risk from fires, explosions, mechanical and electrical breakdown, and natural hazards

- mining
- mineral and coal processing
- metallurgical refining
- petrochemical, chemical and pharmaceutical
- power generation
- semiconductor
- pulp and paper
- warehousing
- general manufacturing
- telecommunications

- $US 6 Billion surplus
- 51 offices worldwide
- 4800 employees
- 1500 loss prevention engineers
- 80 specialized in mining and metallurgy
- industrial loss prevention
- standards
- technology
- research
sulfur dioxide acid plant
sulfur burning acid plant
acid plant hazards

- corrosion to equipment
- corrosion to structures
- overpressure of equipment
- implosion of equipment
- heat of reaction
- environmental release
- fire
- explosion
- mechanical damage to rotating equipment
- refractory failure
- storage tank collapse
- catalyst poisoning
reactions to produce acid appear simple but control of hazards is far from simple:

- $\text{SO}_2$ and sulfuric acid highly corrosive
- $\text{SO}_3$ is highly reactive and unstable
- exothermic heat is generated by process
history, being the most patient of teachers, is always willing to repeat any lessons forgotten - or ignored - by its students

some loss case studies to demonstrate this
corrosion in an acid plant heat exchanger

Nickel
Refining Plant
Plant produces:

- high purity nickel metal
- high purity cobalt metal
- by-product ammonium sulfate

- acid leaching in high pressure autoclave reactors
- solvent extraction
- hydrogen sulfide reactions
- hydrogen reduction reactions
- ammonia reactions
- hydrogen sintering
- briquetting
There are no pyro-metallurgical processes (smelting or roasting) nor SO$_2$ waste emissions at this plant.

Instead, acid for processes is produced by burning sulphur.
heat exchangers
what happened

- acid plant designed for continuous operation with typically 2 shutdowns maximum per year
- heat exchanger had 5 to 7 year life
- plant had significant commissioning problems
- acid plant cycled an estimated 100 times in two years
- chance for operational error multiplied
- chance for moisture entry multiplied
what happened

• strong acid entered exchanger
• strong acid mostly due to carryover
• moisture then entered the circuit (steam leak or moisture due to many start-up/shut downs)
• strong acid diluted below 93%
• tubes were cut as if by a “laser”
• significant corrosion and sulfate build-up to plant found as well.
results

• heat exchanger had to be replaced
• entire plant down due to lack of acid for processes
• several month outage of entire plant
wet electrostatic precipitator

acid leak attacks carbon steel tube sheet
electrostatic precipitator

sparking burns hole in adjacent tube

may cause fire if plastic is present
electrostatic precipitator

broken discharge electrode

may cause fire if plastic is present
corrosion on SO₂ blower blades

excess carry over of acid mist from drying tower can corrode metal blades and cause catastrophic failure
pregnant converter

bulging caused by stress from weight of converter and internal pressure
damaged refractory
caused by thermal cycling - allowed heat to damage steel shell
acid plant loss lesson - candle filter failure

• poorly designed candle filters allowed significant acid carry-over resulting in damage to heat exchanger from corrosion and sulfate build-up
• stick tests & drain tests indicated that there was significant acid mist carryover from the absorption towers.
• when opened, candle filters were found to be shrunken, sagging, and tearing away.
• approximately $3m in damage.
filter tearing

sagging distorts brackets
Heat exchangers 
corrosion and 
sulfate fouling 
of tubes can 
cause overheating
SO\textsubscript{2} blower overspeed to destruction =
entire plant shutdown for 9 months
zinc refinery

occupancy: gas cleaning plant
downstream of zinc roaster

an explosion with an ensuing fire occurred in the electrostatic precipitator units that resulted in physical damage to equipment and temporarily interrupted production operations for the Zinc and Sulfuric Acid plant.

The blast from the explosion physically damaged 3 electrostatic precipitators including sections of the ducting system, frames, expansion joints, and plastic valves.
Location where the Explosion was registered
plastic fire hazards
Copper Smelter
sequence of events:

- cooling water pumps for saturation tower flood due to overflow from nearby tank
- cooling water supply fails
- hot gases at 2100° F enter plastic tower and duct
- by-pass damper designed to send hot gases to stack fails
- thermocouple designed to shutoff process fails when wetted (and cooled) by poorly located waterspray nozzle
- plastic vessels and ducts destroyed
primary factors:

• lack of process safety management program
• process hazard analysis not conducted
• management of change not done
• many changes and good intentions over many years cause system to fail in unexpected sequence
• lack of fixed fire protection
• smelter shut down 11 days
Nickel Smelter

Air Cleaning Plant Downstream of Nickel Smelter
ESP’s prior to loss
Nickel Smelter

Primary Factors:

• Plant undergoing planned shutdown

• Wire discharge electrodes inside ESP dropped onto polypropylene diffuser mesh

• Short circuit tripped remote circuit breaker

• Breaker reportedly reset several times but kept tripping

• Ignition of plastic internals

• No detection/waterspray out of service due to shutdown sequence

• Fire noticed by black smoke

• Fire suppressed – exposures protected by hose streams

• Fire Destroyed two (of eight) plastic precipitators
sulfuric acid storage tank

acid tank failure with environmental release
mechanical integrity
best practice
factors
harsh corrosive operating conditions of acid plants require careful extra attention to

- reliability engineering
- material selection
- good operating principals
- superior maintenance procedures

because
extensive downtimes are not an option

especially for waste emission (pollution control) acid plants associated with metallurgical smelting
FM Global experience shows that the mechanical integrity of equipment can be reliably assessed using seven key Best Practice factors:

- environment
- design and operating conditions
- age and history
- maintenance
- operators
- safety devices
- contingency planning

Primarily impacts frequency of loss

Primarily impacts severity of loss
environment factors:

- there is no evidence of corrosion on the outside of equipment, **under insulation**, or structural members or cladding.
- there is no imminent potential for structural collapse due to corrosion.
- there is no evidence of or potential for accelerated degradation of FRP materials due to UV
- exposures to natural hazards (wind, freeze, flood, etc.) have been identified and quantified.
corrosion on structural steel can cause structural failure
corrosion under insulation

can cause failure of vessel and loss of containment
design and operating condition factors:

• corrosion has been documented, corrected and monitored.

• a corrosion detection and measurement system is in place and effective.

• plant design includes inherently safer water-acid interfaces

• plant design includes methods to detect and remove acid mist carry over

• metal materials of construction suitable to operating conditions have been used. (hint: don’t skimp on cost in this factor)

• a program for managing physical metallurgy issues is in place

• the plant is operated in accordance with manufacturer’s recommendations.
sulfuric acid corrosion rates* (mils per year)

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<td>120</td>
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</tbody>
</table>

* 310 SS
$P_{\text{water}} > P_{\text{acid}}$
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• metal materials of construction suitable to operating conditions have been used. (i.e., don’t skimp on cost in this factor)

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acid drain - cold pass gas heat exchanger
acid drain – SO$_2$ blower
**age and history factors:**

- The plant operates at or below original design capacity or has been subjected to a formal de-bottlenecking procedure.

- There has been no history of abnormal process cycling.

- Refractory in heat exchangers is within its design life.

- Modifications have been properly managed using a MOC program.

- The catalyst is still within its expected life.

- The same catalyst has been used as per the initial design or an MOC procedure was used to understand the process chemistry.
maintenance factors:

- internal inspection program
- a corrosion measurement program is used and is effective
- there is a high quality water quality monitoring.
- a comprehensive maintenance program exists for all alarms, sensors, probes.
- there is a program for double blocking on all hazardous acid pipe work.
- there a program to ensure no short-bolting on acid tank man holes/access ports.
- mist eliminator pads are carefully checked for proper condition
- regular inspections and checks (i.e., stick testing for water entry)
stick tests
operator factors:

• **process safety management is culturally embedded**

• operators and engineers understand the process chemistry, especially potential upset conditions.

• **there is a good overall understanding of the process and equipment**

• safe start-up/shut-down procedures are provided and documented

• operators are knowledgeable about the importance of draining during shut down.

• operators are knowledgeable about weak strength of atmospheric storage tanks.

• **communication with other plants on site**
safety devices:

• a means of detecting and alarming water entry into acid systems is provided

• all pressure vessel components have suitable pressure relieving devices.

• large rotating equipment $\text{SO}_2$ blowers have fixed automatic vibration monitors and shutdown interlocks

• suitable vacuum breakers are provided for acid tanks
contingency planning factors:

• two smaller plants are better than one large plant

• agreements and service contracts regarding bottleneck equipment are in place for vendors, suppliers and OEM technical advisors.

• *a spare so$_2$ blower and motor are available*

• design drawings for long lead time components are current and available.

• a source of available spare parts has been documented if parts are not on site and if the OEM is no longer in business, or the equipment is obsolete.
conclusions

• acid plants have unique hazards and exposures many of a **mechanical integrity** nature

• acid plants often do not fall under a PSM law and voluntary application of PSM is not widespread nor culturally embedded in this industry

• most critical PSM elements are process hazard analysis, management of change, and **mechanical integrity**

• key equipment factors can be used to help understand and control **mechanical integrity** hazards

• encourage **mechanical integrity** “best practices” for this industry
“It is unwise to pay too much. But it’s worse to pay too little. When you pay too much, you lose a little money, that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing you bought it to do. The common law of business balance prohibits paying a little and getting a lot. It can’t be done. If you deal with the lowest bidder, it is well to add something for the risk you run. And if you do that, you will have enough to pay for something better.”

John Ruskin (1819-1900), a prominent 19th century English critic who was an astute observer of social and economic issues