NORAM

Serving the Sulfuric Acid Industry

CONVERSION TO ABSORPTION

WHO IS THE NORAM GROUP OF COMPANIES?

Established in 1988, NORAM is located in Vancouver Canada and has over 250 employees across various business groups:

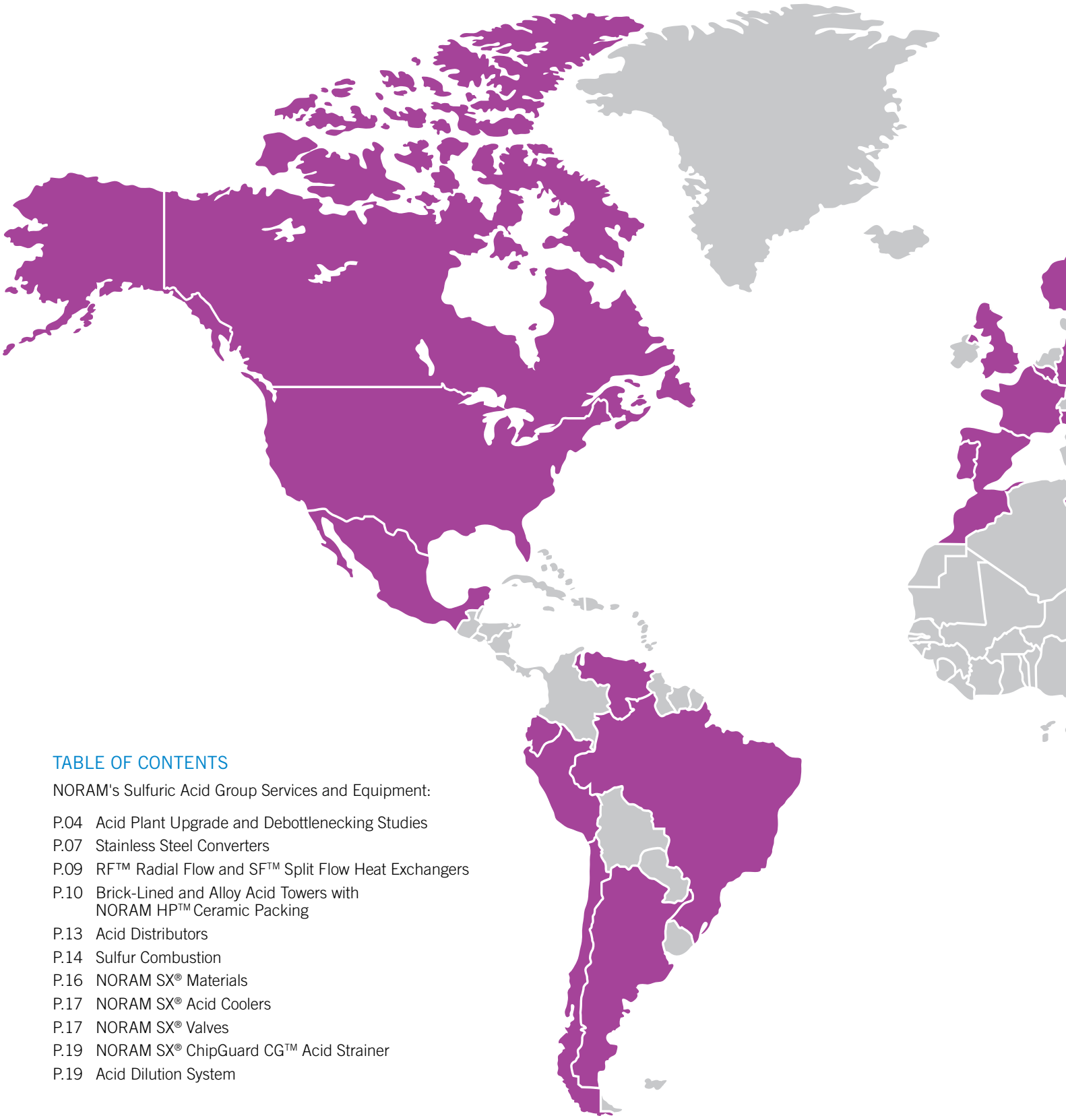
Together, the NORAM Group offers unique process and equipment solutions to clients and industries in over 40 countries.

NORAM'S SULFURIC ACID GROUP

We supply engineering and equipment services worldwide to the sulfuric acid and sulfur dioxide industries. We have established an extensive track record as a supplier of sulfuric acid and sulfur dioxide plants and equipment to provide superior reliability and process performance that enables clients around the world to:

> Increase production capacity.
> Extend the service life of existing facilities.
> Improve operating economics and cost-effectiveness.
> Meet more stringent environmental emission standards.

THE NORAM GROUP'S CLIENTS SPAN THE GLOBE



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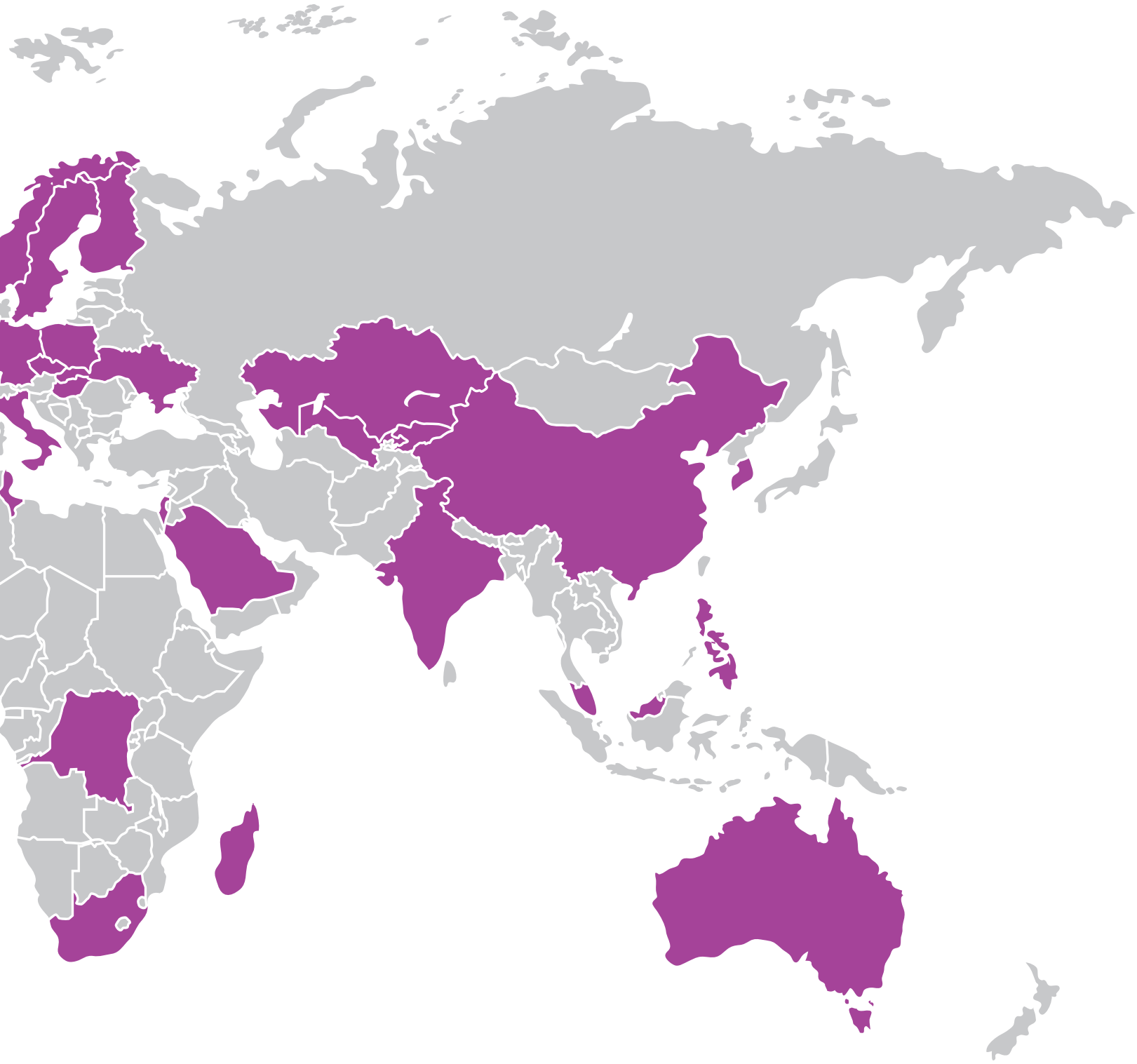
NORAM's Sulfuric Acid Group Services and Equipment:



■ Countries where the NORAM Group has done business

ACID PLANT UPGRADE AND DEBOTTLENECKING STUDIES

NORAM has decades of expertise and experience in all aspects of sulfuric acid plant design and operation. This established the fundamental knowledge base that enabled us to successfully undertake over 300 acid plant debottlenecking and/or optimization studies worldwide. These studies led to several successful operational solutions, resulting in the detailed design and supply of a substantial number of new NORAM proprietary equipment including converters, acid towers, radial flow gas-gas heat exchangers and many more.

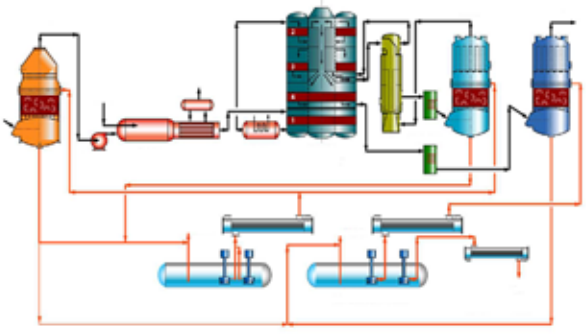
Our approach to upgrade and/or debottlenecking studies typically starts with a thorough review of existing plant operations, including temperature and pressure surveys as well as a review of the performance of existing equipment. Once completed, the current operation of the acid plant is modeled using our proprietary mass and energy balance program as a baseline after which bottlenecks are identified and various mitigation strategies and new/modified equipment identified. Our extensive track record of green and brownfield project execution provides clients with the certainty of successful, timely and cost-effective implementation.

Proprietary Equipment and Technologies

We have established an extensive track record as a supplier of superior, reliable and efficient acid plant equipment. NORAM has been an innovator in the acid industry for over 30 years with numerous patents, trademarks and know-how, offering state-of-the-art technologies including, but not limited to:

> Stainless Steel Converters
> RF™ Radial Flow Gas Heat Exchangers
> SMART and Trough-Type Acid Distributors
> High Performance (HP™) Saddle Packing
> Acid towers, tanks, piping, valves and coolers in NORAM SX®
> Ducting Design and Supply
> Sulfur and Regeneration Furnaces

Sulfuric Acid Plant Flow Diagram



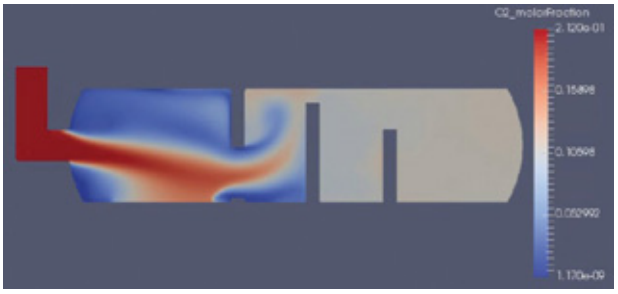
Design Tools and Software

NORAM uses a combination of both state-of-the-art, commercial software packages and proprietary, in-house design tools coupled with experienced design engineers to execute projects.

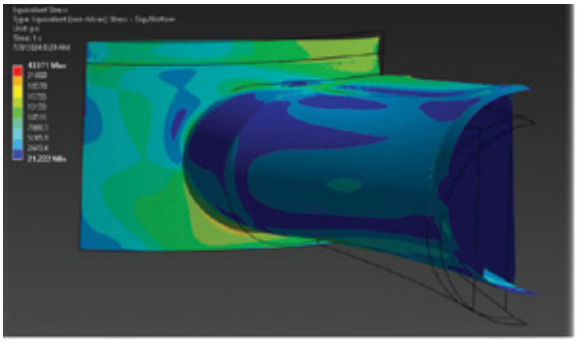
Our proprietary Mass and Energy Balance program is used to simulate acid plants and includes extensive physical properties, correlations, etc. Existing plants are modelled, and the results compared to actual operating data from the plants as a base-line before assessing bottlenecks and identifying opportunities for improvement.

Our proprietary Heat Exchanger Rating program is used to design or simulate radial flow and split flow heat exchangers to provide optimized, efficient designs. The program's results have been have been correlated with actual plant operating data over many years and fine-tuned during the successful supply of more than 120 radial flow heat exchangers.

Extensive use is made of Computational Fluid Dynamics (CFD) modelling and Finite Element Analysis (FEA) during the design process to provide cost-effective yet robust, practical equipment designs.



The design of acid plant ducting is not a trivial exercise requiring the assessment of several variables. NORAM has honed its ducting design methodologies to an art form over the last 30 years providing practical, fit-for-purpose designs.



STAINLESS STEEL CONVERTERS

Converter Design

The catalytic converter in an acid plant contains multiple beds of vanadium pentoxide catalyst required for the exothermic conversion of SO_2 to SO_3.

Traditional converter designs have used carbon steel shells, often with brick lining around the hot first bed, and cast iron posts and support grids to hold the catalyst mass. These converters often experience gas bypassing between catalyst beds, maldistribution of gas in the catalyst mass, poor reliability of bed supports, creep deformation of mechanical components, and leaking nozzles.

NORAM offers modern, light-weight, all-welded stainless steel converters with uniform gas distribution in the catalyst beds and low overall pressure drop. Unless required for internal heat exchangers, NORAM converters are “core-less”. Catalyst supports and bed division plates are catenary-shaped to accommodate thermal expansion and eliminates the requirement for bed plate support beams that must be used in flat plate bed support systems. The primary benefit of the curved plate design is that plate and shell stresses induced by plate expansion and contraction are minimized. FEA and CFD analysis are extensively used to ensure cost-effective, robust designs and uniform gas distribution.

NORAM's converters also include a dedicated preheat duct which diverts hot gas from bed 1 to beds 3 and 4 during start-up, as shown on the image on the right. This allows the catalyst beds to reach the required operating temperature faster reducing start-up emissions.

Our converter design allows shop fabrication of converter modules for assembly in the field. This enhances quality and minimizes field erection time.

Ducting Design

Ducting is an integral part of sulfuric acid plants and probably one of the most challenging areas to design. Considerations are high operating temperatures, large volumes of corrosive gases and significant pressure thrusts between connecting equipment subjected to radial and axial thermal expansion.

NORAM’s systematic approach includes a detailed evaluation of the operating conditions and requirements followed by stress and flexibility analysis to determine optimal placement of supports and expansion joints. Finite Element Analysis is extensively used to optimize and confirm the designs.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RF™ RADIAL FLOW AND SF™ SPLIT FLOW GAS HEAT EXCHANGERS

NORAM's RF™ Radial Flow Gas Heat Exchanger offers a fundamental improvement in the performance of gas heat exchangers over designs traditionally used in the sulfuric acid industry with significant improvements in heat transfer rates and reductions in pressure loss compared to single and double-segmental heat exchangers.

In a NORAM RF™ Gas Exchanger, tubes are arranged in an annular pattern using disk and donut baffles. Flow is directed from an inner core outward across the tube bundle and from an outer annulus inward across the tube bundle. The gas turns in the inner core and outer annulus are not restricted by tubes so that pressure losses are minimized. The flow resistance across the tube bundle is uniform, resulting in uniform flow and low pressure drop.

NORAM's SF™ Split Flow Gas Heat Exchanger is a patented variation of the RF™ Exchangers specifically developed to address several common heat exchanger issues in sulfuric acid plants. In some applications, such as SO_3 Coolers and Cold Exchangers, acid condensation can occur in the vicinity of the cold, bottom tubesheet resulting in corrosion and sulfate formation, which increases pressure drop and ultimately could lead to failure.

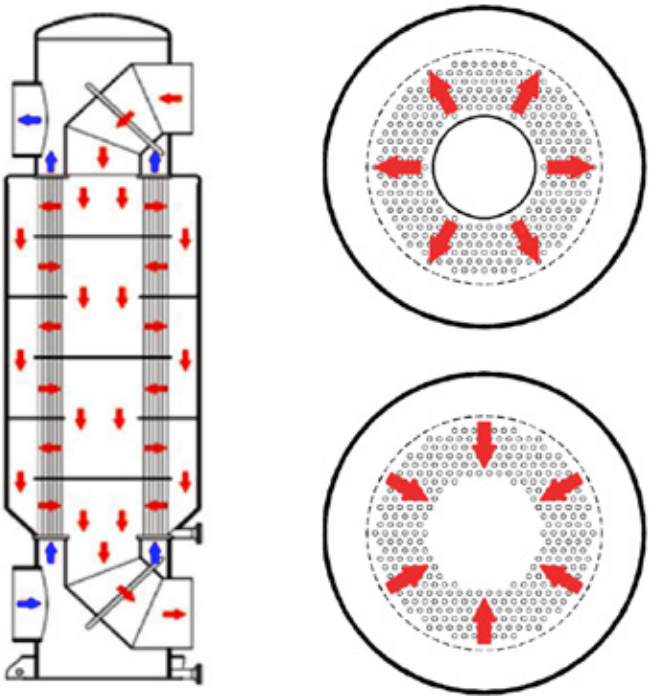
In such cases, the SF™ Gas Exchanger reduces the likelihood of these issues by raising the temperature of the 'cold' tubesheet and of the tube area near the tubesheet by directing some of the hot gas directly to the cold tubesheet through a core-tube. This "hot-sweep" elevates the tubesheet temperatures to above the dew point minimizing or eliminating the formation of acid condensation. The bulk of the gas flow follows the normal counter-current flow arrangement with respect to the tubes with the "hot-sweep" forming a small co-current section at the bottom of the exchanger.

Acid Plant Preheat System

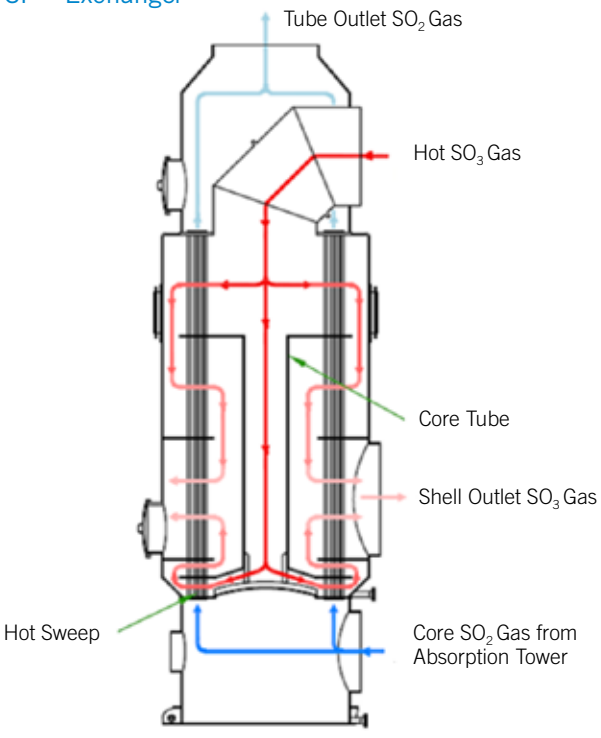
A NORAM preheating system employs our patented Split Flow (SF™) technology in a "cold sweep" configuration. A slip-stream of process gas is diverted through the core tube to the 'hot' bottom tubesheet of the exchanger to aid in reducing the metal temperature at the hot flue gas inlet. This allows higher inlet gas temperatures to be used and improves the heat transfer efficiency resulting in:

- Smaller heat exchangers.
- Reduced fan and duct sizes.
- Less maintenance.

RF™ Exchanger



SF™ Exchanger

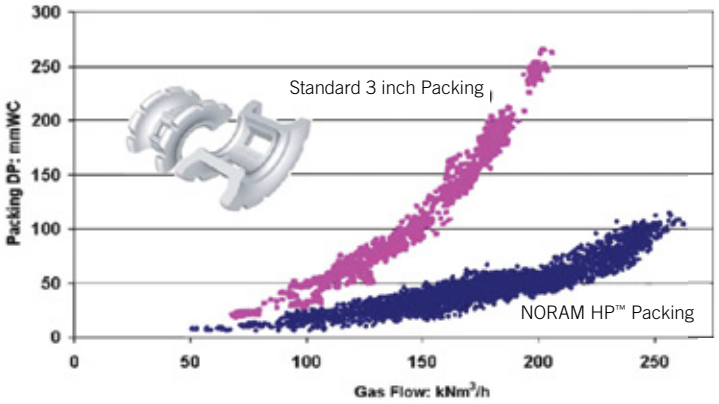


BRICK-LINED AND ALLOY ACID TOWERS WITH NORAM HP™ CERAMIC PACKING

NORAM offers brick-lined and alloy towers along with pump tanks made in NORAM SX®. Towers and tanks are custom designed taking into consideration the client's specific requirements, operating conditions and site constraints. NORAM's brick-lined towers comprises the wetted sections in carbon steel lined with an acid-proof membrane between the steel and acid resistant bricks. The upper section of the tower is in stainless steel. The packing is supported by a self-supporting ceramic dome offering significant advantages over arch-and-beam packing support. The self-supporting dome transfers the load to the tower walls eliminating the need for support beams thereby leaving the bottom of the tower free of obstruction to the gas flow and facilitates tower access for maintenance.

In alloy towers, NORAM's high silicon SX® material is used for the wetted surfaces in the tower. NORAM SX® towers are significantly lighter than brick-lined options allowing for easier and faster installation.

Pressure drop comparison between standard packing and NORAM HP™

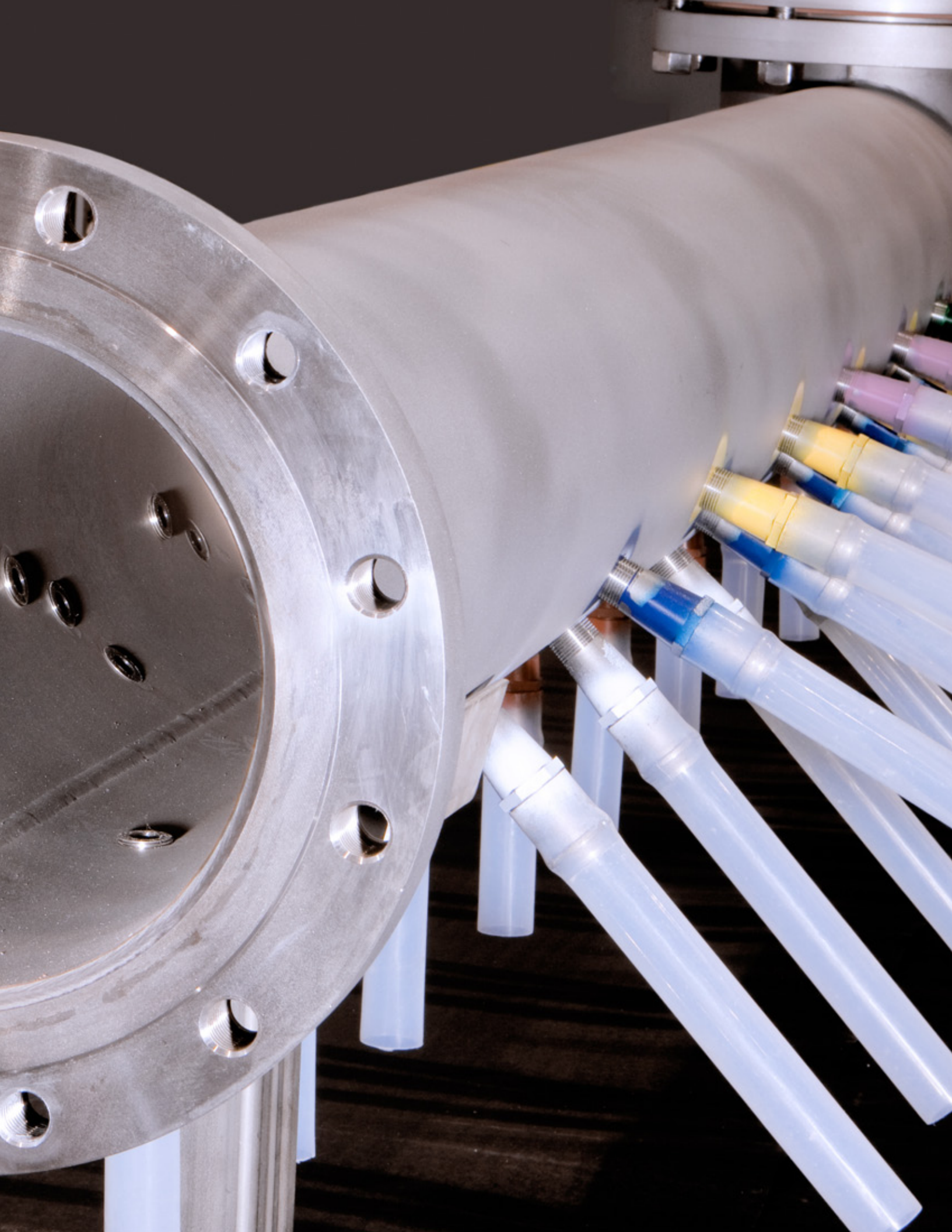


In addition, for the same operating conditions, the tower diameter could often be reduced as there is no brick-lining.

NORAM provides all the internals to acid towers including NORAM HP™ (High Performance) saddles, trough or SMART™ distributors as well as mesh pads in NORAM SX®.

NORAM's HP™ packing is semi-toroidal in shape, providing random interlocking and uniform void space, increasing mass transfer efficiency as well as a significant reduction in pressure drop compared to standard 3" packing. HP™ saddles are uniformly shaped and sized, which are extremely strong therefore reducing the amount of chips formed.

NORAM HP™ packing is ideally suited to debottleneck acid towers due to the low pressure drop compared to conventional 3" saddles enabling an increase in gas throughput in an existing acid tower by more than 25%.



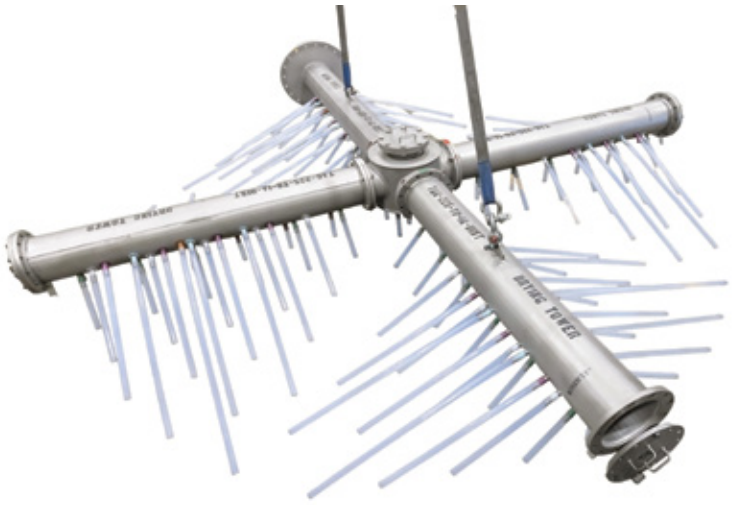
ACID DISTRIBUTORS

The NORAM SMART™ acid distributor and NORAM trough distributor provide uniform acid distribution across towers with minimal acid spray generation.

Special care is taken in the design of the irrigation point layout to ensure a slightly higher irrigation rate in the wall region of the tower, where the larger local void fraction of the packing reduces mass transfer efficiency, which can cause slippage of SO_3.

A NORAM trough distributor provides well-dispersed acid across the tower with more than 4 irrigation points per square foot. Acid flows under gravity into the packing for optimum performance and minimal spray formation. The design prevents debris in the acid from obstructing the downcomer tubes and the acid flow in the troughs can be visually inspected.

The SMART™ distributor is comprised of a main acid header pipe, which delivers acid to distributor arms. Various configurations are used depending on the tower geometry. Parallel arms are used in large towers, whereas a single arm is sufficient in small towers. Downcomers are fitted onto the distributor arms to deliver the acid into the packing domain to minimize acid mist carryover. The downcomer outlets are buried in the packing. The number of irrigation points depends on the irrigation rate, and is typically between 1 and 1.5 irrigation points per square foot of tower cross-sectional area.



The downcomers comprise of proprietary venturi orifice adapters onto which large diameter FEP tubes are shrink-fitted. The assembled downcomers thread directly into the distributor arms.

Inspection ports on the tower shell and blind flanges on the distributor arms allow the removal of debris from the SMART™ distributor without requiring tower entry, significantly reducing risks to personnel.

Sufficient liquid head is provided over the venturi orifice adapters, which eliminates the time consuming effort of leveling which is required for trough distributors.

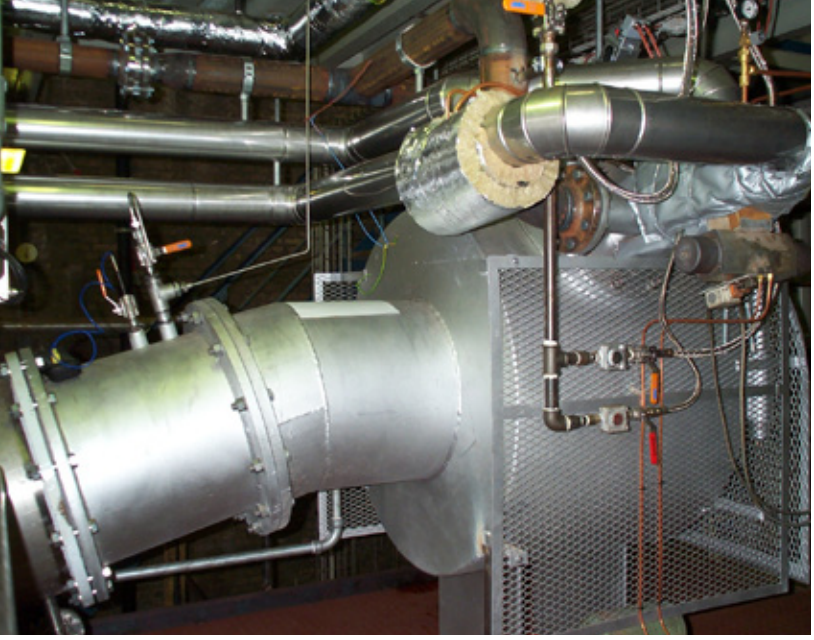
SULFUR COMBUSTION

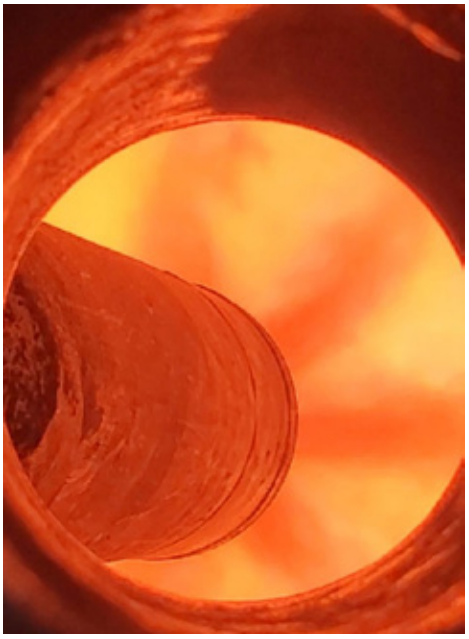
NORAM's sulfur and spent acid furnaces are custom designed using the latest design tools to provide high efficiency combustion that meets the required capacity and SO_2 strength.

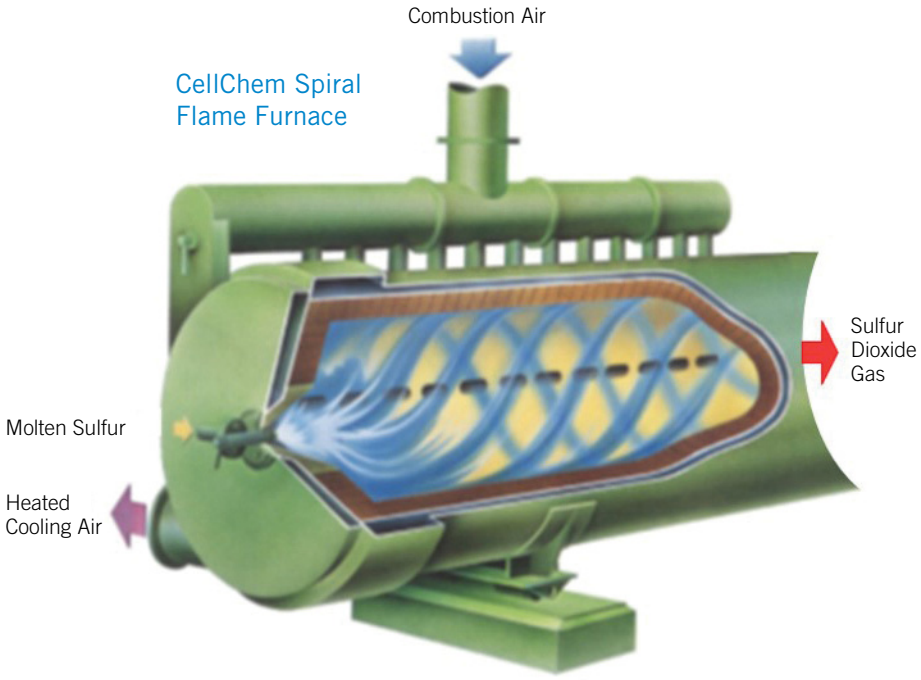
NORAM's furnaces have turbulent, well-mixed combustion zones within the furnace reducing the formation of hot spots, keeping the overall combustion temperatures uniform to achieve efficient and complete combustion while minimizing NOx formation. Computational Fluid Dynamics (CFD) modeling is used to provide pressure, temperature and flow maps of furnace combustion gases which is used to optimize sulfur or acid injection equipment orientation, gas flow patterns and rates, and baffle arrangements. CFD modeling allows NORAM to eliminate stagnant regions in the furnace design.

NORAM utilizes both pressure and air atomized sulfur guns in either conventional large-scale furnaces or small-capacity, specialized CellChem Spiral or Cyclone Flame furnaces to produce SO_2 concentrations between 10% and 19%.

CellChem furnaces produce relatively high strength SO_2 gas in a compact design. When the technology was introduced in 1960, the burner had less than one third the volume of a conventional burner of the same capacity. This was attained by producing smaller droplets of sulfur in a custom air atomization sulfur gun and by introducing high-velocity combustion air tangential to the combustion chamber, giving the flame a spiral pattern. Stable concentrations of up to 19.5 vol% SO_2 have been achieved without sulfur break-through enabling very compact furnace designs with minimal amounts of sulfur trioxide (SO_3) being formed in the furnace. Minimizing SO_3 formation reduces corrosion and product quality problems downstream since any SO_3 is typically converted to sulfuric acid or sulfate ions in downstream operations.





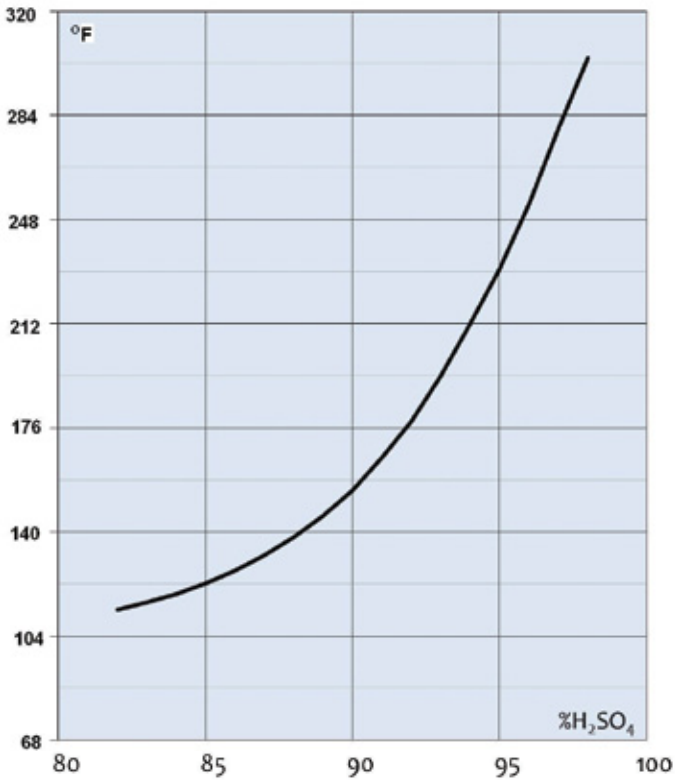

Combustion Air
CellChem Spiral
Flame Furnace
Sulfur
Dioxide
Gas
Molten Sulfur
Heated
Cooling Air

NORAM SX® MATERIALS

NORAM SX® is NORAM's trademark for high silicon, austenitic stainless steel, UNS S32615, originally developed by Sandvik specifically for use in hot concentrated sulfuric acid. NORAM SX® is considered the benchmark in sulfuric acid service with over 25 years of unparalleled performance, offering numerous advantages over other materials of construction with excellent mechanical and corrosion properties. Corrosion rates of NORAM SX® are practically zero in the typical operating range of drying and absorption circuits, even at high acid velocities. The resistance against occasional process excursions and upset conditions is also exceptional.

NORAM SX® is readily workable and matching welding consumables are available for GTAW, GMAW and SMAW processes and complies to ASME II Part D, ASME VIII Div 1 and PMA-EN.

Isocorrsion Curve 0.1mm/year



Cooling Water / Acid

Temp	Max Chloride Concentration
Max 80 °C	<100 ppm Cl^-

Acid Concentration 98.0 – 99.9%

Temp	Max Flouride Concentration
≤ 75 °C	5 ppm F^-
76-95 °C	2 ppm F^-
≥ 96 °C	1 ppm F^-

NORAM provides the following in NORAM SX®:

- Acid Towers including:
  - Acid Distributors (trough and SMART™)
  - Internal Acid strainers
- Acid Coolers
- Acid Piping and Fittings (ø from 1" to 30")
  - Pipe
  - Elbows
  - Reducers (concentric/eccentric)
  - Tees (equal and reducing)
  - Flanges
- External Chipguard Acid Strainer
- Wafer-Style Butterfly Valves: Sizes – 3" to 30"
  - Advanced triple eccentric design.
  - Designed for control and shut-off applications
  - Class V in EN 60534-4 / ASME B16-104.
  - The solid seat.
- Segmented Ball Valves: Sizes – 1" to 3"
- Special parts such as Strainers, Vortex breakers, Thimbles, Thermo-wells and Dip Pipes are also available.

NORAM SX® ACID COOLERS

One of the greatest improvements in acid cooler design is the introduction of the alloy shell and tube acid cooler. NORAM SX® Acid Coolers provide simple, reliable and low maintenance solutions for acid cooling by applying the excellent corrosion resistance of NORAM SX® eliminating the need for anodic protection.

NORAM SX® acid coolers are designed for optimal thermal performance, without the limitations on acid velocity and acid temperature as is typical for anodically protected coolers and plate and frame coolers.
The benefit is a compact design with a large operating flexibility. Maintenance costs are minimized by eliminating the need for inspection and maintenance of the anodic protection system, as well as the need for associated spare parts.

NORAM SX® VALVES

We also supply a range of Butterfly Valves in NORAM SX® which has numerous advantages:

- Advanced triple eccentric design with unique disc shape.
- Designed for control and shut-off applications.
- Tightness class in accordance with EN 60534-4 Class or ASME B16-104 Class V as standard.
- The solid seat remains unaffected by high flow velocities and temperatures. A good valve function is achieved even in difficult applications.
- The valve assemblies are delivered factory tested as complete units with actuators, positioners and accessories.
- A front retaining ring which can be removed to replace the valve seat.
- Rebuilt kits are available which allows the valve seat and shaft packing to be replaced.


NORAM SX™

NORAM SX® CHIPGUARD CG™ ACID STRAINER

Sulfuric acid circulation systems often experience problems caused by entrainment of solids into critical pieces of equipment. Solids can be entrained into the hot sulfuric acid circuits from a number of sources including: construction debris, ceramic packing chips, breakage from brick-lined equipment, and corrosion byproducts. If the solids are not removed, they are conveyed into the acid plant equipment with the acid circulation flow. This can cause a range of problems in an operating plant including the plugging of acid coolers, acid distributors and equipment erosion which reduces service life.

NORAM's SX® ChipGuard acid strainers efficiently and reliably remove solids from the circulating acid featuring:

- Low pressure drop to prevent hydraulic issues and pump NPSH issues.
- Can be located at ground level, downstream or upstream of the acid pumps to simplify cleaning and to protect as many pieces of equipment as possible.
- Robust mechanical design.

ACID DILUTION SYSTEM

Acid and water do not mix readily due to their substantial difference in density which may result in concentration layering in acid pump tanks or localized areas of higher and lower concentrations resulting in increased corrosion and other safety concerns. Acid dilution systems in acid circuits need to be carefully evaluated and designed to prevent any issues.

NORAM offers both internal and external acid dilution systems. In a typical acid plant, strong acid is returned to the absorption tower from the pump tank via an acid cooler. Internal dilution systems use conventional dip pipes and spargers located on the acid return line from the acid towers. For external systems, a static mixer is used. A slip stream of acid is diverted from the main acid recirculation line and passed through a static mixer where water is introduced before returning the required acid concentration to the pump tank. Dilution water is injected into the acid stream ahead of the static mixer against sufficient backpressure to avoid flash evaporation.

3D SECTIONAL VIEW
OF A LARGE DIAMETER
NORAM CONVERTER

PRODUCTS AND SERVICES NORAM SUPPLIES TO THE SULFURIC ACID INDUSTRY:

NORAM Plant Upgrade and Debottlenecking Engineering Studies
NORAM Plant Preheating Systems
NORAM Stainless Steel Catalytic Converters
NORAM RF™ Radial Flow Gas-To-Gas Heat Exchangers
NORAM SF™ Split Flow Gas-To-Gas Heat Exchangers
NORAM Brick-Lined Acid Towers
NORAM Sulfur and Spent Acid Burners
NORAM Cellchem Sulfur Burners
NORAM Anodically Protected Acid Coolers
NORAM HP™ Saddle Packing for Acid Towers
NORAM Smart Acid Distributors for Acid Towers
NORAM Trough Acid Distributors for Acid Towers
NORAM SX® ChipGuard CG™ Acid Strainer
NORAM Entrainment Mitigation Device (EMD)
NORAM Acid Dilution Systems
NORAM Gas Ducting
NORAM Sulfur Guns
NORAM SX® Acid Coolers
NORAM SX® Towers
NORAM SX® Pump Tanks
NORAM SX® Material
NORAM SX® Acid Distributors
NORAM SX® Piping
NORAM SX® Valves

NORAM supplies engineering services and equipment worldwide to the sulfuric acid, nitration and pulp and paper industries.

NORAM Electrolysis Systems Inc. focuses on electrolytic solutions in the lithium industry.

Axton is a leader in industrial metal fabrication of high-performance equipment.

NORAM International is a Swedish-based engineering company providing process-industry related products and services.

BC Research Inc is a technology incubator, specializing in custom research process development and technology commercialization.

ECOfluid offers a wealth of knowledge and expertise in the design, construction and operation of wastewater treatment plants.

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