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PCS Phosphate's New 4500 STPD Sulfuric Acid Plant in Aurora, NC

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The largest sulfuric acid plant in North America was recently placed into operation for PCS Phosphate Company, Inc. in Aurora, NC. This 4500 STPD sulfur burning plant was designed and built by MECS, Inc. of St Louis, MO. The PCS 7 plant includes MECS Heat Recovery System (HRS), which recovers waste heat from the sulfuric acid process. The new plant recovers 95% of the heat generated and supplies approximately 700,000 pounds per hour of steam to the turbogenerator and fertilizer complex. Utilizing the steam recovered from the sulfuric acid process saves approximately 800,000 tons of carbon dioxide per year that would otherwise be emitted by burning fuel at the plant site to generate the same level of steam. In addition, the plant is designed to high environmental standards, 2.0 lbs SO_2 / ton H_2SO_4 and 0.75 lbs acid mist /ton H_2SO_4. The emissions for this plant are half of the current US EPA standard for SO_2 emissions.

This paper will cover the performance and features of the new plant such as ZeCor acid towers, large single compressor, cylindrical superheater and novel expansion joints.

HOW IT WAS BUILT

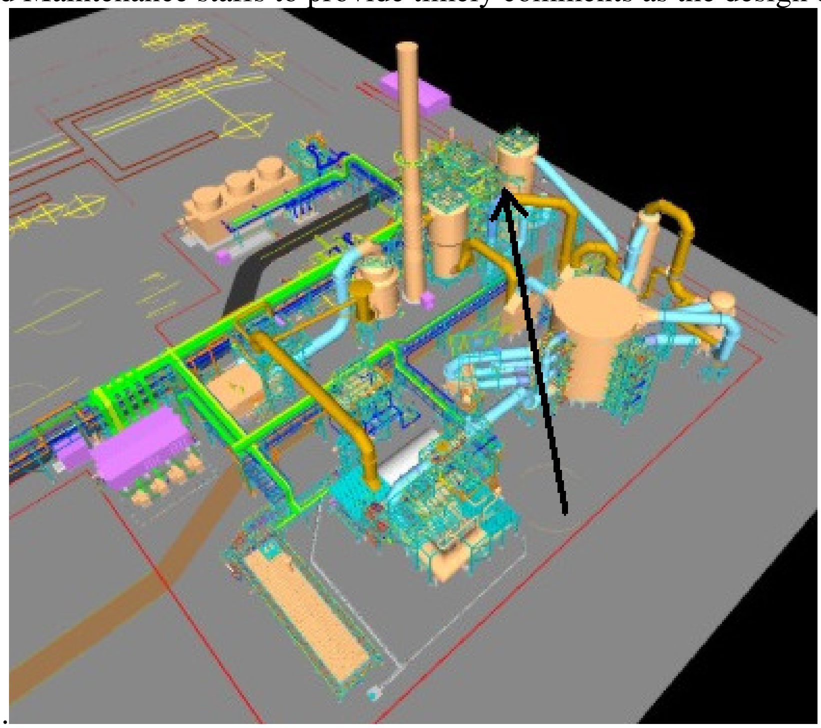
The plant was designed and constructed with close cooperation between MECS and PCS.

The project scope was jointly developed beginning with a project conceptual kick off meeting in 2005 where MECS presented a standard MECS design. PCS modified the preliminary design concept with their special requirements. MECS then prepared a more detailed design, including mechanical specifications for major equipment items, and a detailed cost estimate. From 2005 to 2007, the design was refined as the project passed through the PCS capital budgeting process. In late 2007, PCS accepted the project and authorized funding to develop mechanical specifications and place major equipment items on order with the vendors. Full project funding was authorized at the beginning of 2008 and field construction activities commenced in April 2008. The plant came on line in January 2010.

During the design phase PCS actively participated in all major decisions. MECS was included on PCS's Process Hazards Review (HAZOP) team. The design also included all elements to comply with Process Safety Management (PSM). This joint participation was facilitated by MECS providing all project documents to PCS over the internet as they were developed.

3D MODELS

In addition to normal drawings and specifications, MECS provided PCS's project team and the construction staff with on site access to updated 3D models as the design was developed. With this tool PCS was able to review the layout / design with their Operation and Maintenance staffs to provide timely comments as the design developed.



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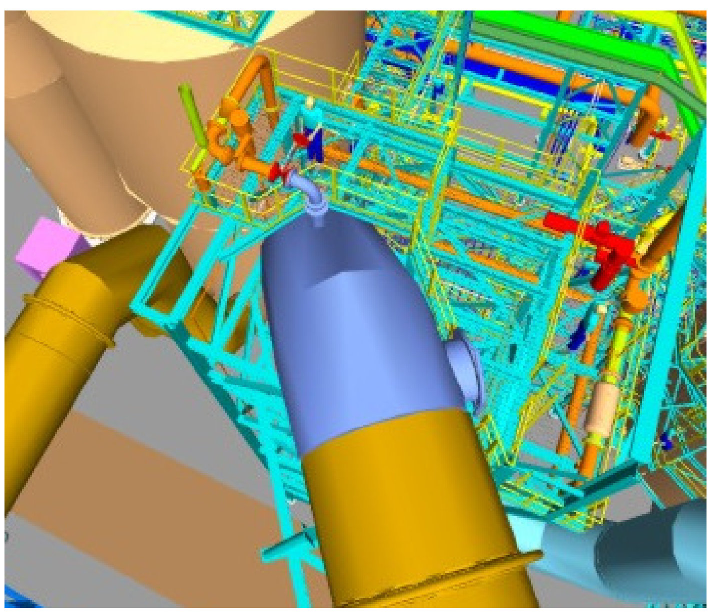
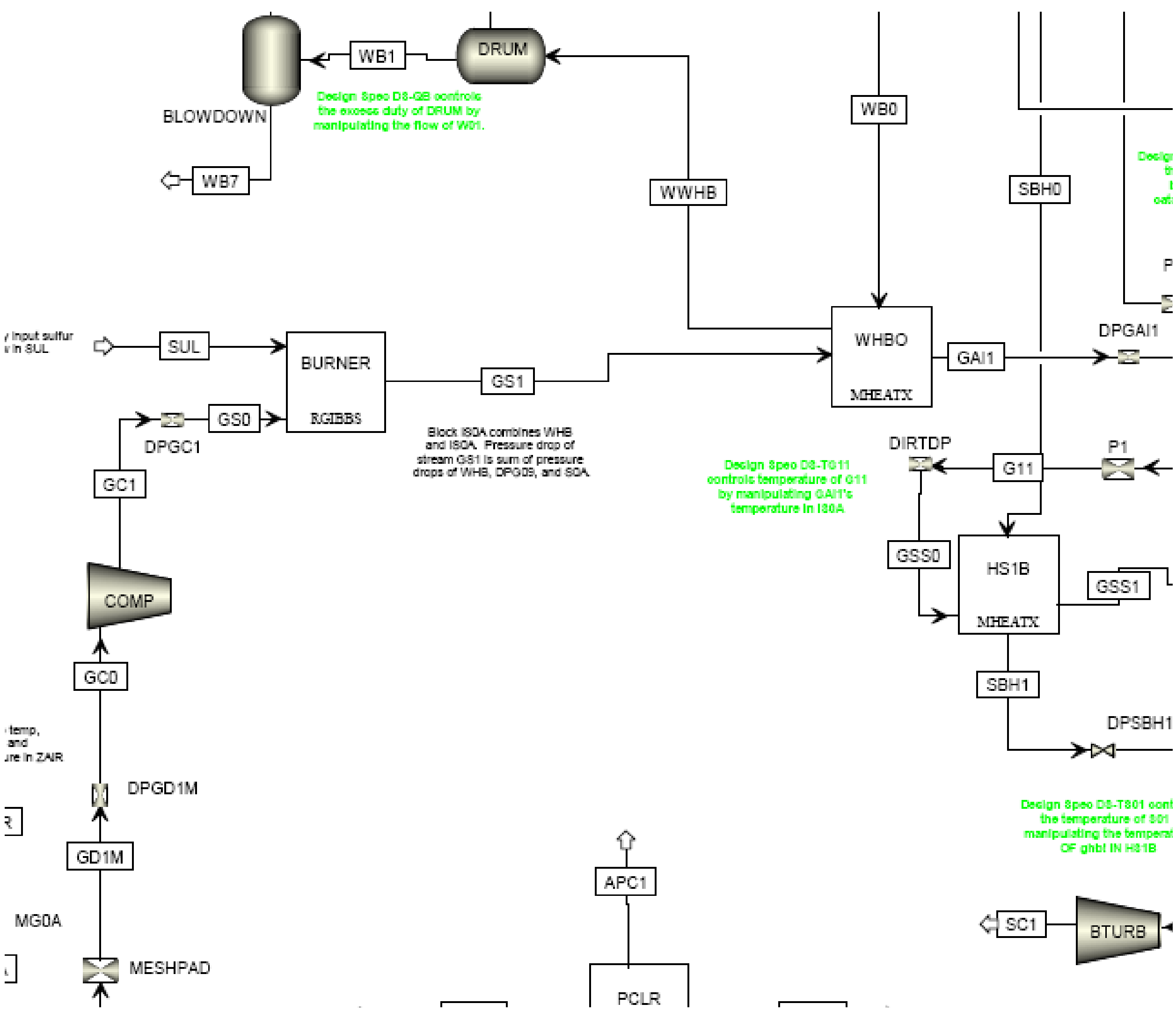
The 3D models enabled PCS to focus in on how the detailed design was progressing and to see items like valve accessibility and platform placement.



MECS CUSTOMIZED ASPEN SIMULATION

MECS modeled the entire sulfuric process with an ASPEN simulation using customized blocks with MECS reaction kinetics and physical property correlations to accurately calculate equipment duties. During the early phase of design, MECS used this model to optimize the process and rapidly develop different case scenarios for review by PCS. PCS and MECS jointly selected the final parameters for the process and the detailed design then proceeded from an accurate model of the process.

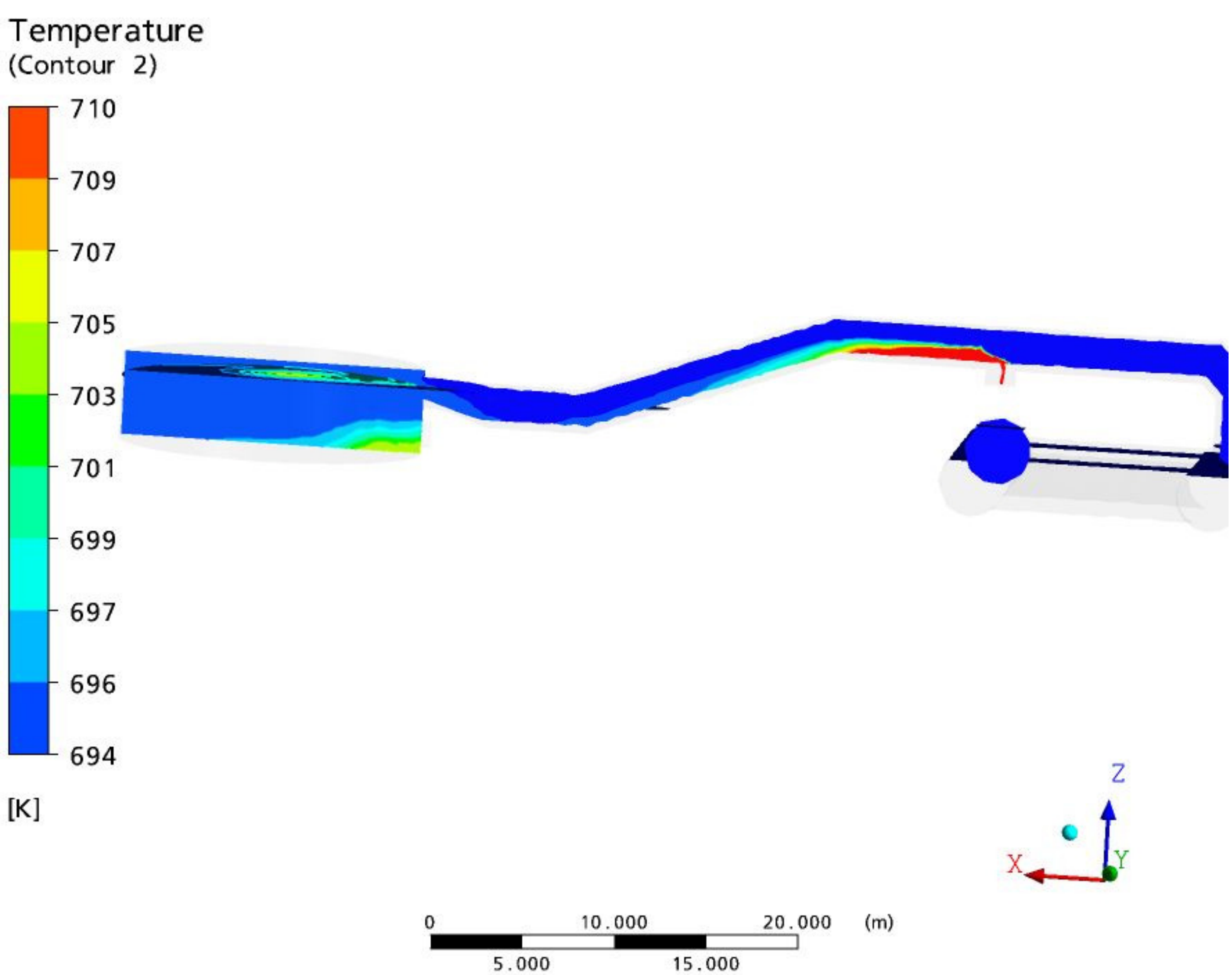
A small section of the simulation graphic, showing the compressor, burner, boiler, and superheater is shown below



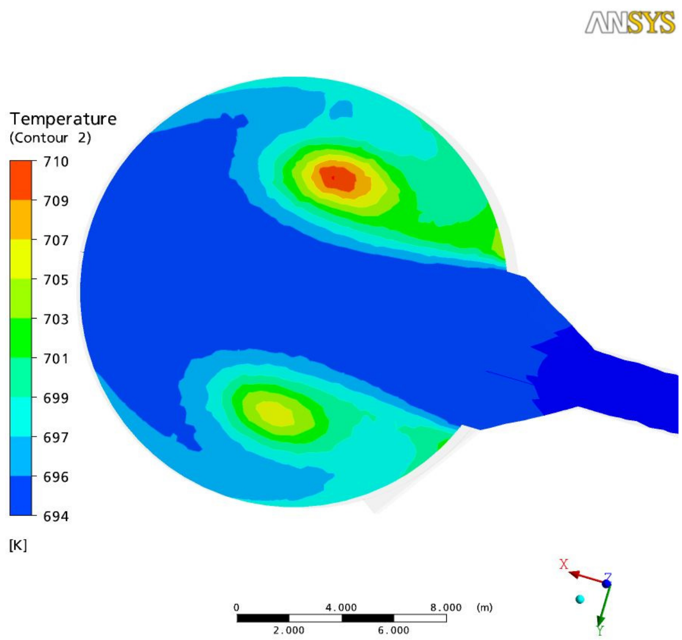
CFD MODELING OF LARGE GAS DUCTS AND VESSELS

The PCS 7 plant is a large, 4500 STPD, plant with dual waste heat boilers and a gas side bypass on Superheater 1A. The PCS 7 plant was designed to meet an SO2 emissions requirement of 2 lbs SO2 / ton H2SO4, which is more stringent than the current EPA requirement. The Converter is 54 ft in diameter with nominally 8 ft diameter ducts. CFD studies were made on Passes 1 and 2 to determine if duct layout would cause any gas distribution problems that would limit the conversion of SO_2 to SO_3.

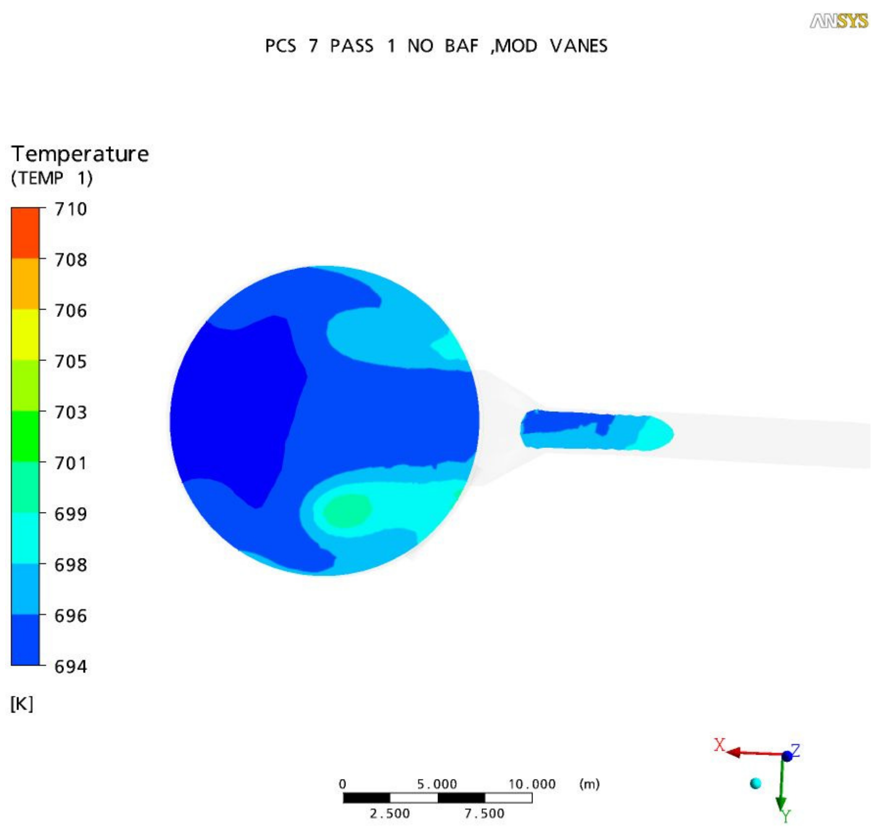
Pass 1 Temperature distribution with 511-190A Rev 1 turning vanes.



Pass 1 Inlet temperature distribution with standard inlet vanes



Pass 1 Temperature distribution with modified turning vanes



The CFD plots with the revised turning vanes show a more uniform temperature across the bed. To put the actual impact of the relocated vanes in perspective, MECS extracted calculated temperature values at the top of pass 1, calculated the impact on conversion with SO2OPT, and compared them in the following table:

	Normal Vanes	Modified vanes
STDEV F	5	2.2
Calculated conv ave F	1.09 lb SO2/ ton	1.09 lb SO2/ ton
Calculated conv max F	1.10 lb SO2/ ton	1.09 lb SO2/ ton
Calculated conv min F	1.12 lb SO2/ ton	1.09 lb SO2/ ton

Even though the effect was small, modifying the turning vanes improved the uniformity of gas mixing to Pass 1. There was almost no cost penalty or pressure drop penalty for this change as it only affected the spacing of the vanes.

JOINT PRE-COMISSIONING PLAN

PCS and MECS developed a joint pre-commissioning plan with both companies actively participating in the development and execution of the plant start up.

First a priority listing of the plant systems was developed and each system assigned a number as follows:

TURNOVER SYSTEMS & HANDOVER PRIORITY LIST

System Number	System
1	Power and Control
2	Cooling Tower
3	Main Air Blower
4	Boiler Feed Water
5	Waste Heat Boiler and Sulfur Furnace
6	Dump Condenser
7	Sulfur System
8	Process Gas System
9	Strong Acid System
10	Heat Recovery Systems
11	Utilities Systems

A pre-commissioning plan was developed for each system. Inspection, testing, flushing, lubrication, and mechanical acceptance documents were also developed for each piece of equipment, pipe system, and instrument in the plant. All inspection records were logged in record books before the systems were turned over to operations. An example of an inspection sheet for a pipe system is shown below.

INSTRUMENT AIR SYSTEM PIPING

Project	PCS Phosphate Plant No. 7	**Engineer**	NJD
Location	Aurora, NC	**Date**	6-Jul-09
MEN	6234	**Equipment No.**	N/A
		Item No.	2.1.2.2_IAH

Condition	MECS Dwg. / Spec. Ref.	Required Condition	Actual Condition
1. Ensure construction check-out is complete and all construction and contractor forms are complete and signed.		Complete	
2. Check pipe routing against the P&ID's. Ensure all piping is installed, and that it is the correct size. Verify all orifice sizes are correct (if applicable).	321-220	Complete	
3. Ensure gaskets are installed in all flange connections, and that all flange connections are tight.		Installed	
4. Ensure all piping instrumentation is installed and operational.	N/A	N/A	N/A
5. Ensure all required valves are installed. Ensure there are no obstructions blocking valve operation.	321-220	Installed	
6. Ensure all flange covers are installed, if required.		Installed	
7. Verify all control valves installed correctly.	N/A	N/A	N/A
8. Verify all required relief valves are installed, operational, and have been tested. Ensure the valves are not blocked shut (if applicable).	N/A	N/A	N/A
9. Ensure required piping supports are installed.		Installed	
10. Ensure baskets are installed in any in-line strainers (if applicable).		Installed	
11. Ensure the lines have been pressure tested as required per application.	N/A	N/A	N/A
12. Ensure heat tracing and/or insulation are installed and operational (if applicable).	N/A	N/A	N/A
13. Ensure painting is complete and touched up, as required.	372-102	Complete	

LARGE EQUIPMENT SIZE

The large size of the plant stretched some of the vendors' capabilities to provide a single piece of equipment to meet the required duty. The project team was required to make decisions on whether to select two pieces of equipment in parallel or accept a vendor's offer to build an item near the limits of their manufacturing experience. In the final design most equipment items were single units. The exceptions where parallel units were provided were:

- Dual HRS Acid Circulation pumps (5000 gpm each) installed in dual pump boots on a single Heat Recovery Tower
- Dual HRS Boilers with individual steam drums (101 kpph steam each)
- Dual HRS Acid Distribution Headers in single Heat Recovery Tower (combined flow of 8,600 gpm)
- Dual High Pressure Boilers with common steam drum. (Combined steam rate of 508 kpph)

Dual Pump Boots with HRS Diluter in the foreground.

Dual HP Boiler Shells –above is the common steam drum

SINGLE MAIN COMPRESSOR

A single train Main Compressor with steam turbine drive was provided by Seimens AG of Germany. The unit has a capacity of 210,000 SCFM and the capability to turndown to 50%. In order to achieve the turndown ratio the system utilized a variable speed turbine with inlet guide vanes to restrict flow at the turbine minimum speed. To help protect the compressor during a surge condition an automatic surge control system was designed to redirect gas flow through a recycle duct to the Drying Tower. Using this duct, gas flows down to 10% of design can be provided to the furnace for refractory heat up.

A unique feature for a MECS designed sulfuric acid plant is that the compressor is started and run up to minimum speed against a closed discharge valve. During the warm up period the gas is recycled to the Drying Tower. One advantage of this type of start up is that the compressor can be brought up to operating speed without blowing any of the heat out of the sulfur furnace and converter. This feature, along with MECS Cesium promoted catalyst, facilitates low emission start ups.

Compressor installed in blower building

Half of the split casing on the shop floor in Germany

3/1 STAID MECS CONVERTER AND CATALYST

The MECS designed converter is a 54 ft ID stainless steel converter with an internal staid support system. A staid design is very robust and is designed to minimize shell buckling in this large of a vessel. Each converter pass was provided with a heat up duct. The converter diameter was increased to meet PCS requirements for low pressure drops and a nominal 3 year catalyst screening cycle. This eliminated the cost of engineering and purchasing a hot gas filter.

The process design of the converter is for a 3/1 IPA gas flow with MECS XLP catalyst in the first, second and third passes and cesium SCX-2000 in the forth converter pass. Gas ducts and inlet nozzles were designed with CFD analysis to promote uniform gas flow over the entire converter bed. The performance of the converter has been excellent; easily meeting the emission guarantee of 2.0 lbs of SO_2 per ton of H_2SO_4.

The large size of the converter minimizes heat loss and extends the time the plant can be kept down for changing heat up blinds or conducting hot shut down maintenance activities. This can permit low emission restarts with out reheating the converter with fuel. During the initial start up of the plant the SO_2 emissions rarely exceeded 100 ppm SO_2.

In January 2010, during the initial heat up of the plant, the furnace was preheated as part of the refractory cure. The plant can be on line in 36 hours when starting from a cold condition. This includes the time to preheat the furnace, change blinds for one dry blow, and install / remove the start up blinds, vents, and oil gun.

The plant was down for a 52 hour period in January. The converter cooled off at the following rate during this time:

Heat Loss Rate of PCS 7 Converter System

Date	Time	Pass 1 Inlet Temp °F	Pass 1 Outlet Temp °F	Pass 2 Inlet Temp °F	Pass 2 Outlet Temp °F	Pass 3 Inlet Temp °F	Pass 3 Outlet Temp °F	Pass 4 Inlet Temp °F	Pass 4 Outlet Temp °F
17-Jan-10	9:00 AM	767	1,130	803	929	813	855	723	757
19-Jan-10	12:30 PM	460	443	524	485	458	538	301	503
Delta	51.5	307	687	279	444	355	317	422	254
Deg F / Hr		6	13	5	9	7	6	8	5

MECS Converter with heat up ducts

Staid supports in converter

HRS SYSTEM WITH STEAM INJECTION

The HRS system consists of a steam injection vessel, a two-stage packed heat recovery tower, two horizontal steam boilers, a HRS heater, a HRS preheater, an in-line diluter, two acid circulating pumps (located in separate pump boots with both pumps operating), and two HRS acid drain pumps. Treated water is pumped through the HRS preheater to the deaerator. Water from the deaerator is pumped through the HRS heater, where it is heated before going to the two HRS boilers. As a result the MECS HRS system efficiently recovers 203,000 lbs per hour of 50 psig steam.

For the first time in North America a HRS system has been equipped with steam injection. Approximately 30 to 40 % of the HRS dilution water is injected as steam into the MECS steam injection duct upstream of the HRS Tower. The performance of the steam injection system has met all of its objectives:

- Reduced vibrations in the dilutor system
- Stronger acid to the first stage with lower corrosion rates in piping and acid distributor
- Smaller pumps and acid circulation piping in main HRS circulation system.
- Smaller sized dilutor vessel.

The steam injection system also provides the opportunity to make about 10% more low steam if low pressure dilution steam was available in the plant to upgrade to the HRS operating steam pressure.

HRS Tower with Steam Injection Duct

CYLINDRICAL SHELL SUPERHEATER

Historically the duct from Pass 1 is the hottest metallic duct in a sulfuric acid plant. For the past 30 years, most plants have produced 750+ ^{o}F superheated steam in a superheater located after Pass 1. This superheater and duct are subjected to high levels of thermal expansion and stress. Duct, expansion joints, and superheater gas side casing failures have been numerous in this area on other plants.

A cylindrical shell superheater was selected for PCS 7 plant as the cylindrical shell is inherently stronger than a boxed unit of the same size and metal thickness. To help insure a robust design a finite element analysis was also performed.

A gas side bypass was used for temperature control. With this arrangement the tube wall temperature does not get as hot as a superheater with a water side bypass. As a result Cr Mo tubes were used to eliminate the stress corrosion problems associated with stainless steel tubes, which are normally used for the higher tube wall temperatures encountered with water side bypass.

Installed superheater in the plant

Superheater before shipment

MECS MIST ELIMINATORS

The towers were fitted with MECS Brink® Mist Eliminators. High Efficiency style ES Brownian collection beds were used in the Heat Recovery and Final Towers, and CK-1P impaction beds were used in the Drying Tower. The plant acid emissions were less than the design of 0.075 lbs/ton H_2SO_4 during the demonstration test and the sticks used in the stick test from all 3 towers were clean, as can be seen in the attached picture.

MECS ES Mist Eliminators in HRT

Stick Tests during the plant demonstration tests.

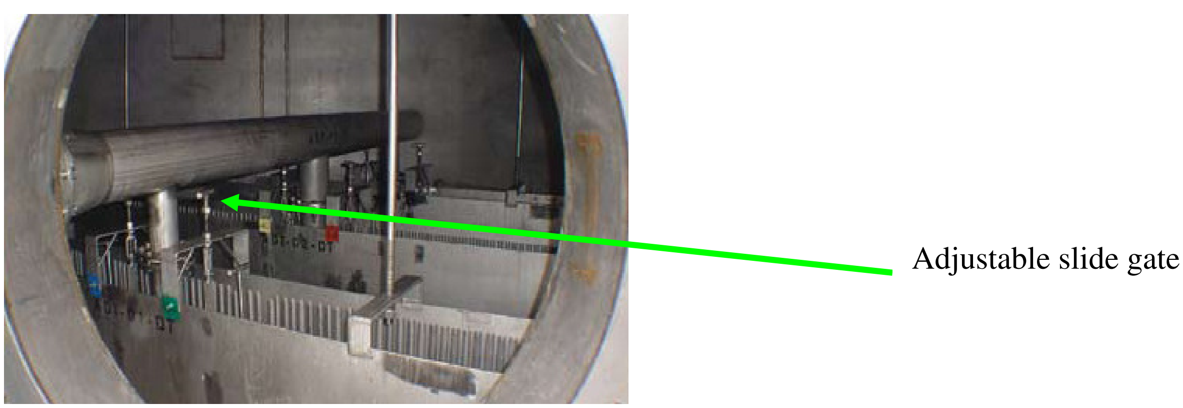
LOW PRESSURE DROP WAVEPAK PACKING IN DT AND FAT

MECS WavePak packing was used in the Drying and Final Towers. Wavepak has about 50 % of the pressure drop of the more traditional 3 inch saddles. It saves about 4 in wc in each tower. In a plant this size an 8-in wc pressure drop savings equates to 0.33 MW of power reduction in the main compressor. The annual savings at $50 MW-hr would be approximately $ 132,000.

MECS Uniflo Acid Distributors of ZeCor™ Alloy

The adjustable slide gates in the MECS Uniflo Distributors permit the operator to balance the acid flow to maintain uniform distribution over the towers. The distributors are fabricated from MECS ZeCor™ corrosion resistant alloy.

The Final Tower was fabricated from ZeCor™. ZeCor™ towers generally have lower maintenance costs than brick lined carbon steel towers.



The photo below shows sticks dipped at the end of each the seven troughs in the Drying Tower. The height of the acid in the troughs had a maximum variation around 1/2 inch which equates to a uniform flow with flow variations of less than 5% anywhere in the tower.

MECS Anodically Protected Acid Coolers

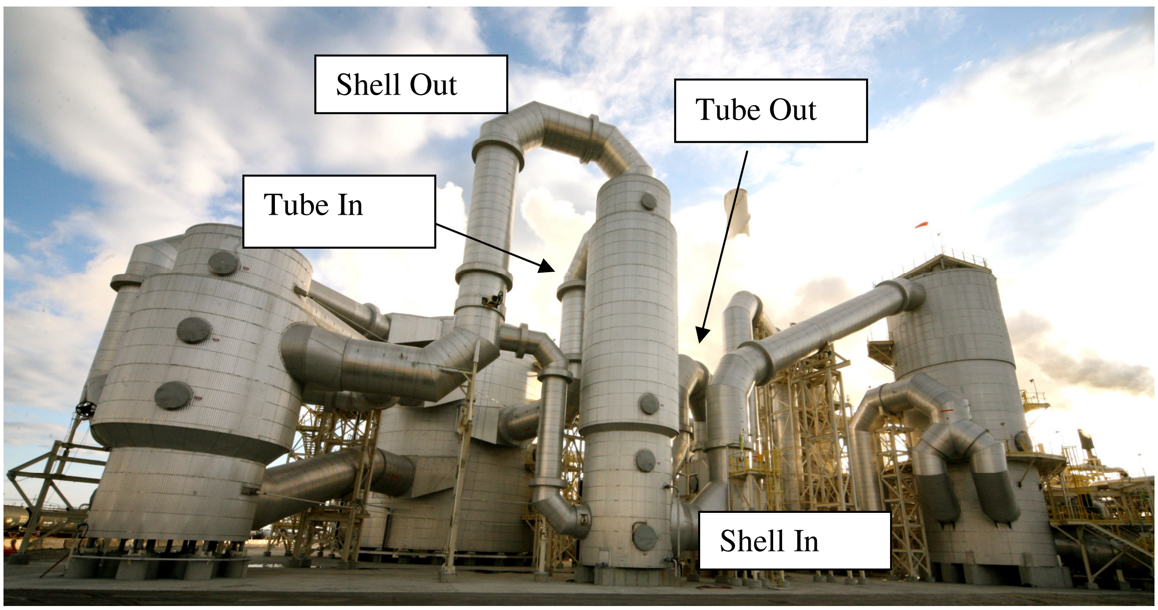
The Drying, Final, Product, and HRS Second Stage acid coolers are MECS Filmgard 5 anodically protected shell and tube heat exchangers. These coolers are expected to last the life of the plant. The anodic control systems are programmed into the Honeywell DCS. Plant operators can monitor the operation and change set points of the coolers from the DCS screens.

Final Absorbing, Product, and Drying Acid Coolers

RADIAL FLOW GAS / GAS HEAT EXCHANGERS

A disc and donut (radial flow) design was used for the Cold and Hot Interpass heat exchangers.

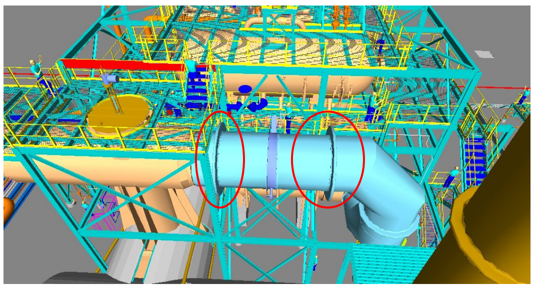
In the Cold Interpass heat exchanger the cold gas from the HRT enters the unit through the bottom core tube and flows upward through multiple shell passes. This arrangement improved plant layout and decreased overall vessel diameter as the shell side core tube inlets eliminated the shell side bustles which would have increased the diameter of this large exchanger. A disc and donut design provides an equivalent heat transfer to a segmental baffled design, with less pressure drop.



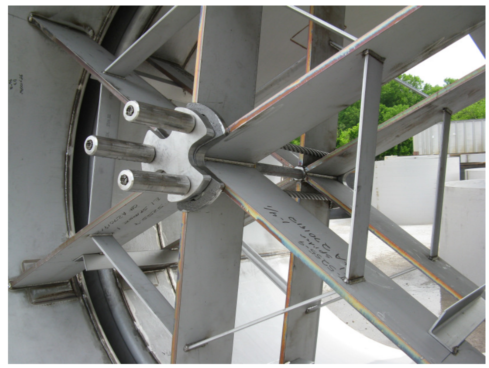
Cold Interpass Heat Exchanger

SWIVEL EXPANSION JOINT

The large plant size and expansion movements required special attention to thermal growth. MECS developed a Swivel Expansion Joint to use in place of a multi-bellows expansion joints when the thermal movement of the duct connecting the associated equipment was in more than one plane. An internal cable allows for multi-directional movement and also accounts for the internal pressure thrust being exerted from the single convulsion joint. This design eliminates the need for the external tie-backs that would be required when using a typical multi-bellows expansion joint.



Swivel joints in duct from Boiler to Pass 1 near Boiler Bypass Valve



Three cable expansion joint

PROJECT OVERVIEW

The PCS No. 7 Sulfuric Acid Plant was started up on January 26, 2010, and began operating at its designed capacity of 4,500 tons per day.

The project took 26 months to design, construct and prepare for facility start-up. Requiring 975,000 work hours, the project was completed without any lost-time injuries. The recordable incident rate was 1.82, well below the national average of 5.40.

Quoting Joel Rivers of PCS –"we had a few challenges here and there, but all-in-all, among the start-ups that I have been involved in during my 30 years of construction, it was a rather smooth start-up. We were starting-up a lot bigger plant than we are used to operating, so that comes with some different types of challenges. But from my view, I thought it went very well and our project came in under budget."

REFERENCES

K. Haywood   Sulfuric Acid Today   Spring / Summer 2010 Cover Story