Reducing Emissions and Meeting Marketplace Needs
A Review of a Plant Modification

Richard L. Davis, P.E. & James D. Carnes
Davis & Associates Consulting, Inc.
Lakeland, Florida

Presented at the
Central Florida Section of the American Institute of Chemical Engineers
Clearwater Conference
June 13, 2010

Reducing Emissions and Meeting Marketplace Needs
A Review of a Plant Modification

Richard L. Davis, P.E. & James D. Carnes
Davis & Associates Consulting, Inc.

This paper will examine how a sulphuric acid plant operator implemented plant changes to react to changes in environmental regulation and the marketplace. The paper will examine how technical options were evaluated and a plan was developed to meet their corporate objectives and governmental requirements.

The plant was built as part of the World War II war effort to expand the country's production capacity of ammonium nitrate. Over the years the site has been transformed to meet a changing marketplace. The sulphuric acid plant originally supported the production of concentrated nitric acid, which is not required now. Currently, the plant produces acid for the regional merchant acid market.

The plant owner was faced with increasing environmental concerns to reduce the sulphur dioxide and acid mist emissions from its sulphuric acid plant. Davis & Associates Consulting, Inc. (DAC) was retained to review the possible routes to reduce emissions. The paper will provide an overview of the abatement options considered.

After extensive review, it was decided that the conversion to double absorption was the best option. DAC offered various double absorption options and two cost estimates were developed. DAC was given the go ahead to finish the engineering on August 15, 2007 with a targeted start-up date of June 30, 2008.

DAC worked with Penn Pro of Mulberry, Florida, to perform the detailed engineering. With the tight project schedule the procurement of major equipment quickly became critical. The paper will review the project execution of this fast track project and how the owner and DAC put together an effective project team for the design, procurement, construction, and the successful commissioning of the plant.

Davis & Associates Consulting, Inc.

Reducing Emissions and Meeting Marketplace Needs
A Review of a Plant Modification

Introduction

This paper will examine how a sulphuric acid plant operator implemented plant changes to react to changes in environmental regulation and the marketplace. The paper will examine how technical options were evaluated and a plan was developed to meet their corporate objectives and governmental requirements.

This paper does assume that the reader has a basic understanding of the contact process for the production of sulphuric acid.

Background

An ammonium nitrate facility was built in 1942 as part the war effort. The facility included a single absorption sulphuric acid plant that supplied make-up acid for nitric acid concentration. The facility changed ownership a number of times, and the product mix has been changed. The production of ammonia was shut down and replaced with pipeline ammonia. Nitric acid capacity was increased and is now one of the plant's products. The nitric and sulphuric acid concentrators have been shut down, and the sulphuric acid plant now supplies regional acid consumers.

Environmental requirements for the facility have changed over the years. Environmental agencies wanted the plant owner to reduce sulphur oxides (SOx) emissions from the sulphuric acid plant and the owner retained Davis & Associates Consulting, Inc. (DAC) to review abatement options in 2003.

Sulphur Dioxide Abatement Study

Various abatement systems were reviewed, and the evaluation included a process review, order of magnitude capital estimate, and estimated operating costs. The design basis for process comparisons maintained the same production rate, assumed that the plant utility systems were adequate and that the abatement systems could achieve an emission rate of 4 lb of sulphur dioxide (SO2) per ton of acid produced. The following process schemes were reviewed:

- Ammonia Scrubbing
- Caustic Scrubbing
- Hydrogen Peroxide Scrubber
- Cansolv
- Activated Carbon
- Ion Exchange
- Tower (Modified Lead Chamber) Process

Adding Fifth Catalyst Bed
Double Absorption Conversion

Capital Cost Estimates

The summary of the capital costs is listed below:

	Capital
Fifth Catalyst Bed	0.8
Hydrogen Peroxide	1.4
Activated Carbon	1.6
Caustic Scrub	1.7
Ammonia Scrub	1.9
Ion Exchanger	2.7
Double Absorption	3.9
Cansolv	4.1
Lead chamber	6.0

The above capital estimates should not be used separately, but as relative comparison.

Potential for Increased Production

The two adsorption processes (Activated Carbon and Ion Exchanger) do not handle increased SOx levels easily.

Ammonia and caustic scrubber options can allow for increased acid and other saleable sulphur compounds, but as acid production increases, the production of other sulphur compounds increases at a faster rate. The existing plant can operate close to 98% conversion of SO2 to acid, and with a scrubber, 2% of the sulphur would be in the form of saleable products. If the acid production is increased the conversion to acid would decrease and the volume of saleable sulphur compounds would increase. For example, if the sulphur to acid conversion decreases to 96%, the production of other products would more than double.

Tower Process is well suited to increase acid production while maintaining very low emissions of SOx. The existing converter conversion efficiency would reduce if the production was increased, but the Tower Process can handle the increased SOx load while maintaining low emissions.

Cansolv can handle increased quantities of SO2, but there will be increased costs mainly associated with increased steam consumption.

Double Absorption conversion usually has the potential for increased production due to the fact of a higher concentration of SO2 can be fed to the catalytic converter with the double absorption conversion.

After reviewing the available process routes to reduce SOx emissions, the owner chose the conversion to double absorption.

Double Absorption Conversion

Background

The existing plant has a variable speed motor driven blower located before the air drying tower. The majority of the dried air was used to cool the process gas leaving the first catalyst bed of the converter. The preheated air was used as combustion air to the sulphur furnace. The furnace produced approximately 10 volume percentage concentration of sulphur dioxide (SO2) entering the first catalyst bed. After the furnace, the gas is cooled in a fire tube boiler that generates 350 psig saturated steam. The remainder of the dry air was used to quench cool the converter gases following the second and third catalyst beds. After the fourth bed, the gases are cooled by an economizer before entering the absorption tower.

The existing converter is sixteen feet in diameter with an overall height of 30'-9". The converter was loaded with a maximum charge of catalyst of 59,780 liters of catalyst distributed as follows:

	Catalyst Loaded (liters)
First Bed	15,680
Second Bed	12,000
Third Bed	15,300
Fourth Bed	16,800
Total	59,780

The mechanical integrity of the converter was questionable. There was antidotal evidence that portions of the shell were very thin. There was a broken cast iron grate under the third bed that was stabilized years ago, but the new and hotter future process conditions created some concerns.

The arrangement of the supporting cast iron posts obstructed the possibility to install an internal refractory liner to protect the converter shell from the hot (1130 - 1150°F) process gas following the first catalyst bed. Individual sections of refractory were installed between the support posts that protected some of the shell, but sections would routinely fail. The new process conditions would increase the first pass outlet temperature and the refractory liner would help to protect the converter shell.

The second catalyst bed was not performing as expected. It was believed that catalyst had shifted, causing a thin region to develop and reducing the bed's performance, but the same loss of performance could have been caused by a partially collapsed catalyst gird support.

Asbestos was present in areas of the converter and its insulation system that must be handled appropriately.

Options Reviewed

The existing converter was not large enough or suitable for the planned double absorption conversion. A converter replacement or a modification to the existing converter would be required to meet the requirements for double absorption. To optimize the full potential of the acid plant, a new converter would be required. It was determined with a new converter the plant could operate at 550 stpd. This would require a minimum of approximately 88,800 liters of catalyst with the following distribution:

	Catalyst Loading (liters)	Catalyst Loading (liters/stpd) [1]
First Bed	15,000	27.3
Second Bed	18,600	33.8
Third Bed	30,200	54.9
Fourth Bed	25,000	45.5
Total	88,800	161.5

1. Based on daily production rate of 550 st per day

This equates to 161.5 liter per daily short ton of acid produced based on a converter feed gas of 11.8% sulphur dioxide to the converter.

The existing water cooling system was limited and was operating beyond the design conditions of the cooling tower system. Any additional production would increase the heat rejection to the system that could not be accommodated by the current cooling water system. All options reviewed would increase the production rate and include a new cooling tower system.

Two options were developed to achieve the conversion of the plant to double absorption:

- The first option uses the existing converter with its limitations and risks that limits the potential production to approximately 400 – 450 stpd
- The second option replaces the converter in addition to the conversion of the plant to double absorption. The production was estimated to be 500 – 550 stpd.

With each option the process review included process analysis, process flow diagrams, equipment list, process description, utility usage, preliminary general arrangement, and capital cost estimates.

The owner ensured that the electrical and steam distribution systems were adequate for the project requirements. All of the existing utility systems were determined to be adequate by the owner.

Case 1 – Modified Existing Converter

The objective of this case is to convert the plant to double absorption and maximize the sulphuric acid production utilizing the existing converter.

The existing converter has limited capabilities and its continued use carries risks with the double absorption conversion project. These issues are

- Converter was not designed as double absorption converter
- There is existing structural damage in the No. 1 Bed outlet region.
- Process temperatures in this bed will increase
- Limited volume for catalyst

With these limitations, the full potential production capabilities of the rest of the existing equipment could not be fully developed. .
This option was estimated to produce 400 – 450 stpd of sulphuric acid with SO2 emissions less than 4 lb of SO2 per ton of acid produced. The existing converter was loaded with 59,900 liters of catalyst, but to meet the full potential a minimum of 63,800 liters would be needed in the first three catalytic stages. In addition, the existing converter was not originally designed to provide indirect cooling between the second and third catalyst beds required to achieve the plant's full potential. Also, there was no means to positively isolate the gases before and after the interpass absorption tower. Positive isolation prevents sulphur trioxide (SO3) by-passing of the interpass absorption unit, which is crucial for the conversion efficiency needed to produce the required emissions of SO2.

To provide cooling after the second bed required the reduction of the third catalyst bed level to provide necessary space on the converter shell to install a new gas nozzle. Two, 50% flow sized, ducts would be installed to direct the process gas leaving the second catalyst bed to a new steam superheater to cool the gas before entering the third catalyst bed. From the superheater the gas entered the converter through a new gas nozzle. With the reduction of the existing third bed level the converter now can hold the following catalyst charge:

	Catalyst Loading (liters)	Catalyst Loading (liters/stpd) [1]
First Bed	15,000	33.3
Second Bed	12,000	26.7
Third A Bed	8,700	-
Third B Bed	16,800	56.7
Total	52,500	116.7

1. Based on daily production rate of 450 st per day

The existing converter modified to be a three stage converter with the third stage being divided into two beds. The shortened third and the existing fourth bed create the third stage.
A new stand alone one bed converter will be installed to convert the remaining SO_2 following the interpass absorption tower. The new converter would initially be charged with 20,500 liters of catalyst, but was designed to handle more than 32,000 liters of catalyst. This provided the following distribution of catalyst:

	Catalyst Loading (liters)	Catalyst Loading (liters/stpd) 1
First Bed	15,000	33.3
Second Bed	12,000	26.7
Third A/B Bed	25,500	56.7
Fourth Bed	20,500	45.6
Total	73,000	162.2

1. Based on daily production rate of 450 st per day

A review of this distribution compared to the optimized distribution shows that the second bed has less than the optimum catalyst charge. The second bed of the existing converter is fully loaded and there is no room for additional catalyst and this is the major area that limits the production to 400 – 450 stpd.

The heat available from the outlet of the first and the third catalyst bed would provide the necessary energy to reheat the gases exiting the Interpass Absorption Tower to the fourth stage inlet temperature. A new economizer would further cool the gases between the cold IP heat exchanger and the interpass absorption tower. An interpass absorption tower, mist eliminators, acid pump, cooler, pump tank would be added. Two gas-to-gas heat exchangers would be added to reheat the SO_2 gas returning from the interpass tower before entering a new one stage converter.

The facility had no need for superheated steam produced by the new superheater; therefore, a desuperheater was included to reduce the steam temperature before being exported.

The sizing basis for all equipment would be based on a production rate of 550 stpd. Therefore, if the converter is replaced in the future, the full potential of the plant could be obtained.

Case 2 Converter Replacement/ Maximum Production

The existing converter has limited capabilities and adds risks to the double absorption conversion project. These issues are:

- Converter was not designed as double absorption converter
- There is existing structural damage in the No. 1 Bed outlet region.
- Limited volume for catalyst

With this option, Case 2, the converter will be replaced with a stainless steel converter sized for a production rate of 550 stpd. The process configuration would include a fire tube boiler to cool the process gas between the first and second catalyst beds. Following the second bed, the Hot Interpass Reheat Heat Exchanger will cool the process gas before entering the third bed while reheating the process gas from the interpass tower before entering the fourth bed. From the third bed the process gas will be cooled by the Cold Interpass Reheat Heat Exchanger and a new economizer before the gas enters the interpass absorption tower. From the tower the gas will be reheated by the Cold and Hot Interpass heat exchangers before re-entering the new converter fourth catalyst stage.

The same interpass absorption tower, mist eliminators, acid pump, cooler, pump tank as in Case 1 would be added with this case.

Project Evaluation

The two evaluations and the cost estimates were provided to the owner. A summary of the two options is shown below:

	Downtime Required (Days)	Production (stpd)	Cost Estimate ($)
Case 1	14	400-450	7.14 million
Case2	21 – 28	550- 550	9.16 million

The owner chose Case 1 that required less plant downtime and the lower production potential and the lower capital requirement.

Project Execution and Timetable

DAC is a small firm and had to form a team to support the project requirements. DAC provided project management and process design services. Penn Pro provided detailed engineering services. DAC retained Ben Trusty to be DAC's project manager. Mr Trusty has an extensive background with sulphuric acid projects.

The owner was responsible for the procurement of all equipment. DAC assisted with the technical review of the quotations and reviewed vendor drawings and other documentation.

The owner hired a local general mechanical contractor and an electrical contractor to construct the plant.

While DAC is a small firm, it is very experienced and knowledgeable with sulphuric acid technology. DAC and the owner both wanted a successful project. This required full cooperation of the parties and the obtaining the best equipment that meets the project requirement, performance, cost and delivery. The owner has been operating this site for many years and has established many relationships with equipments vendors and suppliers. These contacts were solicited for this project. Many of these established providers were used, but without soliciting many other offerings and sometimes being totally declined by established vendors. These economic times were very challenging for all.

With many projects the technology provider puts many restrictions on its clients to use specific technology and their products. This is normally tied to process guarantees that force clients to buy equipment at above fair market value to receive guarantees, which typically increases the total technology fees paid for the project. With this project all equipment was open to a fair, but time constrained solicitation. The project requirements remained a focused objective.

After competitive solicitations the project ended with the following major equipment vendors:

Vendor	Equipment
Acid Pipe Technology	Acid Piping
Kentube	Superheater
Lewis Pump	Acid Circulation Pump
MECS	Catalyst, Mist Eliminator
Mercad	Acid Cooler
Noram	Gas-to-Gas HEX's

Date	Description
2-1-2007	DAC contacted concerning double absorption conversion
2-17	Plant trip completed to discuss the project
2-24	DAC submitted proposal to review two options
3-7	DAC's Received purchase order
5-1	Delivered Final Report
5-4	Met with owner to discuss Final Report
8- 13	Given go ahead to finish engineering for Case One
12-10	Decision for DAC design absorption tower
4-4-2008	Final PFDs and P&IDs issued for construction
?	Construction begun
7-30	Mechanical specs and mechanical equipment manuals issued

8-18 – 8-21	Operator training performed
9-4	Plant shutdown started
9-25	Plant heat-up started
9-28	Leaks in new economizer during dry blows
9-29	Re-started heat-up; on sulphur
10-1	After short outage for repairs, plant on sulpur again

Challenges

Time

Existing Plant Documentation

Plant documentation, as with many older plants, was not complete. Field verifications were necessary for all of the tie-ins. Many tie-ins were between insulated ductwork so that their exact locations were never accurately determined. The ductwork was designed to allow field fit-up.

Converter

The uncertainties of the converter always loomed over the project. The plant could not be started up again until the converter's integrity was established and the necessary repairs were made.

In the spring of 2008 the plant had an opportunity to obtain metal thickness readings from several regions of the converter. The readings showed no significant deterioration of the converter shell, but with the limited readings there was still some concern.

The existing two converter gas nozzles to and from the air preheater were directly over each other on the West side of the converter. It was known that there were a number of gas leaks at the first pass outlet connection. The new Hot Reheat Heat Exchanger was being located further south than the existing air preheater. By installing a new first pass outlet at a new location, we eliminated the unknown condition of the old nozzle. A new 304 stainless steel nozzle and transition piece was built to connect to the new Hot Reheat Heat Exchanger to the south. This change reduced some of the uncertainty of the mechanical integrity of the converter.

Underground surprises

During the excavations, long ago abandoned structures were found. The excavation of the new Water Cooling Tower revealed an abandoned sulphur pit. The main foundation excavation found an undocumented foundation and concrete culvert. These items increased costs and time.

Procurement of Equipment

The overheated economy of 2007- 2008 limited vendor responses, and responses indicated increased costs and extended delivery times. Many traditional vendors refused to bid or their offers did not meet the project requirements.

Acid Tower

The owner had been approached by an acid brick provider that suggested that it could deliver a fully bricked tower to the site at a "very economical" price. The project scope was based on this concept. After the acid brick provider submitted its "very economical" price, which was more than 50% over our estimated costs. Four months into the project it was decided for DAC to provide the complete mechanical design of the tower and all of the internals. The tower was supplied on budget and time even with the late commitment.

Construction Plan

The double absorption conversion must be located as close as possible to the existing plant, but also be constructible. There was area to the East of the plant that was reasonably clear. An old acid tower concrete structure had to be removed. The site was limited, but provided a relatively clear site for the construction of the majority of the conversion. An area of approximately 54 x 65 feet provided space for two reheat heat exchangers, new economizer, interpass tower, pump tank, acid cooler, and an one stage converter. The entire area was built on a monolithic concrete foundation. The area was accessible while the plant was in operation.

The superheater was located adjacent to the converter and could be constructed while the plant was in operation.

The water cooling tower was constructed north of the plant and was put into service months prior to the plant shutdown for the major tie-ins.

At the shutdown, the insulation of the converter was going to be totally removed to allow for a complete review. The air preheater had to be removed to allow for the installation of ductwork connected to the new Hot Reheat Heat Exchanger. The duct from the existing converter to the economizer had to be removed and the new ductwork reconnected.

Start-up

The plant shut down in early September for its planned turnaround and to make tie-ins for the project. The converter turned out to be in better condition that many had thought. New plate was already required at the first pass outlet nozzle due to the relocation of the gas nozzle, but the plate damage extended several feet beyond. This area of plate was replaced.

Summary

The approach undertaken allowed the plant owner the best prices and the best technology to suit the requirements of the project.