Application of Modern Sulfuric Acid Tower Technology

by

Koch, Cecebe and Cargill

Modern tower technology was successfully demonstrated in a recently installed interpass absorption tower at Cargill's No. 7 sulfuric acid plant, East Tampa, Florida. The brick-lined tower featured a low pressure drop self supporting dome packing support, 8 ft. deep high performance FLEXERAMIC® structured packing with 2 ft. layer of random ceramic saddles at the top uniformly irrigated by a well proven no-splash SMART™ acid distributor and candle type mist eliminators to prevent acid entrainment.

The greater throughput capabilities of the dome support, the structured packing and the acid distributor resulted in a lower pressure drop. Good acid distribution at the top, better liquid wetting, and improved radial gas and liquid distribution characteristics of the structured packing increased the absorption efficiency sufficiently to allow a much shorter bed. This translates to approximately 30% increase in absorption efficiency with negligible acid entrainment and no SO_3 slippage.

There appears no danger of flooding in the tower. The combination of the dome support, structured packing and no-splash acid distributor has proven highly successful.

I. Abstract

II. Introduction

A. Overview of installation

B. Reasons for using equipment we did

C. What we accomplished

D. Future work and observations required

III. Discussion of Equipment Design, Operation, Features, and benefits relative to traditional equipment.

A. Distributor

1. Description

- *a) construction details (need photos for presentation)*

2. Features and Benefits

- *a) Process design*

3. Comparative advantage to traditional designs

- *a) Compare to typical pipe lateral design and trough design*

B. Packing

1. Description

- *a) Construction, material*

2. Features and Benefits

- *a) Low Pressure Drop*
  - (1) Higher Throughput,
  - (2) Better absorption
  - (3) Lower energy consumption
  - (4) Packing stability

b) ***Good vapor and liquid distribution***

(1) Good wettig characteristics

(2) Good radial mixing characteristics

c) ***Reduced Liquid Entrainment***

(1) Less splash

(a) *Improved Eficiency*

(b) *Improved mist eliminator perfromance*

(i) Lower Pressure drop

(ii) lower corrosion of downstream equipment

(iii) Improve stack emmissions.

d) ***Reduced Fouling / Cleaner Acid***

(1) No Horizontal surfaces

e) ***High Efficiency***

(1) Lower HTU's

(a) *Higher Mass transfer coefficient*

(b) *Above characteristics all improve efficiecny*

3. **Comparative advantage over saddles**

a) ***Review above features and summarize advantages vesus saddles, i.e. random type packings.***

C. ***Dome Support***

1. **Description**

2. **Installation**

a) ***How it was installed, time to install, strength (determine maximum allowable load)***

3. **Comparative advantage over beams and intermediate supports.**
    - a) *Discusss vapor distribution*
    - b) *Lower pressure drop*
    - c) *Eliminate possible source of flooding*

IV. Conclusions

A. *What we learned*

1. **FLEXERAMIC® works**
    - a) *It operates as predicted from a hydraulic perspective*
    - b) *The efficiency well we don't know*

B. *How we would improve the design*

1. **Eliminate partition rings**

C. *Future work*

1. **Determine HTU's or Kga. at various L/V points**

D. *Use collected data to construct a design procedure to better optimize the tower design.*

E. *Experience to date*

1. **Koch Riverton, WY plant operation**
    - a) *Four years without any problems*
2. **Work in progress**
    - a) *Coulton Chemical - spent acid recovery*
    - b) *Asarco - Smelter*

Introduction

This paper will review the design, construction, installation and operation of an intermediate absorption tower (IPAT) that was built and erected at Cargill Fertilizer's Riverview facility during the summer of 1995. The total time for the internals to be installed was 60 days; a gant chart is given in fig. 1 in the appendix. This tower is part of Cargill's No. 7 H_2SO_4 plant which is rated at 2100 tons/day. The acid and gas flow rates are approximately 5000 gpm and 141,000 ACFM, respectively.

The focus of the paper will be highly qualitative consisting of a comparative discussion between a traditional acid plant design and one with modern equipment to highlight the possible improvements. This is obviously a commercial installation and not someone's research project. Therefore, the type of monitoring and data acquisition equipment needed collect massive amounts of quantitative was never installed, and, as mentioned never our goal.

With this said, here is a brief overview and description of the project. The tower is 20.25 feet in diameter by 47 foot tall carbon steel shell with a brick lining. Between the steel shell and the brick is a Teflon®[1] liner applied with mastic. Another type of liner that is often used is Pyroflex®[2]. It is rubberized asphalt material approximately 1/2" thick that is easily installed in the field. It is ideal for corrosive services such as H_2SO_4 because there are no overlapping seams for acid to get behind. The liner is literally melted as it is applied to the tower shell. Where the ends come together they are melted together to eliminate the seam; thus, forming a continuos liner and eliminating any possibility of an acid leak. The tower sits on an elevated stilt-like concrete structure The tower internals used are unique and state of the art, consisting of a Smart™ Acid Distributor by Cecebe Technologies, FLEXERAMIC®[3] structured ceramic tower packing, and a ceramic support dome both manufactured by Knight/ Ballard. Knight manufacured the acid brick too. Knight /Ballard Field Service installed the brick lining system and all the other tower internals.

Every aspect of the tower's design emphasized the need to minimize the pressure drop across its internals. Doing so will maximize the total system pressure and the mass transfer efficiency since the driving force for mass transfer is pressure gradient / difference between the system pressure and vapor pressure of the solute gas, SO_3. Other important process considerations were distributing the acid and gas uniformly across the tower, and minimizing the amount of acid entrainment to ensure maximum acid mist removal from the candle type mist eliminators placed at the top of the tower and their pressure drop as well . We felt that if the above goals were met the operation of the tower would be optimized.

By ensuring proper gas/liquid distribution and minimizing the pressure drop, the absorption efficiency would be dramatically enhanced. To a certain extent this was

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[1] Teflon® is a registered trademark of the El. DuPont Co.

[2] Pyroflex® is a registered trademark of the M.A. Knight Co.

[3] Flexeramic® is a registered trademark of the Koch Engineering Co., Inc.

proven to be true but more work needs to be done to precisely determine the height of a transfer unit, HTU per foot, or the mass transfer coefficient, Kga. This will help optimize future absorption tower designs. This design is still quite conservative with a lot of over design built in.

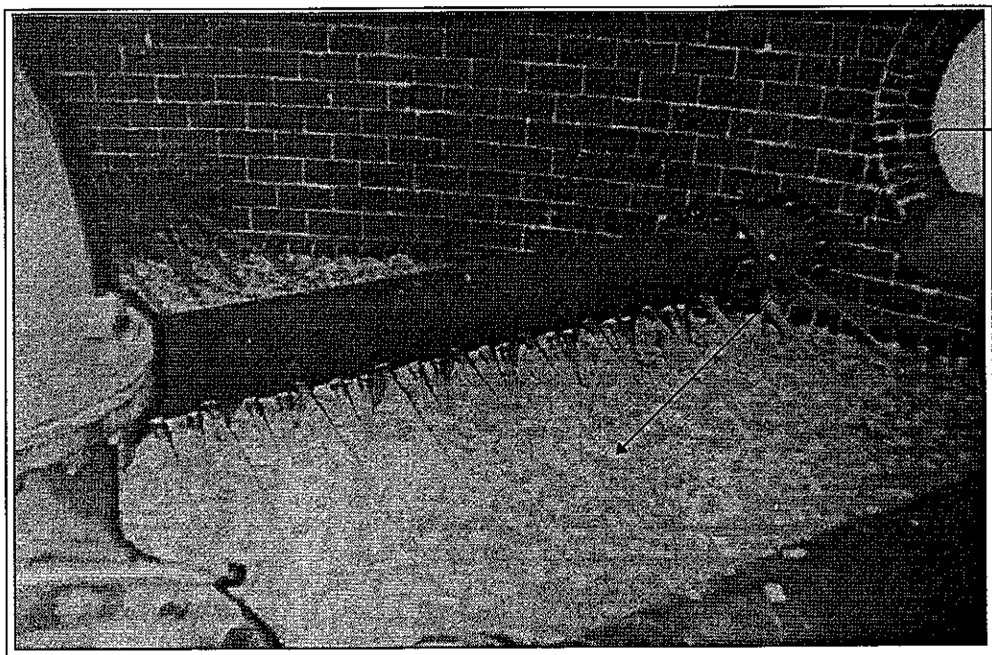
One set back that was not anticipated was an operational upset that occurred several weeks after initial start-up. About three to four weeks after the tower was commissioned the acid plant was brought down for a boiler tube leak. When the plant was being started the furnace temperature was not sufficient for sulfur combustion and elemental sulfur was introduced into the downstream equipment. The sulfur found its way to the IPAT plugging the candle type mist eliminators, possibly packing and or acid distributor. The mist eliminators are easily replaced and were. The packing and distributor are considerably more difficult to replace. As such, to date they have not been replaced or inspected. This has led to very poor acid distribution within the packed bed, and as a result there is some SO_3 bypass. The bypass has not hurt production. Therefore, there is not sufficient need to shut the plant down to inspect and possibly remove the packing or clean the distributor. To help isolate the acid distribution problem to either a plugged distributor or fouled packing we attempted a tower scan which is somewhat like an x-ray to get a peak inside the tower without having to go inside. The scanning service was provided by Koch Engineering's Tru-Tec Division.

The utility and advantage of scanning the tower is that it is performed from outside the tower without having to shut the plant or putting personnel at risk. The technique is rather simple a radiation source is placed on one side of the tower and a detector directly opposite the source measures the intensity of the radiation. The intensity is greatest where the packing is dry that is acid is bypassing that section and least where acid is flowing. Eventually, after many readings from different chord positions and elevations a tower profile is established which shows radiation absorption gradients/ acid flow gradients within the tower, or where the acid is and is not. The goal is to pinpoint the section of the tower where the problem exists and develop a strategy to work around it or fix it. Great idea in theory, but poor idea in reality. The scan was performed but the data collected was highly suspect since some of readings conflicted with known physical features of the tower. So the tower keeps running but we still do not know why the tower is bypassing SO_3.

Distributor

Overview. The acid distributor used for this IPAT was a Cecebe Technologies Smart™ Distributor. As with all the tower internal components, their distributor emphasizes low pressure drop. This truly unique distributor, however, has some other very important characteristics that should also be examined to gain an appreciation for the elegance of the Cecebe's design .

Description. The Smart™ Distributor was designed to take advantage of the good design features of existing distributor designs without any of the negatives. In addition, the mechanical design was kept very simple to facilitate on site assembly and for ease of routine maintenance. The distributor is constructed from pipe spools fabricated from L-14™[3] enabling easy assembly within the tower. The number of laterals are kept to a minimum by the use of downcomers. These downcomers (see photo below) consist of a nominal 1" diameter Teflon® tubing heat shrunk onto a serrated fitting with a male pipe thread, fabricated from Lewmet™[4]. Notice that the other end of the tubing is buried beneath the random saddles to eliminate acid from splashing up into the gas stream. Although, not readily apparent from the photo the laterals are on about 75" centers and the downcomers reach to the required drip point locations, see fig. 2 in the appendix for a detailed layout. This minimizes the amount of cross sectional area occupied by the distributor; and therefore, the pressure drop.



Downcomer is buried beneath packing to minimize splash

Cecebe Technologies Smart™ Distributor

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[3] L-14 is a trademark of the Chas S. Lewis Pump Co.
[4] Lewmet is a trademark of the Chas S. Lewis Pump Co.

Process Features. Cecebe determined that the main problems with current distributor designs were: One, difficult to install, maintain, and had limited turndown - trough type distributors, or they needed to be buried within the packing - traditional pipe lateral. A further comparison follows for the three distributor designs mentioned.

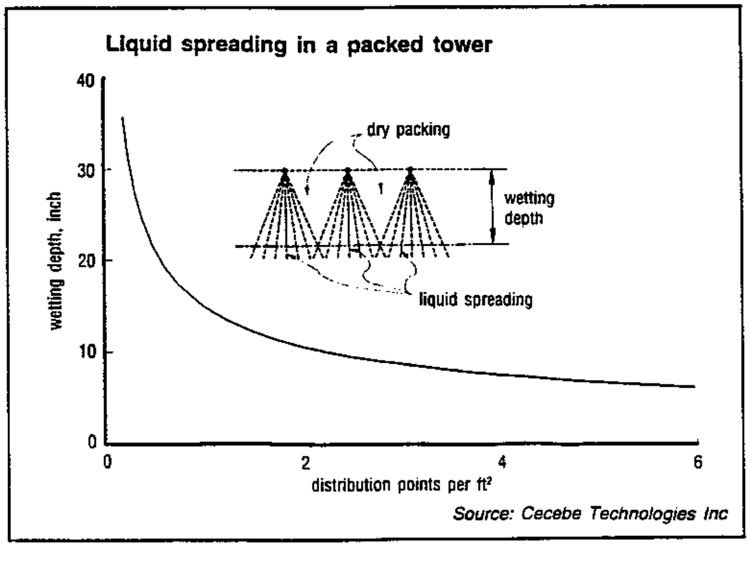
Pipe Lateral Distributor:
- Not Sensitive to leveling
- Good turndown
- Uneven distribution pattern
- Acid delivery creates mist/spray
- Tower blockage (30-50%)
- High Pressure Drop
- Acid Entrainment
- Difficult to Clean
- Corrosion of cast iron units
- Alloy units sensitive to acid strength

Trough Type Distributor
- Uniform distribution pattern
- Acid Delivery without mist/spray
- Sensitive to acid flow/ leveling
- Poor access to packing
- Cleaning difficulty
- Occupies significant height
- Corrosion problems with cast iron unit
- High maintenance for cast iron units
- Alloy units sensitive to acid strength
- Complex and expensive

Cecebe Smart Distributor
- Uniform acid distribution
- Acid delivery without mist/spray
- Leveling precisely is not required
- Good turndown
- No tower blockage
- Proven materials of construction
- Less sensitive to acid strength
- Easy to clean and maintain
- Simple construction
- Cost effective

As can be seen in the above comparison Cecebe has been able to utilize the best features of available designs to create a new innovative hybrid design. One other feature that they have incorporated which is very important is an optimization of the drip point density per unit area.

From a review of the graph below, it becomes very apparent that adding more than 2 drip points per square will not appreciably improve liquid spreading. This means that current trough type distributors which will typically have 4 to 6 drip points/ ft^2 are over designed. This does nothing to improve the performance of the tower. It only creates a piece of equipment that is too expensive and complicated. The other important salient point to note from this graph is that fewer than 2 drip points/ ft^2 will hurt your mass transfer efficiency. The slope of the graph changes dramatically as the number of drip point decrease below 2/ ft^2, signifying the first few feet of the tower packing is now being used to distribute the acid, not absorb SO_3.



Source: Cecebe Technologies Inc

Results. We know the distributor functioned to its design potential for several reasons. One, the measured pressure drop across the packing, distributor, and support, 5 in. wc, was only fractionally higher than the pressure drop calculated for the packing alone. Two, the pressure drop measured across the mist eliminators was exactly as predicted at 5 in. wc. The pressure drop would have been significantly higher across the mist eliminators if there was excessive acid entrainment created by excessive pressure drop or splash from the distributor. Mist eliminators like any other device will have a higher pressure drop when the liquid occupies space intended for vapor/gas flow. Finally, there was complete absorbtion of the SO_3 which is not possible if the distributor is **not** doing its job, i.e. not providing a homogenous flow of acid to the packing below.

Tower Packing

Overview. The purpose of tower packing is to provide the maximum possible surface area between a liquid and gas at the lowest possible pressure drop. This will allow the real goal to be met - MAXIMIZE the mass transfer in the smallest possible column with the lowest operating cost. In essence, this provides the best engineered system solution since it provides the lowest cost. That is dollars invested for moles absorbed. FLEXERAMIC® is able to provide this solution due to its unique physical and geometric properties. A brief review of the pertinent equation and parameters when designing a packed tower should help clarify the discussion that follows.

$$Z = NTU \times HTU$$

Where:

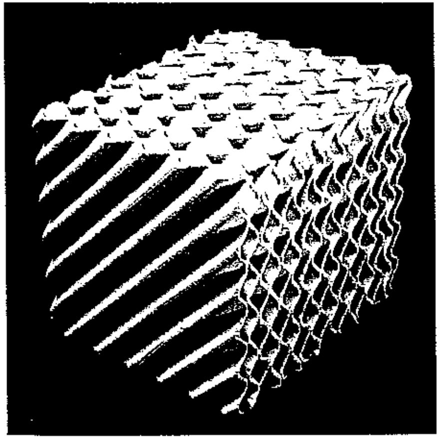
Z	Packed height, ft.
NTU	No. of Transfer Units (dimensionless)
HTU	Height of a Transfer Unit, ft.
K_G	Overall Mass Transfer Coefficient, lb-mole/hr.- ft^2-atm
a	Gas / Liquid Interfacial Area, ft^2/ft^3
S	Tower Cross Sectional Area, ft^2

NTU, The ln mean average of the concentration gradient within the tower of for absorption the difference between the system pressure and vapor pressure of the solute gas. The farther from equilibrium the smaller this number becomes. For a more complete definition see such standard texts as Geankoplis, G., J., Transport Processes and Unit Operations, Printice Hall, Englewood Cliffs, NJ, 1993 PP 619-627.

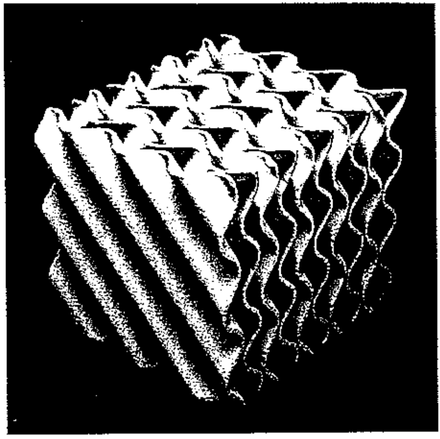
HTU, Mass flow rate of the gas (lb-mole/hr) / $K_G aS$

Keeping in mind the above, a brief description and discussion of Flexeramic will help to illustrate the advantages Flexeramic offers over random packing.

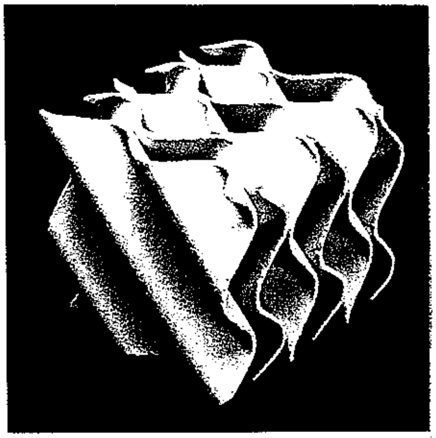
Description. Flexeramic is fabricated from clay, see the appendix fig. 3. for typical material composition and physical properties, that has been extruded into sheets and then fired in a kiln. Each sheet is approximately 1-3 mm thick with uniform undulations. The frequency and amplitude of the undulations can be varied to optimize the tower design, see the photos below.



FLEXERAMIC® TYPE 28. Higher efficiency (lower HTU) than 1-inch saddles, with capacity equivalent to 1.5-inch saddles.



FLEXERAMIC® TYPE 48. Better efficiency than 1.5-inch saddles, with more capacity than 2-inch saddles.



FLEXERAMIC® TYPE 88. Efficiency equivalent to 3-inch saddles, with much greater capacity.

When the sheets are stacked on top of one another the their undulations form channels. The channels on adjacent sheets run 90° relative to each other, or once installed in a tower 45° relative to the vertical tower axis, see fig. 4 in the appendix for a schematic of the channel orientation. The stacked sheets are supplied in 12" by 12" by 12" cubes, to keep the weight manageable, approximately 21 lb for Flexeramic 88.

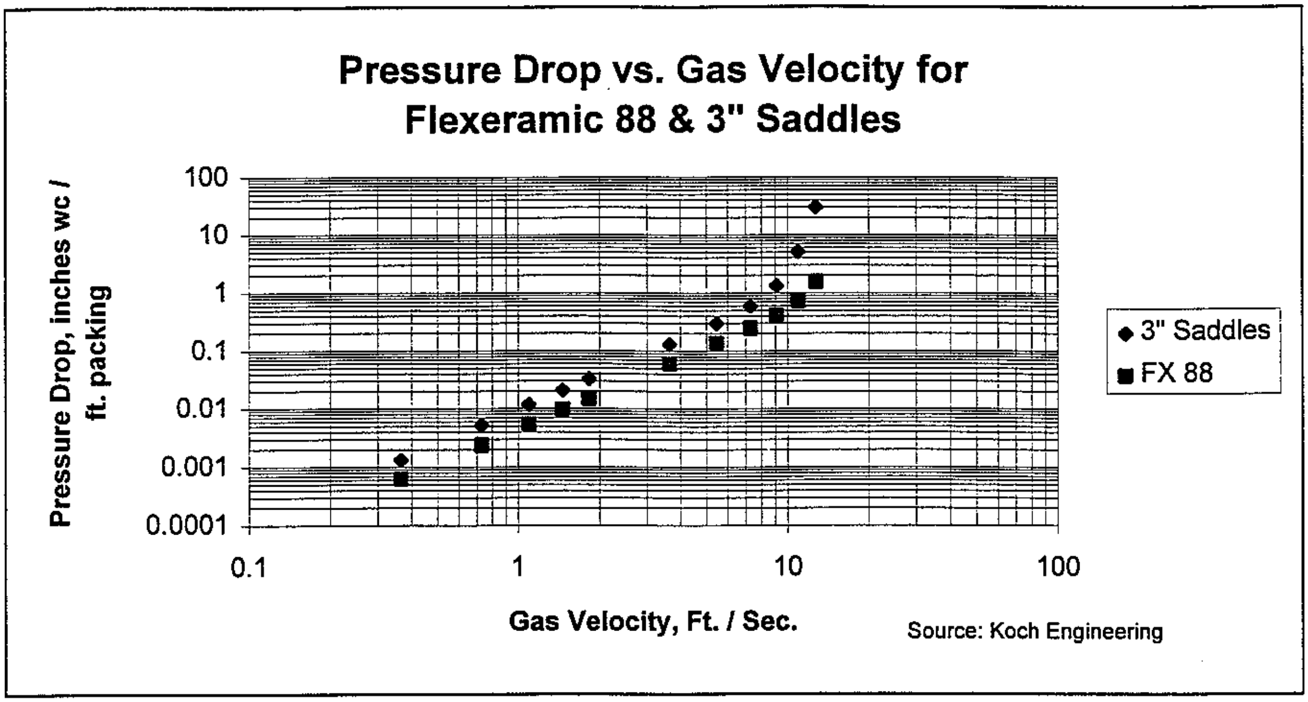
Process Features. The uniform undulations in essence creates a giant inline static mixer out of the packed section of the bed. This helps ensure the gas and liquid are evenly distributed across the tower diameter. By accomplishing this homogenization of the gas & liquid the surface area between them has been maximized; and thereby, so has the mass transfer coefficient. The overall mass transfer coefficient is well known to contain the interfacial area between the gas and the liquid, K_Ga. If the area is maximized then so too is K_Ga, and the smaller the HTU. Structured packing will tend to maximize whatever area is available. If the acid is properly distributed at the top the tower nearly 100% of the theoretical available will be utilized. Whereas, saddles can and do nest on top of each other effectively blinding off a considerable amount of area that is theoretically available for mass transfer. Saddles create a lot of horizontal surface area within the packed bed. These surfaces are extremely detrimental to the tower's overall performance.

Mist entrainment is greatly reduced without horizontal surfaces. As the downward flowing acid hits a horizontal surface its velocity and direction will change abruptly and violently. This energy that is released on impact will form acid spray and mist. At the top of the tower this acid is then entrained and carried upward into the mist eliminators above. When the acid entrainment is great enough the mist eliminators will flood causing acid mist to travel downstream fouling/ corroding extremely expensive equipment, if an IPAT, or out into the atmosphere, if a final absorption tower. Both outcomes will create a problem. Entrainment is amplified further if a traditional pipe lateral distributor is used since the gas velocity between the laterals can be significantly greater than the average velocity. The gas velocity is greater because the number of laterals is greater. The added laterals ensure the proper drip point density but "chokes" the flow area.

Another problem splash creates if it occurs within the tower is backmixing. Backmixing will decrease the local concentration gradient or driving force for mass transfer; thus, decreasing the efficiency of the packing. A deeper packed bed is often used to compensate for this effect. The downside is more packing height increases the pressure drop and reduces the efficiency of the tower further, a vicious circle now begins.

Without stagnant areas created by stacked saddles and without horizontal surfaces accumulation of particulate matter is greatly reduced. As evidence, Koch's Riverton, WY plant shows no iron sulfate accumulation within the tower which has been in operation since September 1993. In addition, the acid is cleaner after a plant start up than when saddles were in place.

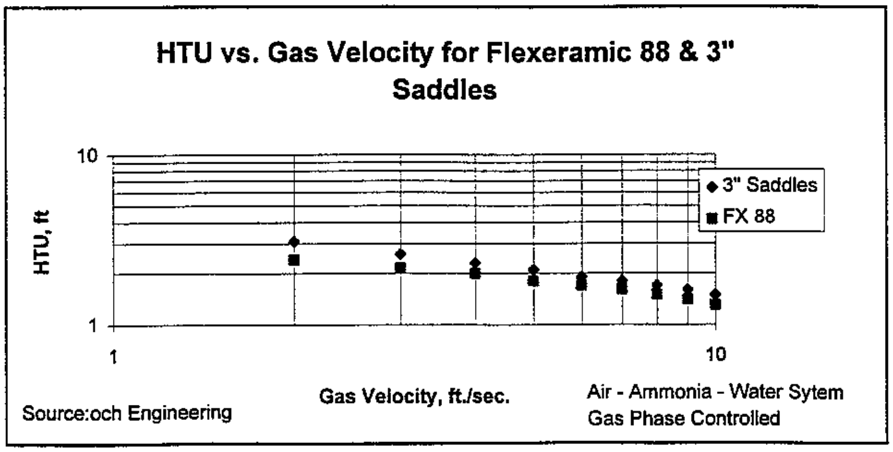
The pressure drop across a bed of Flexeramic is on average 50% less than a bed of comparably sized saddles, see graph below.



Source: Koch Engineering

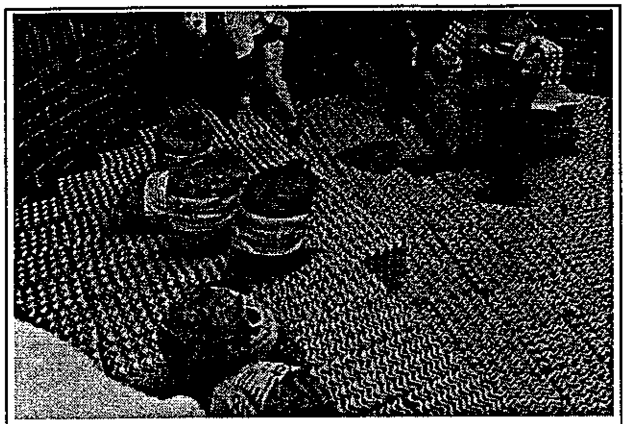
Given that the driving force for SO_3 absorption is the difference between the system pressure and the vapor pressure of the SO_3; the total amount of mass transfer must be greater with any packing that reduces pressure drop while keeping all other parameters constant. One, other interesting characteristic to note in the above graph is how the slope of the pressure drop curve rises almost to infinity as the 3" saddle packing becomes loaded with liquid. At about 11 ft/sec. the pressure drop for the 3" saddles is nearly 30 times greater than the Flexeramic's pressure drop.

The below graph shows how Flexeramic's performance improves with turndown relative to saddles. So if your plant is in a current over supply situation, cutting back production will not hurt the efficiency of the tower. Flexeramic gives the operator better turndown flexibility.



Source:och Engineering

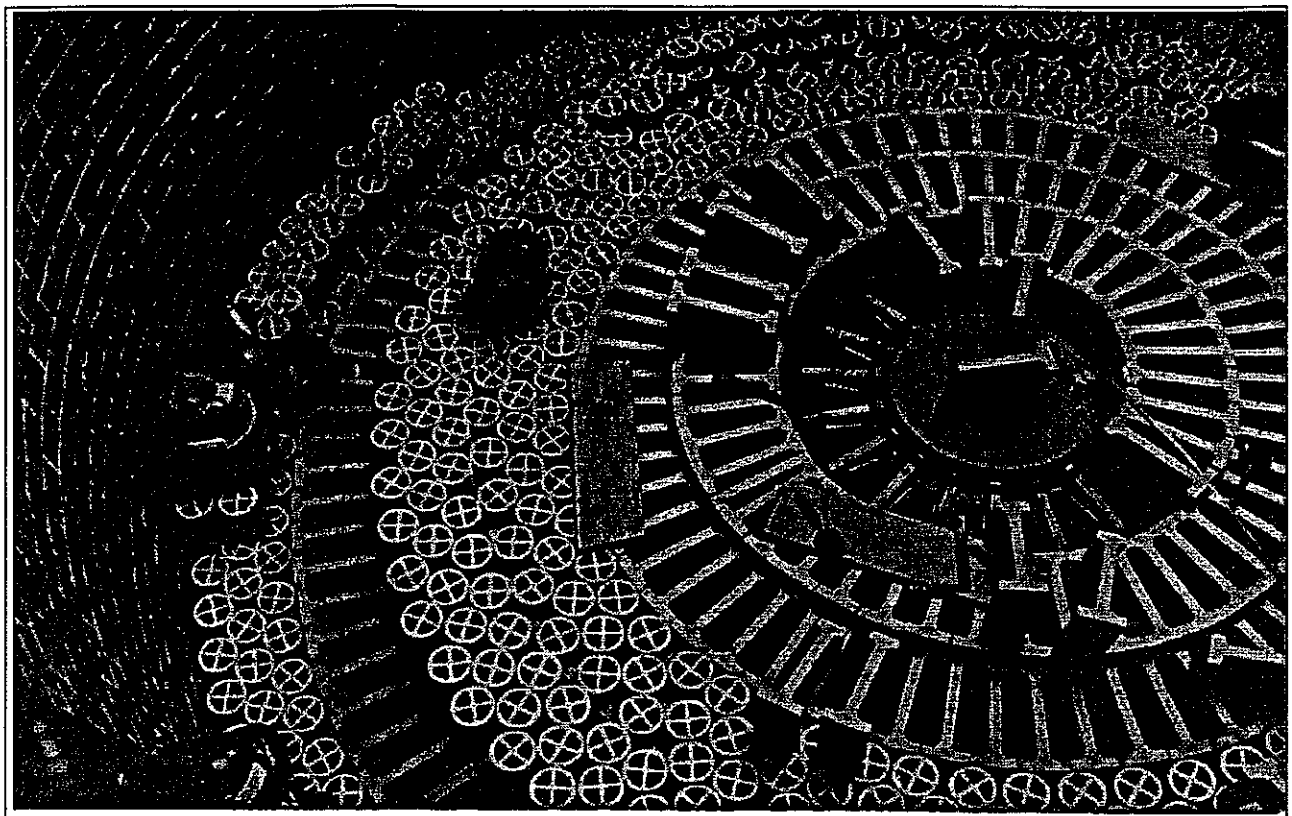
Installation. The packing was shipped on pallets three blocks across and three blocks high. The packing was left on the shipping pallets and lowered into the tower by overhead crane to speed installation. Each layer or element is completely installed before the next begun. To help speed fabrication of the structured packing only the bottom layer of packing was cut to the inside radius of the tower. The voids around the perimeter in the upper layers of structured packing were filled in with 2" saddles. Subsequent packing layers were rotated 75° to ensure there were no open vertical seams for the gas or liquid to short circuit the column. The Cargill tower was packed with 8 layers of Flexeramic which is equivalent to 8 feet. 18-24" of saddles were placed on top to act as an acid disengagement zone and to help establish additional drip points to fully spread the acid before coming in contact with the structure packing below. One partial layer of 6" & 4" partition rings were used to level off the dome support for the first row of Flexeramic to sit on. The tower was packed in approximately four days.



Flexeramic Packing being installed, note 75 Degree Offset to layer below

Packing Support

Overview. Rather than use beam and brick arches as the support structure Cargill selected a dome support. The dome was fabricated much like the ancient Romans built their bridges. Stone blocks, in this case little "I" beam blocks with the flanges angled / beveled at an angle so that each successive block offset vertically and horizontally to its neighbor, see fig. 5 in the appendix for an elevational cross sectional view illustrating the layout of the block. Work begins at the ends or perimeter for a tower until the middle is reached. A "key " stone is then put in place, this puts the entire dome into compression. The weight of the packing and dome is transferred to the vessel wall. As such, the vessel must be reinforced at this location with essentially a thick steel belt. With the "key" stone in place the temporary support scaffolding is then removed, leaving a dome support without any intermediate supports. Koch Engineering's M.A. Knight division designed, fabricated, and installed the dome. Installation took approximately 4 days.



Installation of dome tower packing support. Notice the shape of each block.

The strength and longevity of this design are well proven since Roman arch type bridges are still in standing today. In some cases these bridges are over two thousand years old. A better reference would be very hard to find. The compressive load the dome can support is extraordinary, typically 18,000 to 23,000 lb/ft^2 or more than 11 tons ft^2. A complete summary detailing the domes physical data and chemical composition is given in fig. 5 in the appendix.

Process Features. The dome design was not selected for its strength or longevity as such but for its "openness". The dome allows the gas entering the tower to fully expand and evenly distribute across the tower diameter. In addition, the dome does not choke the gas flow. The dome occupies only 40% of the cross sectional area of the tower. Whereas, a typical arch support system might occupy over 50% of the available area All this means is the pressure drop across the dome is less and the tower packing sees an even gas flow. Thus, maximizing the efficiency of the absorption process.

The arch supports can actually be more detrimental to proper tower performance than creating a slight pressure drop increase. This design can channel the gas up one side of the tower so that the gas velocity is not just 10% higher but maybe 50-100% higher than the calculated average. Therefore, the pressure drop might well be over 4 times higher with the arch supports since the pressure drop is proportional to square of the gas velocity. This higher pressure drop alone is bad enough but regions of excessively high gas velocity can create localized regions of instability within the packed bed and flooding in the lower portion of the tower. Flooding typical occurs in the bottom portion of an absorbtion tower because the gas loading in highest there. It has not been absorbed. Once flooding occurs the mass transfer efficiency quickly drops.

Results. The dome helps to ensure a homogenous gas distribution to the tower packing with a minimal pressure drop. The proof is that the measured pressure drop across the dome, packing, and distributor was only fractionally higher than across the value predicted for the packing alone. In addition, there was no sign of SO_3 bypass during initial operation. This means the tower packing was being fully utilized for mass transfer.

Conclusions

We know column design works. Unfortunately, the installation has raised many more questions without ready answers.

The towers hydraulics were accurately predicted from existing correlations. This was readily proved from actual operating pressure drop readings However, can we operate at a lower acid recirculation rate than 5000 gpm (15 gpm/ft^2) while keeping the gas rate constant? Maybe. Additional work needs to be done to determine K_Ga / HTU.

We know that 8 ft of structured packing with two feet of saddles on top is adequate for complete absorption. However, can we use only 6 feet of structured packing next time? The answer again, maybe. We need to determine HTU as a function of liquid and gas rates.

Can we take advantage of the lower pressure drop of the structured packing? We might be able to build a smaller diameter column with a pressure drop comparable a to a larger diameter tower packed with 3" saddles.

With better gas distribution at the bottom of the tower due to the dome's more open structure can we shorten the bed depth and shorten the tower? Maybe.

We have lots of answers but a lot of questions too which is good but we have a long way to go before we can design that theoretically optimum H_2SO_4 absorption tower. May the next installations in the coming months will help answer a few questions. These installations will be interesting because they are not sulfur burning plants. One is a spent acid recovery plant and the other is a smelter application.

Future Work

We need to <u>quantify</u> the <u>qualitative</u> features of the packing.

How well does the packing radially spread the acid?

Does it spread the liquid sufficiently to reduce the height of the saddles which are being basically used as a distributor?

Can we simplify the Cecebe distributor by decreasing the number of downcomers?

What is the acid entrainment rate (lb/hr) from the packing?

How well does the bottom section of the packing distribute the incoming gas?

Everything points to absolute necessity to develop a correlation for K_ga/HTU as a function of liquid rate and gas rates. This, unfortunately, may not be readily forthcoming. It may have to be an evolutionary process where we push the design envelop a little more with each new installation. Time will tell.

Experience

The Flexeramic installation at Koch Sulfur's Riverton, WY plant continues to function properly. It was put into service September 1993.

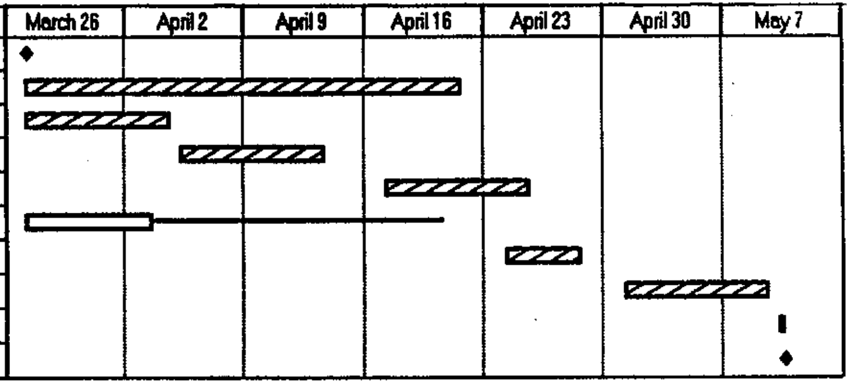
Coulton Chemical will be installing Flexeramic at their Cairo facility in early July 1996. The Cairo facility recovers spent acid from a nearby refinery.

Asarco will be installing Flexeramic at their El Paso facility in late August / early September 1996. It will be installed in their IPAT tower. The purpose is to increase the gas flow rate through the tower by 40%.

APPENDIX

CARGILL
#7 IPA TOWER LINING/PACKING INSTALLATION

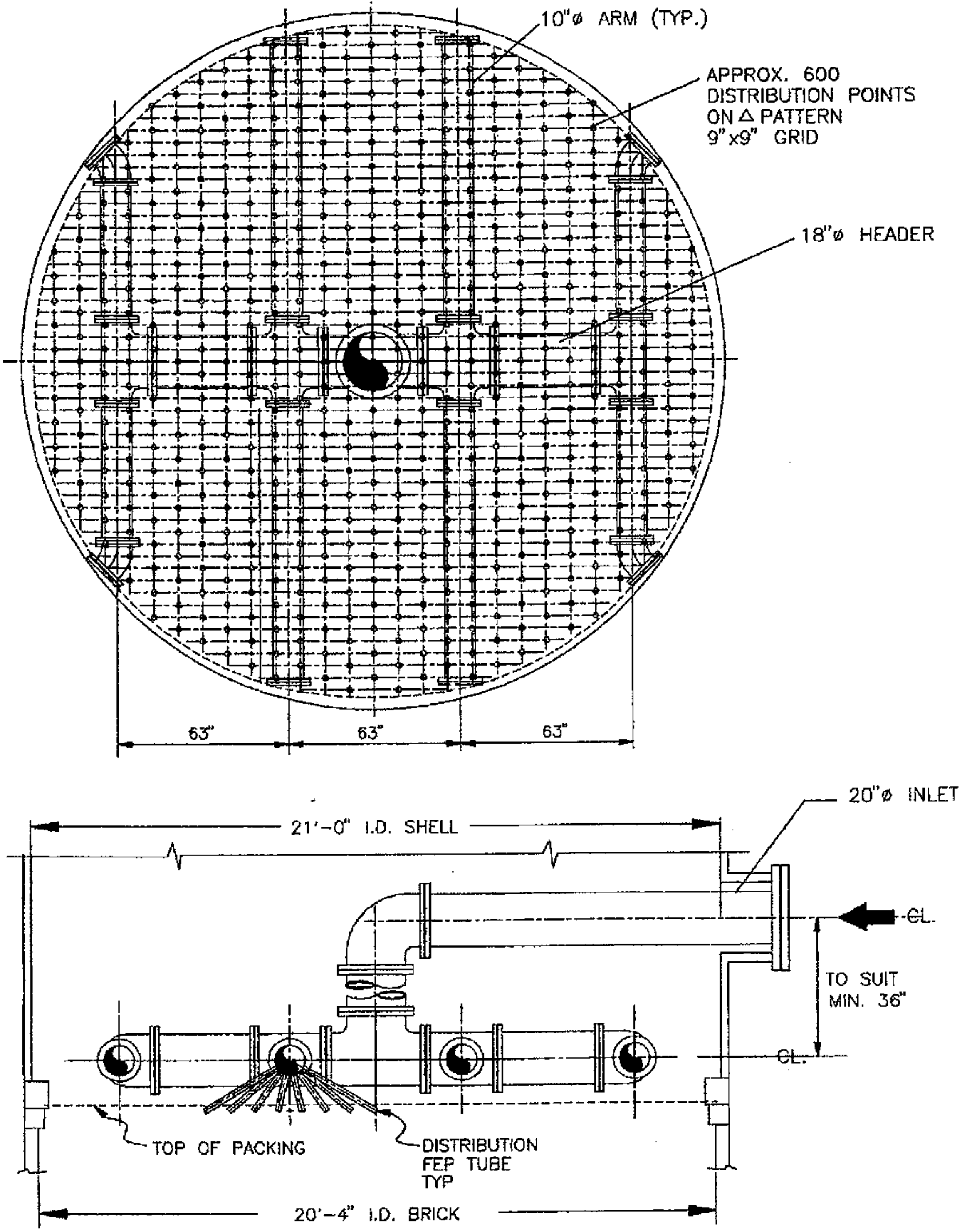
Activity	Days	Start	Finish
Project Start	0d	3/27	3/27
Pecora/Teflon Installation	19d	3/27	4/21
Brick Floor	7d	3/27	4/4
Brick to Packing Support	7d	4/5	4/13
Top Out Brick	7d	4/17	4/25
Line Nozzles	6d	3/27	4/3
Dome Installation	5d	4/24	4/28
Flexeramic Installation	7d	5/1	5/9
Weld Tubesheet	1d	5/10	5/10
Project Complete	0d	5/10	5/10



Date: 3/30/95

Critical ▨ Milestone ◆ Float —
Noncritical ▭ Summary ▬
Progress ■ Rolled Up ◇

Figure 1



MATERIALS:

FITTINGS: HS MEEHANITE
FLANGES: DUCTILE IRON
PIPES: HS MEEHANITE/L-14
ORIFICE ADAPTOR: LEWMET 66
TUBES: FEP
GASKETS: CUSTOMER STD. OR GLASS FILLED PTFE
BOLTS/NUTS: 304/316 SS
SUPPORTS: 316L

CECEBE TECHNOLOGIES INC.				
CARGILL, FLORIDA				
TITLE: ACID DISTRIBUTOR IN 20'-0" I.D. VESSEL WITH ONE ELEVATED 20" INLET			CLIENT DRAWING NO.	REV.
SCALE: NONE	APPROVED BY:	DRAWN BY H.T.L	NORAM DRAWING NO. A-500-1600 OPTION No. 3	REV. A
DATE: JAN 18.95	CHECKED BY:	REVISED		

Figure 2

PROPERTIES OF CHEMICAL STONEWARE FLEXERAMIC® STRUCTURED PACKING

I. TYPICAL CHEMICAL COMPOSITION

	%
SiO_2	66.1
Al_2O_3	27.6
Fe_2O_3	1.3
TiO_2	1.5
CaO	0.2
MgO	0.5
K_2O & Na_2O	2.8

II. PHYSICAL PROPERTIES

Specific Gravity (ASTM C 373)	2.6
Water Absorption, % (ASTM C 373)	1-2%
Acid-Resisting Property, % Wt. Loss (ASTM C 279)	4-6
Thermal Conductivity BTU/hr-ft-°F	8

III. DESIGN CHARACTERISTICS

	TYPE 28	TYPE 48	TYPE 88
No.Pcs./$Ft.^3$	1	1	1
Packing Density, Lb/$Ft.^3$	42	37	21
Free Space, %	70	74	85
Surface Area, SF/ft^3	86	48	31
Compressive Strength	270	140	95

Figure 3

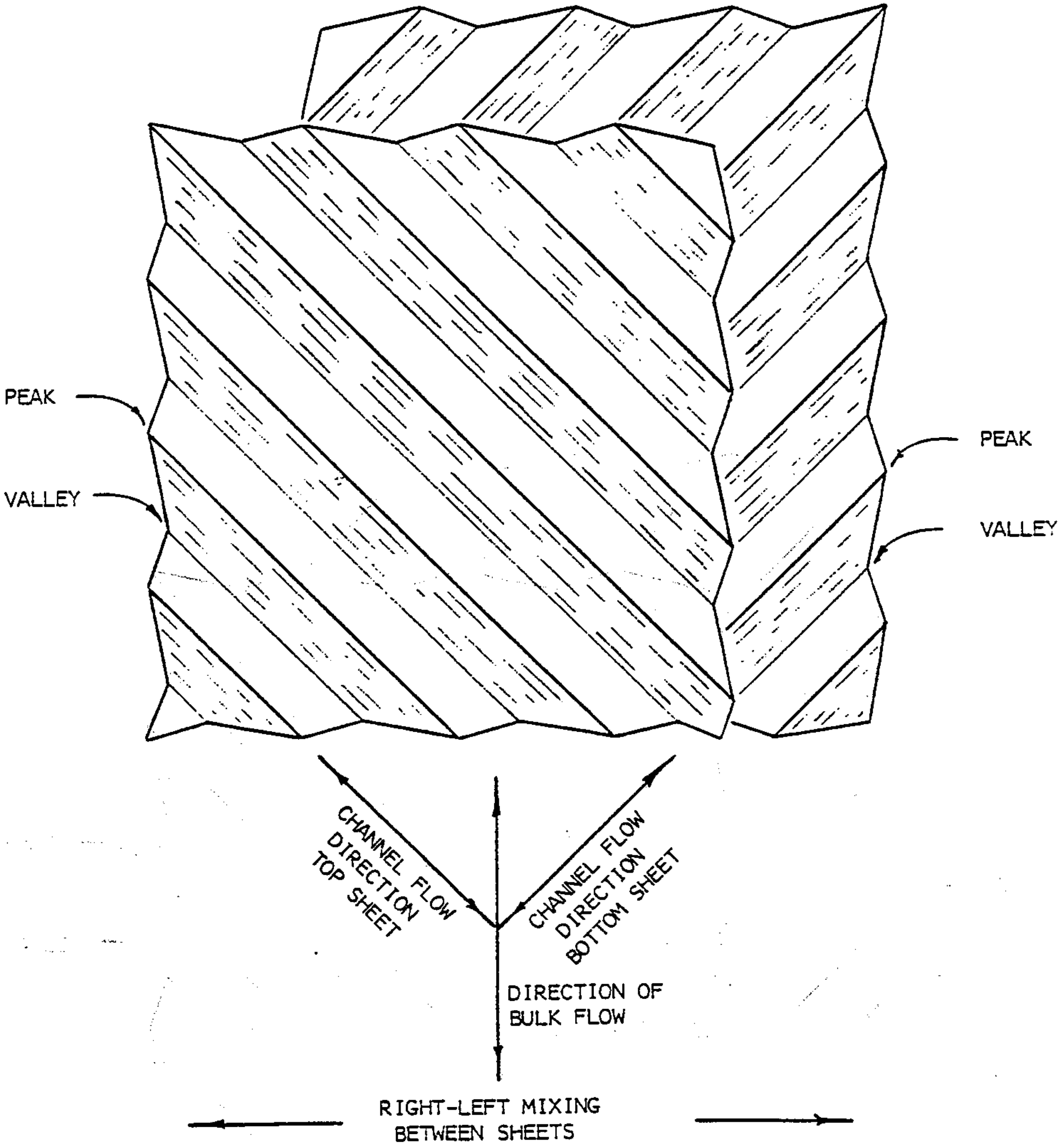

PEAK
VALLEY
PEAK
VALLEY
CHANNEL FLOW DIRECTION TOP SHEET
CHANNEL FLOW DIRECTION BOTTOM SHEET
DIRECTION OF BULK FLOW
RIGHT-LEFT MIXING BETWEEN SHEETS

Figure 4

SELF-SUPPORTING DOME PACKING SUPPORT

The Self-Supporting Dome Packing Support consists of custom-made ceramic pieces which when assembled yield an open area of 60%.

The individual pieces of the Dome are made from a high silica, low alumina body designed for increased acid resistance. The extruded piece has good mechanical strength which permits an allowable loading of 1,200 lb. per square foot for the Packing Support assembly. The pieces have very low porosity and are extremely hard and abrasion resistant.

TYPICAL PHYSICAL DATA

Bulk Denisty, lb/cu.ft.	143-146
Compressive Strength, lb/sq.ft.	18,000 - 23,000
Coefficient of Thermal Expansion	3.89×10^{-6}
Modulus of Rupture	3,000 - 4,200 PSI
Poisson's Ratio	0.19
Specific Gravity	2.38 - 2.50 g/cc
Water Absorption	2.0 - 4.0%
Young's Modulus	6.35 E+06 PSI
Acid Solubility	4.0 - 6.0 % wt loss

The above Physical Data was derived by using ASTM Test Specifications C 20, C 133, C 279 and C 885.

TYPICAL CHEMICAL DATA

	WEIGHT %
Silica (SiO_2)	72.71
Alumina (Al_2O_3)	21.52
Titania (TiO_2)	1.19
Iron Oxide (FE_2O_3)	1.05
Lime (CaO)	0.24
Magnesia (MgO)	0.34
Potassium Oxide (K_2O)	1.75
Sodium Oxide (Na_2O)	1.05

Figure 5

Koch Dome
Support Assembly
(Typical Arrangement)

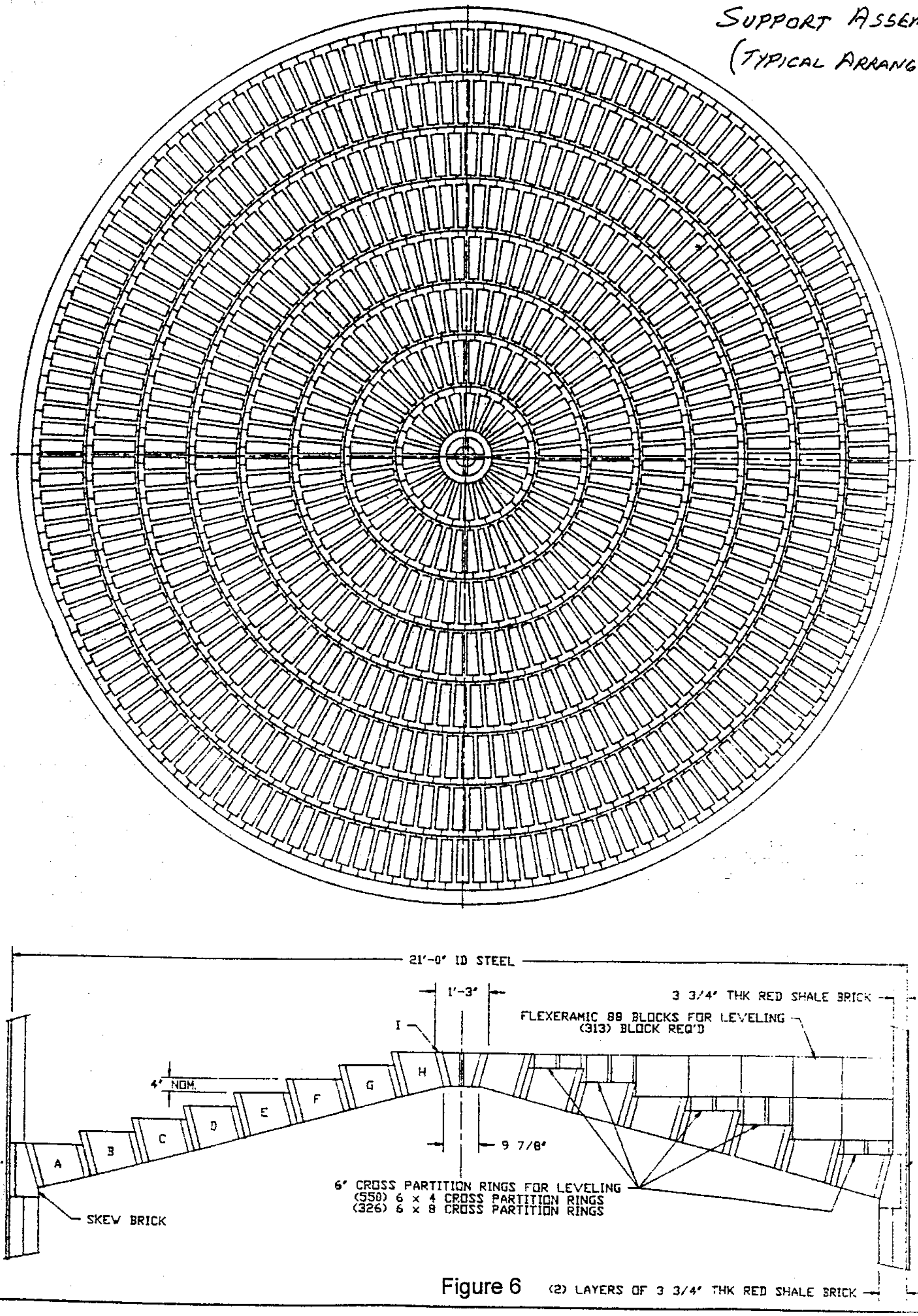


Figure 6