THE DESIGN AND SELECTION OF SCRUBBERS FOR GRANULATION PLANTS

By: Arthur O. Hansen
Robert J. Danos

For The
Central Florida Section, A.I.Ch.E
Annual Spring Meeting
Clearwater, Florida
May 24, 1980

GULF DESIGN DIVISION
BADGER AMERICA, INC.

BADGER BUILDING
1401 NORTH WESTSHORE BLVD.
P. O. BOX 22317, TAMPA, FLORIDA 33622

A Raytheon Company

1.0 INTRODUCTION

The purpose of this paper is to discuss methods for designing, evaluating, and selecting scrubbers for large granulation plants (DAP plants unless noted otherwise).

Many of the problems in granulation plant startup and operation involve the scrubber system. This is practically true for DAP where the primary scrubbers, and more recently the tailgas scrubbers, are an integral part of the process.

The problems may be due to the fact that the operator fails to consider that a granulation plant produces two main product streams - granular fertilizer and water vapor. The plant could be viewed as a sophisticated evaporator with essentially all of the water leaving the scrubber system. We will return to this thought later.

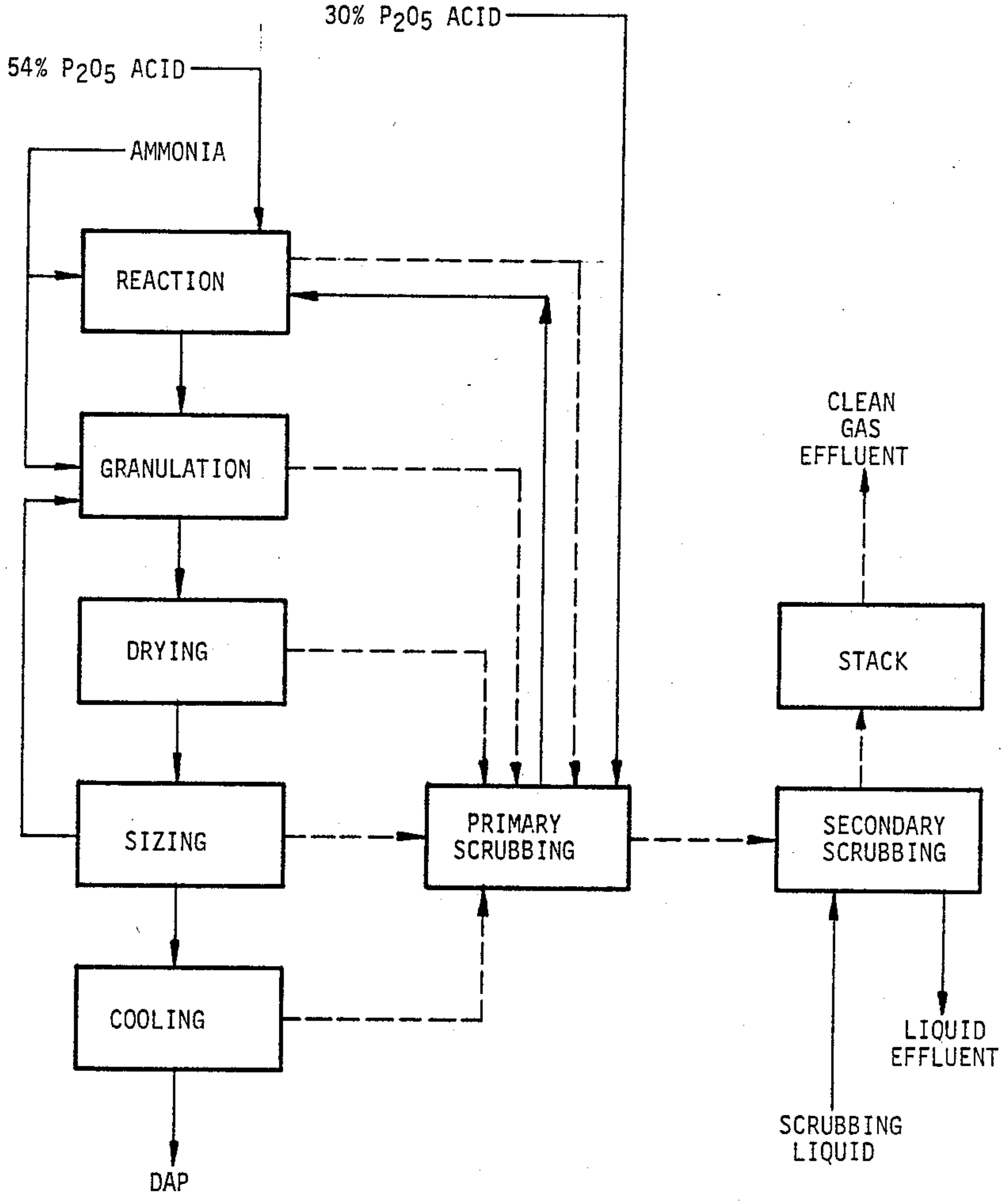
A typical flow diagram for granular DAP is shown in Figure 1.

Granulation plants continue to get larger in capacity and size. Two of perhaps the world's largest plants in the world were designed for Fertimex by Gulf Design division of Badger. These plants are guaranteed for 80 TPH of 17-17-17, 20-10-10, 15-30-15, 18-46-0 and 16-20-0. The tailgas scrubber is 26 feet in diameter by 59 feet high and is the largest equipment item in the plant. Large plant scrubbers are in the field erection category. These plants generally have more scrubbers and design becomes more critical to minimize cost.

This paper would be useful for those who are interested in modification required for increasing capacity. Badger (Gulf Design) is currently assisting in the modification of scrubber systems in Louisiana and Illinois.

FIGURE #1

DAP BLOCK FLOWSHEET



As you know, the environmental agencies have been emphasizing liquid effluent controls in the recent past. Zero discharge laws have tended to negate the approach of cooling and thereby condensing the stack water. This results in a more difficult "hot" tailgas system, and requires the use of a recirculated scrubbing liquid having a low fluoride vapor pressure.

The basic requirements for scrubber selection are:

a) capabilities of meeting process requirements and environmental standards

b) reliability and ease of operation

c) cost factors - capital and operating costs

To accomplish this objective, the procedure and sequence shown in Figure 2 is used.

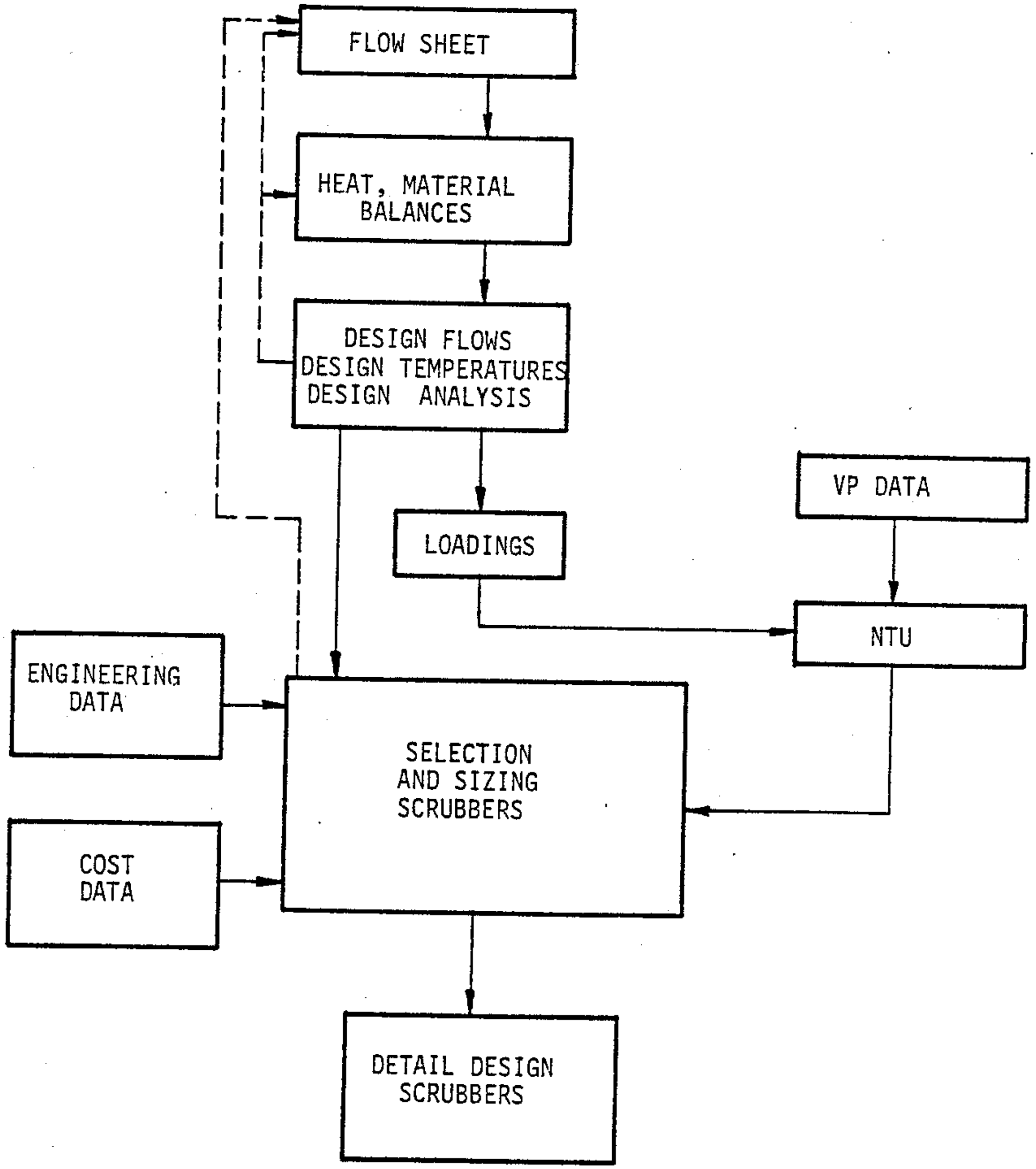
The heat and material balance work will establish the flow composition and temperatures for the basic design. To this input we add the other inputs of vapor pressures, design velocities, and other design operating and cost considerations.

2.0 DESIGN AND PRELIMINARY SELECTION

The heat and material balance in Figure 3 shows the input and output streams from the overall plant.

The plant inputs consist of feed material and the heat of reaction, fuel combustion and heat from steam in the vaporizer. Outputs include product DAP, combined gases to the tailgas scrubber and some minor heat losses. The heat and material balance excludes the tailgas scrubber.

FIGURE 2


FLOW SHEET
HEAT, MATERIAL BALANCES
DESIGN FLOWS
DESIGN TEMPERATURES
DESIGN ANALYSIS
VP DATA
LOADINGS
NTU
ENGINEERING DATA
SELECTION AND SIZING SCRUBBERS
COST DATA
DETAIL DESIGN SCRUBBERS

OVERALL DAP BALANCE
(DATUM 32 °F)

		POUNDS PER 1000 POUNDS DAP							MBTU / M LB
STREAM	TEMP.	AIR	NH3	P205	OTHER	DRY	H20	TOTAL	HEAT
H_2O	90						167	167	8
H_2SO_4	109					19		19	0
30 Acid	140			293	187	480	497	977	68
54 Acid	170			172		269	50	319	18
NH_3L	40		222			222		222	2
Air In	86	(4491)				(4491)	71	71	136
Reaction Heat									520
Drying Heat							10	10	255
Vaporizer Heat	(For Reactor NH_3 Only)								72
Total Input			222	465		990	795	1785	1079
Product	120		222	465		990	10	1000	27
Gas to TGS	156	(4491)				(4491)	785	785	1011
Dryer Loss									25
Dryer Reaction Heat									16
Total Output			222	465		990	795	1785	1079

Figure #3

Note that in this balance the gas leaving is carrying 785 pounds of water per 1000 pounds of DAP product. This design is good for a plant having limited evaporator capacity. The design contains a generous amount of air flow sufficient to carry out the water at a reasonable temperature (156°F). The water input shown is a contingency only and ordinarily would be eliminated and substituted by increasing the ratio of 30% acid to 54% acid. Now the inputs and outputs are defined.

To prepare some good specifications for vendor bids, a balance is needed on the scrubber system, as shown on Figure 4. To do this it is necessary to do a balance on each equipment item in the plant to get the composition and heat content of all these gases (reactor, granulator, dryer, cooler, and vents). The scrubber system balance must then be checked further by individual balances on each individual primary scrubber. This must result in product streams having reasonable and correct compositions. Vapor pressures, humidities, temperatures, mole ratios, solubilities must check out correctly.

Loading and Efficiencies

The design loadings for a typical 60 TPH DAP plant are shown in Figure 5. This figure lists typical design loadings to the scrubbing system of a 60 TPH granular DAP plant. Bear in mind that a considerable amount of dust has already been removed by the dry cyclones.

The first column titled RGC refers to the combined vent gases from the reactor, granulator, and cooler. This design permits us to operate at a lower temperature by diluting the hot RG gases with dry, low temperature product cooler gases.

The other columns show the dryer (D), equipment vent (V), and tailgas (T) scrubber inlet gases.

PRIMARY SCRUBBER BALANCE

		POUNDS PER 1000 POUNDS DAP							MBTU/M LB
STREAM	TEMP.	AIR	NH_3	P_2O_5	OTHER	DRY	H20	TOTAL	HEAT
H_2O	90						167	167	8
H_2SO_4	109					19		19	0
30 Acid	140			293	187	480	497	977	68
R Gas	240	(153)	11			11	317	328	371
G Gas	157	(384)	22			22	102	124	126
D Gas	200	(1670)	11			11	177	188	278
C Gas	155	(1145)					18	18	53
V Gas	155	(1151)					18	18	54
Reaction Heat									184
Total Input		(4503)	44	293	187	543	1296	1839	1082
Gas to TGS	156	(4503)	2				785	785	1011
Scrub Acid	156		42	293	187	543	511	1054	79
Unaccounted									-8
Total Output		(4503)	44	293	187	543	1296	1839	1082

Figure #4

TYPICAL DESIGN LOADINGS - 60 TPH DAP PLANT

SCRUBBER	REACTOR GRANULATOR COOLER	DRYER	VENTS	TAIL GAS
GAS FLOW IN, CFM	78,000	60,000	40,000	178,000
DUST				
Loading GR/FT^3	3	3	3	0.03
Efficiency, %	99	99	99	
TPH Collected Dust	1.0	0.8	0.5	0.2
AMMONIA GAS				
Loading, TPH	2.0	0.7	0	0.13
Efficiency	95	95	-	
TPH Collected	1.9	0.67	-	0.12
FLUORINE GAS				
Loading, lbs F/Day	**	**	**	500-1000
Efficiency				94-97
Mist, lbs P_2O_5/H				90
Exit lbs F/Day - Stack				30
Allowed				(40)

** Normally not specified

FIGURE #5

Dust

In each case the typical recovery is 99% on dust. The tons per hour of collected dust in this primary system is 1.0, 0.8 and 0.5 respectively for a total of 2.3 tons. The remaining dust .02 tons is collected in the tailgas scrubber. The 2.3 tons of dust adds approximately 4% solids to the recirculating scrubber acid. This value can increase considerably during upset conditions.

In a GTSP plant, the material entering the scrubber system is lost and not returned to process. Fortunately, GTSP is less dusty and the loadings are about one third that of DAP.

NH_3

Typical DAP design calls for a 5%, 10%, and 5% loss of total process ammonia input from the reactor, granulator and dryer respectively. This means that the scrubber system is handling 20% of the ammonia. A poorly operated or designed plant is one where the scrubber is handling a larger fraction of the ammonia. Most plants eventually operate at 150-180% of the original guaranteed production rate - this means that the scrubbers must operate effectively at this higher capacity.

Fluoride

DAP contains about 2% fluoride which is equivalent to 4% ammonium flouride. Ammonium fluoride is the salt of a weak volatile alkali and a weak volatile acid. By the term weak we mean a material with a low ionization constant. We can therefore expect some HF vapors from the rotary dryer. From a MAP dryer, we would expect more fluoride loading because MAP probably contains ammonium bifluoride which has a higher fluoride vapor pressure.

In addition to the above, there is some ammonium fluoride volatilization from the preneutralizer, or reactor tank. The addition of phosphoric acid to a hot slurry can also "flash" off fluoride at the surface. We prefer to minimize this by introducing the acid just below the liquid surface to avoid the "frying pan" effect.

Despite the aforegoing, the fluoride loading to the primary scrubber is usually not specified because the primary scrubbers are regarded mainly as "fluoride-strippers" instead of fluoride scrubbers. In any case, the stripping factor outweighs the significance of the scrubbing factor. It may be noted that most plant data has limited design value because it does not differentiate between gaseous, entrained liquid, or solid dust forms of fluoride. We will elaborate on fluoride stripping later.

The last column shows the loadings to the tailgas scrubber. Whereas the primary scrubbers are designed primarily for dust and ammonia recovery, the tailgas scrubber is designed primarily for fluoride recovery.

The input loading 500-1000 pounds fluoride (it is preferred to avoid the word fluorine) per day depends on the acid used in the primary scrubbers. For 30% P_2O_5 filter acid the lower figure (500) may be used. If 30% P_2O_5 is prepared from a blend of 52% P_2O_5 and water, the higher figure may be used. There are differing opinions on this. The use of 40-42% P_2O_5 from the evaporators is not recommended because its fluoride vapor pressure is about 20 times too high and it tends to form NH_4HF_2 fume (submicron) which is impossible (almost) to scrub out.

To achieve the design of 30 lbs F per day exit stack with an input loading of 1000, the requirement is 97% efficiency.

It should be noted that the allowable EPA standard of 40#F/day includes the fluoride in dust or entrainment in addition to the liquid. Tailgas scrubber liquid may be pond water, sea water, or recirculated fresh water.

Let us briefly mention the scrubbing loads required for Granular Triple Superphosphate (GTSP) by the slurry process. There is, of course, no ammonia loading. The dust load is only about 1/3 that of DAP. The fluoride load is very high. Typically about one third of all the fluoride entering with the rock and acid is evolved to the scrubbing system. This amounts to about 800 pounds per hour for a 50 TPH plant with about 86 lb/day allowed out the stack. Usually two stage or three stage scrubbing with pond water, or recirculated fresh water is used.

Scrubber Types and Design Factors

Typical granulation plant scrubbers are shown in Figure 6 and Figure 7.

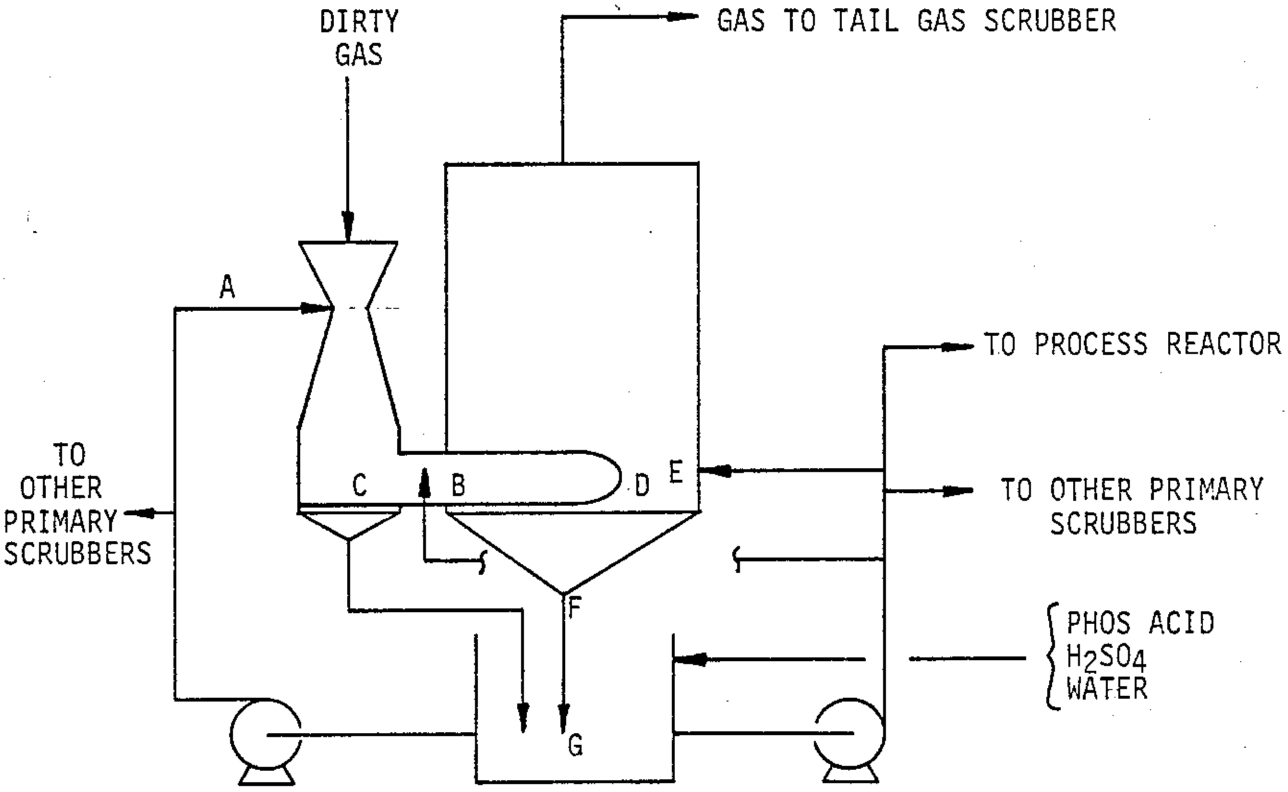
Figure 6 shows popular current types. The primary scrubber consists of a venturi followed by a cyclonic spray scrubber. The low pressure pump circulates the scrubber liquid "A" to the venturi. This liquid becomes atomized in the "hurricane" velocity area of the throat. Part of the liquid "C" is recollected at the "flooded elbow" which drains to the scrubber tank. The gas flows from the venturi and enters tangentially into the cyclone scrubber.

Depending on the vendor selected, high pressure (i.e. 60 psig) sprays are located at area "B" or at area "E". The air velocity at point "D" is called the spin velocity. Most of the liquid drains from point "F" to the vacuum seal tank (scrubber tank) "G". When spray liquid is injected at point "B", the situation approaches two venturi scrubbers in series, followed by a cyclone liquid separator. When injected at area "E", a larger cyclonic section will be required to provide for centrifuging of the liquid against the walls. Radial outward sprays are less efficient than radial inward and are more difficult to check and keep clean.

The "flooded elbow" has been a favored solution to the problem of solids buildup at the elbow. Another design is the "coaxial" type where the venturi section is inside the cyclonic section. The Lurgi type venturi is also located in the cyclonic section. These types require a larger outside shell diameter. Still another type is where the venturi section is horizontal.

FIGURE #6

PRIMARY SCRUBBING



Another type arrangement is where the venturi is substituted by another spray scrubber to make two in series. This has been used for older GTSP plants.

Tailgas Scrubbers

Figure 7 shows a typical packed tower with the stack mounted on top. A de-entrainment section is provided. Solids buildup is minimized by the countercurrent vertical air flow and by use of large high-void space packing such as 3" intalox saddles or woven mesh packing. Polyethylene packing is preferred over polypropylene packing because of its smoother slippery surface, but is more difficult to obtain since a leading packing producer has standardized on polypropylene. Polypropylene is better suitted for hotter gas streams (150-175°F).

Spray Chamber

Removal of the bottom packing, and installation of sprays instead of spargers or weir boxes, results in a typical spray-chamber scrubber. This type has some major disadvantages such as:

a) twice the volume required because of lower gas velocities

b) about three times horsepower required because of pressure sprays.

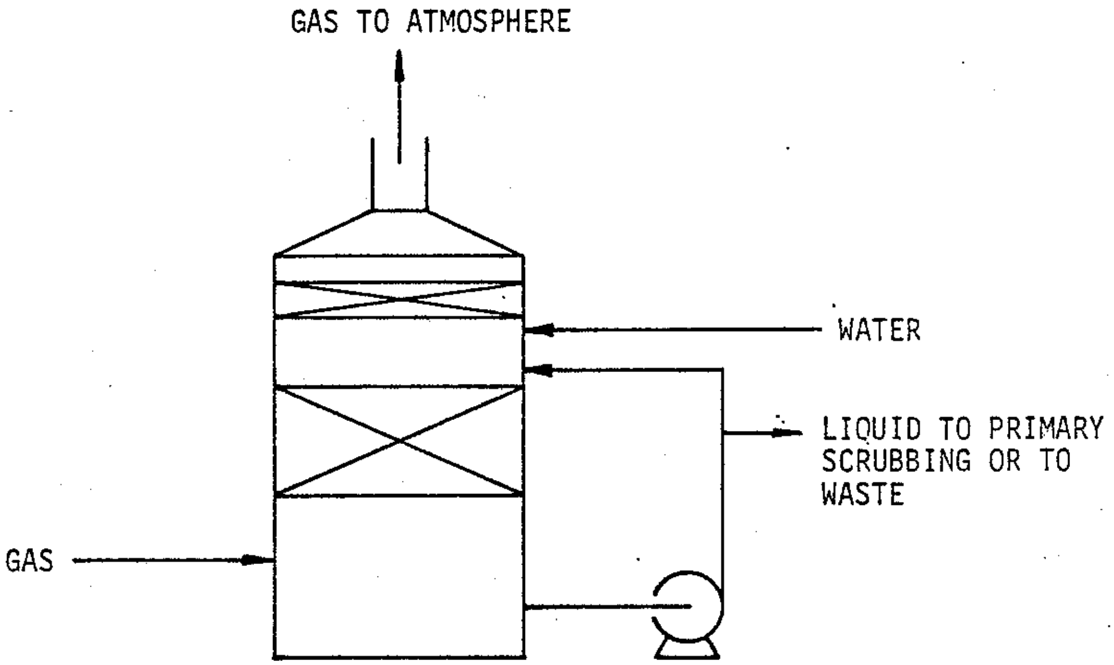
c) limited efficiency

Cross Flow

The cross-flow type packed scrubber requires a smaller amount of scrubber water. However, in many cases it is less efficient and has a much higher tendency to plug up than the vertical countercurrent scrubber. Several phosphate companies in the area have switched to plastic woven-mesh packing with good results.

FIGURE #7

TAIL GAS SCRUBBING



The mesh packing can easily be cleaned with a high pressure water hose. Some recent applications claim woven mesh type packing has more transfer units per foot of packing. This is an interesting claim which would make an interesting subject for a paper if some real good data was available to back it up.

Gas Velocities

Figure 8 shows some ranges of velocities which enable the calculation of scrubber areas.

For example the dryer scrubber in Figure 5 would have a cyclonic section size of:

Diameter = 10.3 ft

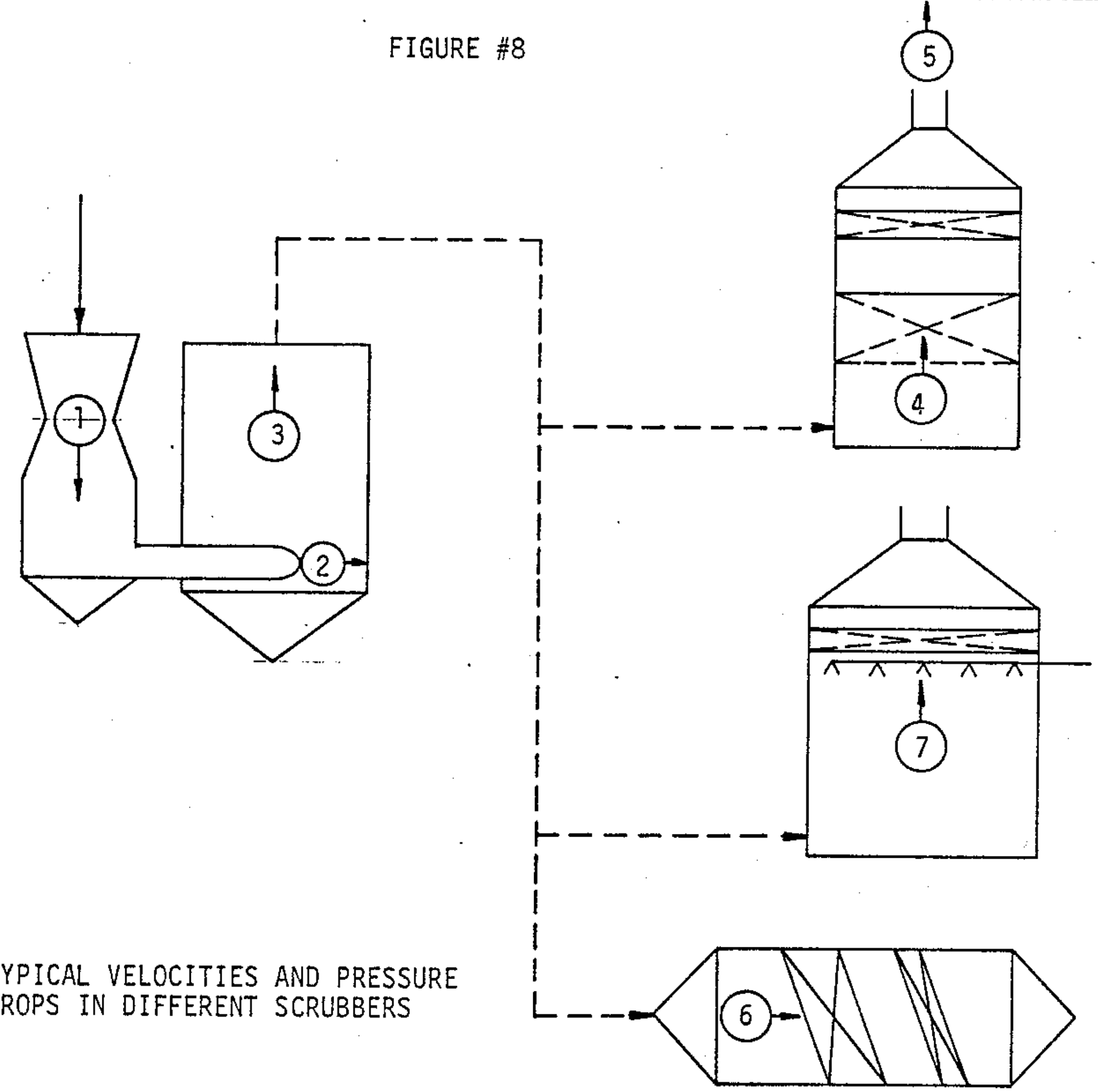
and a venturi throat area of 7.1 ft^2 which would require an opening of 10" x 8'7" wide (venturi throat width is usually limited to 10").

Design Theory and Procedure

A design procedure is summarized on the following page. Procedure is intended to assist the plant process engineer to at least prepare a preliminary design of a scrubber system. This will put him in a better position to evaluate a vendor's bid. It may also be used as a basis for upgrading an existing scrubber.

Some of the subsequent slides in this paper will relate to this summary. These include vapor pressure curves for ammonia, SiF_4, HF and water and also include energy curves which determine how much fan horsepower and liquid pumping is required.

FIGURE #8



TYPICAL VELOCITIES AND PRESSURE DROPS IN DIFFERENT SCRUBBERS

	FPS, 70°F Velocity	ΔP
1. Venturi Throat	130-160	8-12" H_2O
2. Spin Velocity	40- 80	
3. Cyclonic - Avg	10- 13	4" H_2O
4. Packed Tower - Avg (3" I.S.)	8- 10	4" H_2O
5. Stack	50- 60	1" H_2O
6. CrossFlow Scrubber (1" I.S.)	8- 9	4" H_2O
7. Spray Chamber	4- 5	2" H_2O

SCRUBBER SYSTEM DESIGN PROCEDURE - SIMPLIFIED

A. Process Design

1. Heat and material balance - preliminary
2. Calculate NTU (Number of transfer units) preliminary

$$NTU = 2.3\ LOG \quad \frac{P_1 - P^*}{P_2 - P^*}$$

Where P_1 = Partial Pressure of F in inlet gas (or NH_3)
P_2 = Partial Pressure of F in outlet gas (or NH_3)
P^* = Partial Pressure of F in scrubber water (or NH_3)

3. Decide on number and type of scrubber to use
   - (a) Spray Cylonic - usually NTU = 3.0 maximum
   - (b) Venturi - usually NTU = 3.5 maximum
   - (c) Packing - usually No Limit
   - (d) Other types - difficult to predict performance
   - (e) Other factors influencing selection
     1. Dust - Venturi preferred
     2. Silica - Venturi preferred
     3. Entrainment - Packed section preferred
     4. Size - volume of gases
     5. Energy and capital cost
4. Repeat step (2) figuring SiF_4 and HF separately using data from reference #2.

B. Engineering Design - Basic

1. Calculate gas and liquid hydraulic horsepower requirements for NTU needed in primary scrubbing section. See reference 4, 7, 9, 10, 11, 14 Establish Velocities, Liquid Flow and pressure, gas pressure drop
2. Calculate feet of packing for NTU required for tailgas (secondary) scrubbing and for entrainment removal
   - Usually 2-1/2' of 3" intalox saddles equals one transfer unit for gas velocities (G = 800 to 2000 lbs/hr ft^2 and Liquid (L = 5000-20000 lbs/hr ft^2)
   - Usually 2' of 2" saddles will remove 90% of +5 micron entrainment
3. Check heat and material balance
4. Size diameter and height of scrubbers
   - (a) Prepare vessel sketches to scale
   - (b) Select spray nozzles if used (30-50 PSIG pressure preferred)
   - (c) Size venturi throat if used
     130 feet per second preferred
     (8"-11" delta P) with provision for increase
   - (d) Size and list inlet, outlet, instrument and manway openings
5. Calculate system pressure drop - including all ductwork - and specify fan and stack requirements.
6. Check physical properties of fluids - humidities, revise balance if required and repeat design.

C. Engineering Design - Detail - Mechanical, structural, piping, etc.

Transfer Unit

The use of the "transfer units" method in many chemical engineering calculations has become common.

For dust recovery, the number of transfer units (NTU) is merely another manner of expressing efficiency. It is defined as the natural log of the ratio of the inlet loading to the outlet loading. Some sample calculations are shown in Figure 16.

For gas absorption, the NTU becomes more significant since it takes into account the vapor pressure of the contaminant from the scrubbing liquid. For large flows of low pressure scrubbing liquid, a simplified but useful equation is as follows:

$$NTU = Ln \frac{P_1 - P^*}{P_2 - P^*}$$

Refer again to Figure 16 for application of this equation.

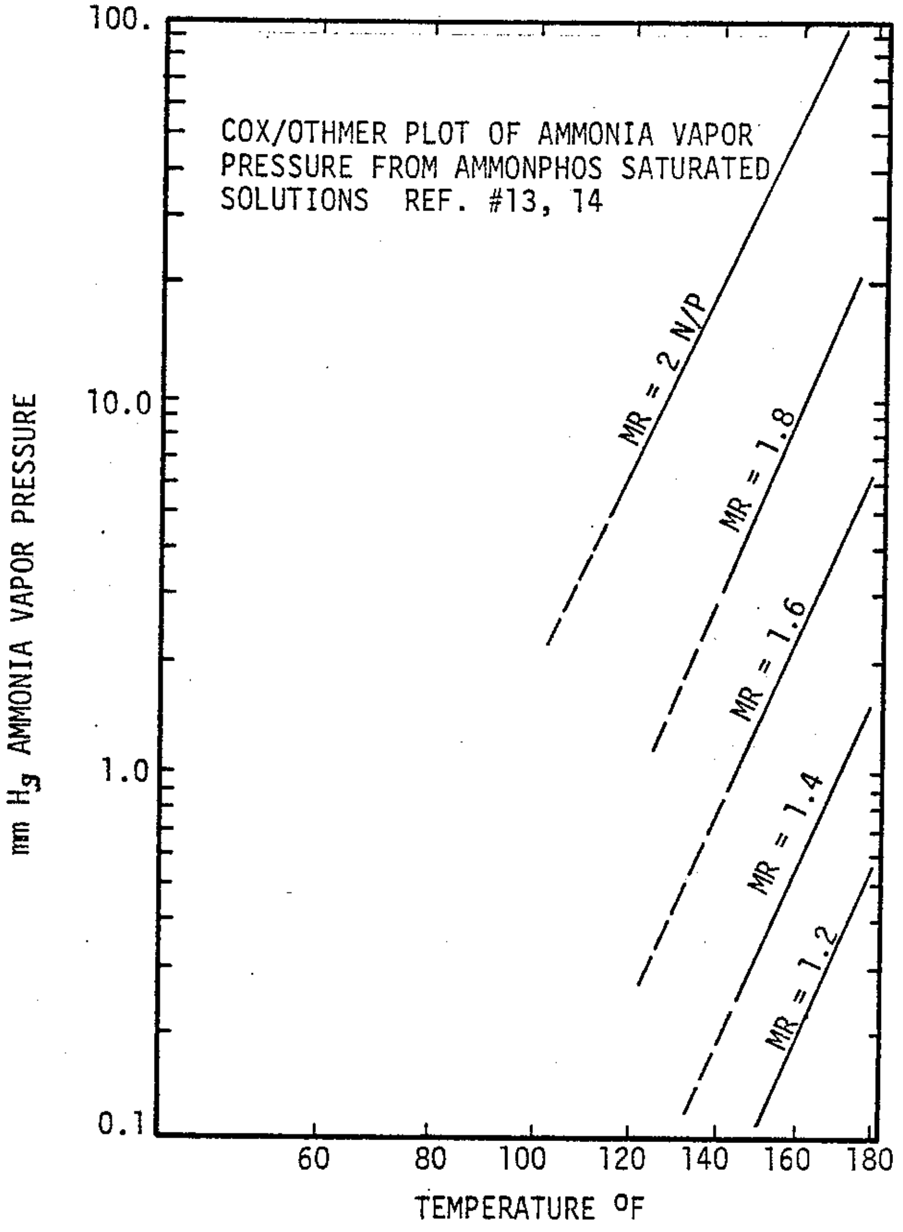
Gas stripping is the reverse of absorption. The quantity of fluoride stripped from a liquid may be estimated by a reverse form of the equation as follows:

$$NTU = Ln \frac{P^* - P_1}{P^* - P_2}$$

Vapor Pressure Data

The Othmer-Cox plot Figure 9 shows the ammonia vapor pressure from pure ammonium phosphate solutions. The data taken from a Monsanto paper (Ref. No. 13, and checked with some extrapolated data from TVA Ref. No. 14). The data appears to argee with limited plant data. The effect of sulfate content tends to cancel the effect of other impurities in plant liquids.

FIGURE #9



COX/OTHMER PLOT OF AMMONIA VAPOR PRESSURE FROM AMMONPHOS SATURATED SOLUTIONS REF. #13, 14

Note that the vapor pressure of ammonia increases rapidly (by a factor of 10) as the mole ratio (N/P) of the ammo phos scrubbing liquid increases from 1.2 to 1.6. To obtain good ammonia scrubbing, the scrubber liquid should have a low mole ratio and/or a low temperature.

Figure 10 shows a crude relationship between fluoride pressure from several liquids including partly ammoniated wet process acids.

We have indicated some vapor pressure curves estimated from back calculation of measured loading to the tailgas scrubber. There appears to be a lack of published data of this type. An added complication is that the acids on this slide are partially ammoniated (mole ratio N/P = 0.04-0.6 range) which reduces the fluoride pressure considerably. An additional source of confusion is that pressure data is usually derived from molor concentrations which in turn is derived from laboratory analysis or mass concentrations. Some gaseous molecular weights are noted as follows: taken from reference #19:

Gas	MW Average
SiF_4	104
HF 25°C	60
HF 40°C	29
HF 60-80°C	21

By ignoring the polymerization of HF gas, a 300% error is possible.

Figure 10 is expressed basis atomic fluorine with a weight of 19 assumed. The chart can be used for roughly estimating the gaseous fluoride loading to the tailgas scrubber.

FIGURE #10

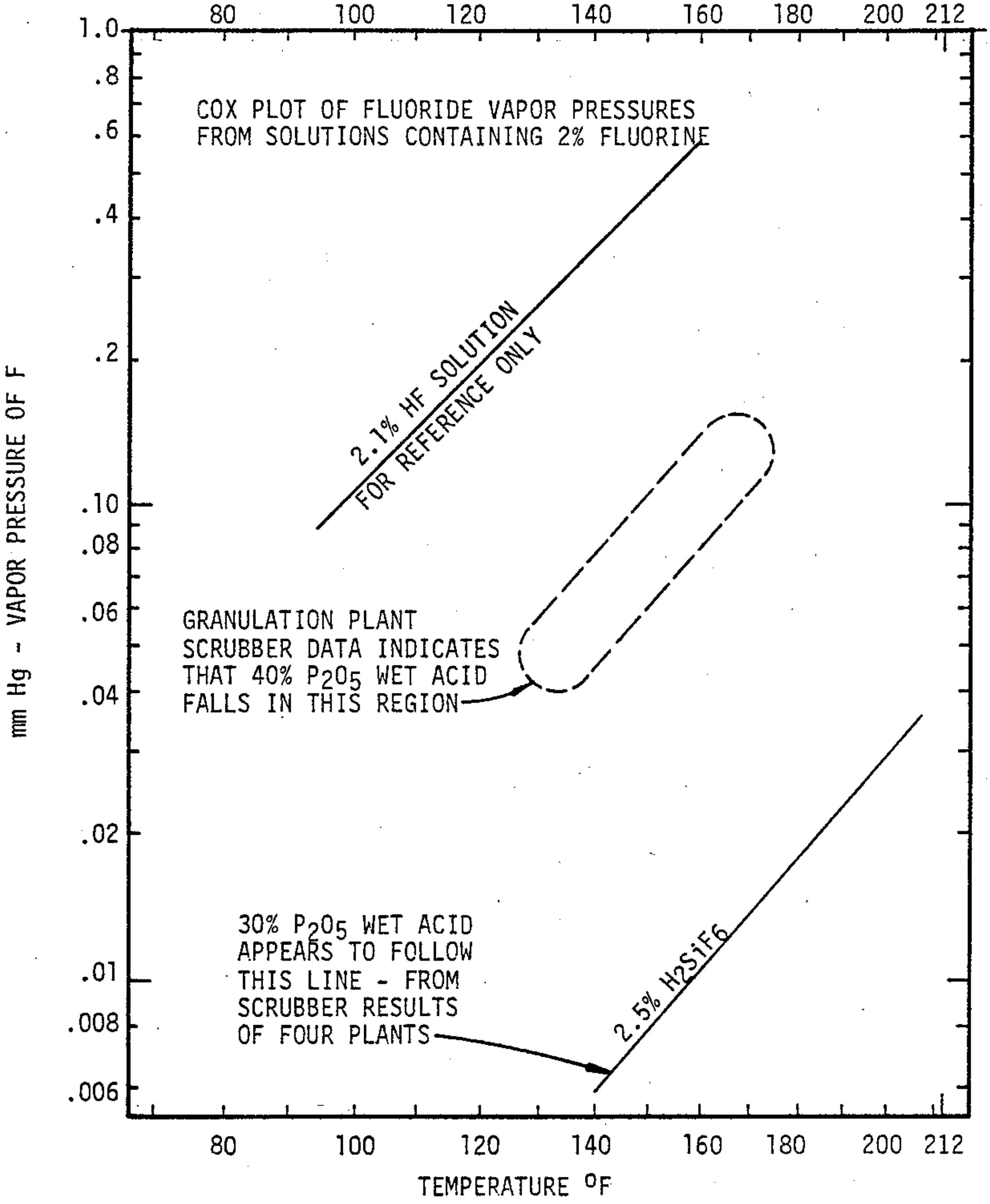

COX PLOT OF FLUORIDE VAPOR PRESSURES
FROM SOLUTIONS CONTAINING 2% FLUORINE
2.1% HF SOLUTION
FOR REFERENCE ONLY
GRANULATION PLANT SCRUBBER DATA INDICATES THAT 40% P_2O_5 WET ACID FALLS IN THIS REGION
30% P_2O_5 WET ACID APPEARS TO FOLLOW THIS LINE - FROM SCRUBBER RESULTS OF FOUR PLANTS
2.5% H_2SiF_6
mm Hg - VAPOR PRESSURE OF F
1.0
.8
.6
.4
.2
.10
.08
.06
.04
.02
.01
.008
.006
TEMPERATURE °F
80
100
120
140
160
180
200
212

Figure 11 shows (indirectly) the relative fluoride pressure versus % P_2O_5 of wet process phosphoric acid, which occurs during evaporation of plant phosphoric acid. It is well known that very little fluoride is evolved in the first stage of a 3-stage system, and that significant release begins at about 36% P_2O_5 with maximum release at 42-46% P_2O_5. We also know that the active silica is gone at about point B and we begin releasing HF instead of SiF_4.

Most DAP plants use 30% acid for scrubbing. A few plants are successfully using 54% acid diluted to 30% or 42% with water. Those who have attempted to operate at point "B" found themselves in trouble because of a submicron fuming of ammonium fluoride. I recall about 13 years ago when we collected a pure white powder from a stack sample which was completely water soluble and which analyzed 66% F.

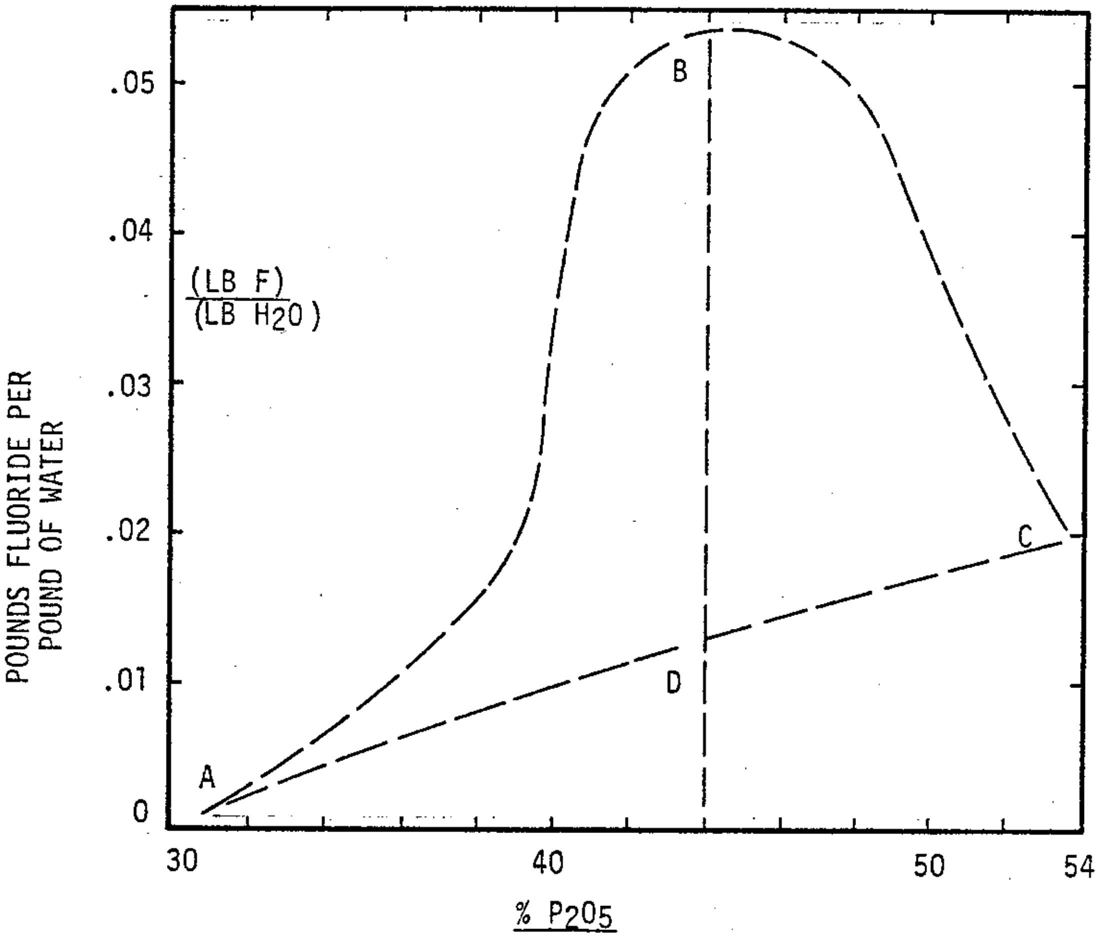
Theoretically, a blend of "A" with "C" should give an acid "D" which should be much different than acid "B".

Since there is an obvious advantage to operating with all the P_2O_5 going to the scrubbers, it is suggested that it be tried by DAP plant operators. One major plant in Central Florida operates in this manner.

Figure 12 is plotted from Russian data (reference #2). This shows the vapor pressure of HF from fluosilicic acid solutions at various temperatures and concentrations. For convenience we have expressed the data in several types of units.

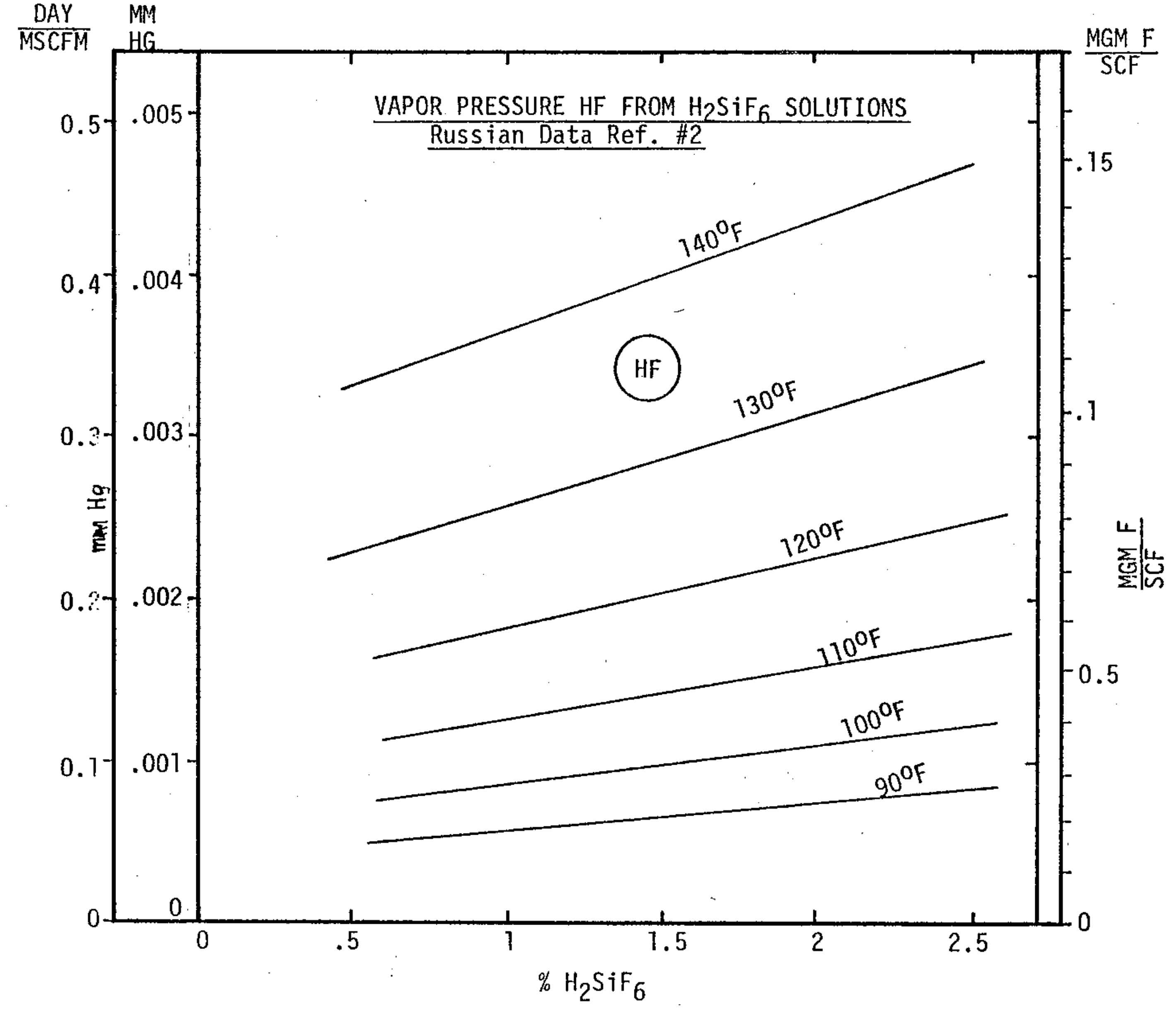
For example, if we bubbled a thousand SCFM of air through 1% H_2SiF_6 at 105° we would expect to get 0.1 #F per day evolved.

FIGURE #11



RELATIVE COMPOSITION OF GASES EVOLVED
FROM EVAPORATION OF PHOSPHORIC ACID
AT 180°F

FIGURE #12



VAPOR PRESSURE HF FROM H_2SiF_6 SOLUTIONS
Russian Data Ref. #2

From the same reference, we have plotted the (SiF_4) silicon tetrafluoride vapor pressure in Figure 13. Note that the pressure is about ten times (10X) less than shown for HF on the previous slide. What this means is that in some of our industry tailgas scrubbers using pond water, we are simultaneously absorbing SiF_4 and stripping HF from the pond water.

It is considered important to run separate sets of calculations for both SiF_4 and HF. I have found these charts useful for scrubber designs and have checked them many times with plant data. I know of some scrubber vendors who use them also.

Figure 14 is a similar graph which I prepared some time ago when designing a 50 TPH GTSP plant. We combined the data of the previous two slides by expressing all fluoride as "F" and compared it with data from a phosphoric acid scrubber (Reference #1) and from a doctorate thesis at the University of Florida (Reference #3). This chart was used only for comparison purposes on a same basis.

In general, these fluoride charts are most useful for phos acid and triple super plants. We use Figures 12 and 13 for checking any design using gypsum pond water as the scrubbing liquid.

Figure 15 shows some average vapor pressures of water from different strength phosphoric acids. Another way is to compare it with pure water by using the term relative humidity. The dotted lines are relative humidity lines. At 212°F and 760 mm Hg, we are on the 100% humidity line.

My experience is that scrubber vendors and process engineers in general do not seem to appreciate or recognize the existence of this data. If we use 30% P_2O_5 for scrubbing, as most DAP plants do, we note that for typical operating temperatures where the scrubber acid tank is 140-170°F, the relative humidity of the acid is only about 62%.

FIGURE #13

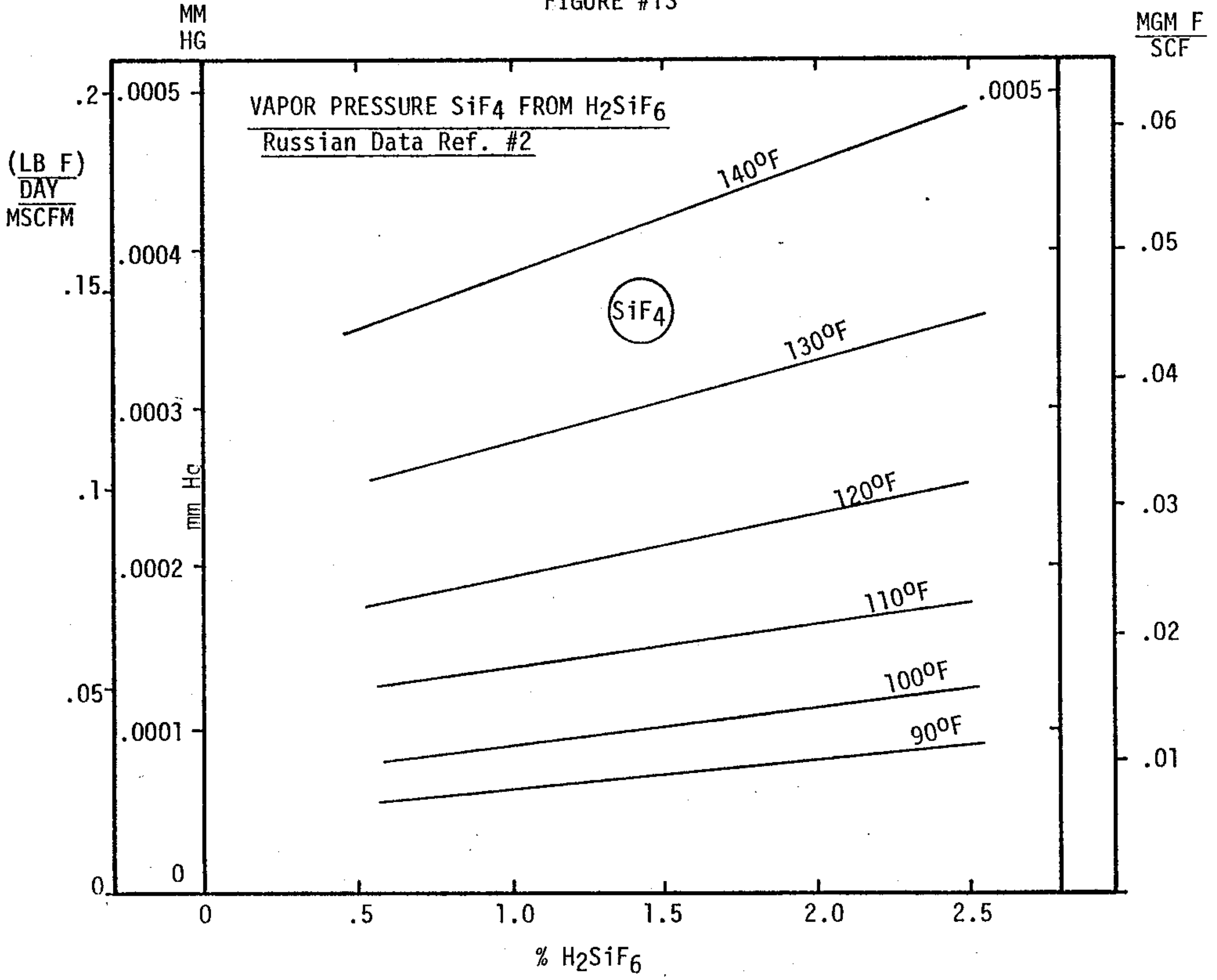

VAPOR PRESSURE SiF_4 FROM H_2SiF_6
Russian Data Ref. #2
SiF_4
140°F
130°F
120°F
110°F
100°F
90°F
(LB F) / DAY / MSCFM
.2
.15
.1
.05
0
MM HG
.0005
.0004
.0003
.0002
.0001
0
mm Hg
MGM F / SCF
.06
.05
.04
.03
.02
.01
.0005
0
.5
1.0
1.5
2.0
2.5
% H_2SiF_6

FIGURE #14

FLUORIDE DATA COMPARISON

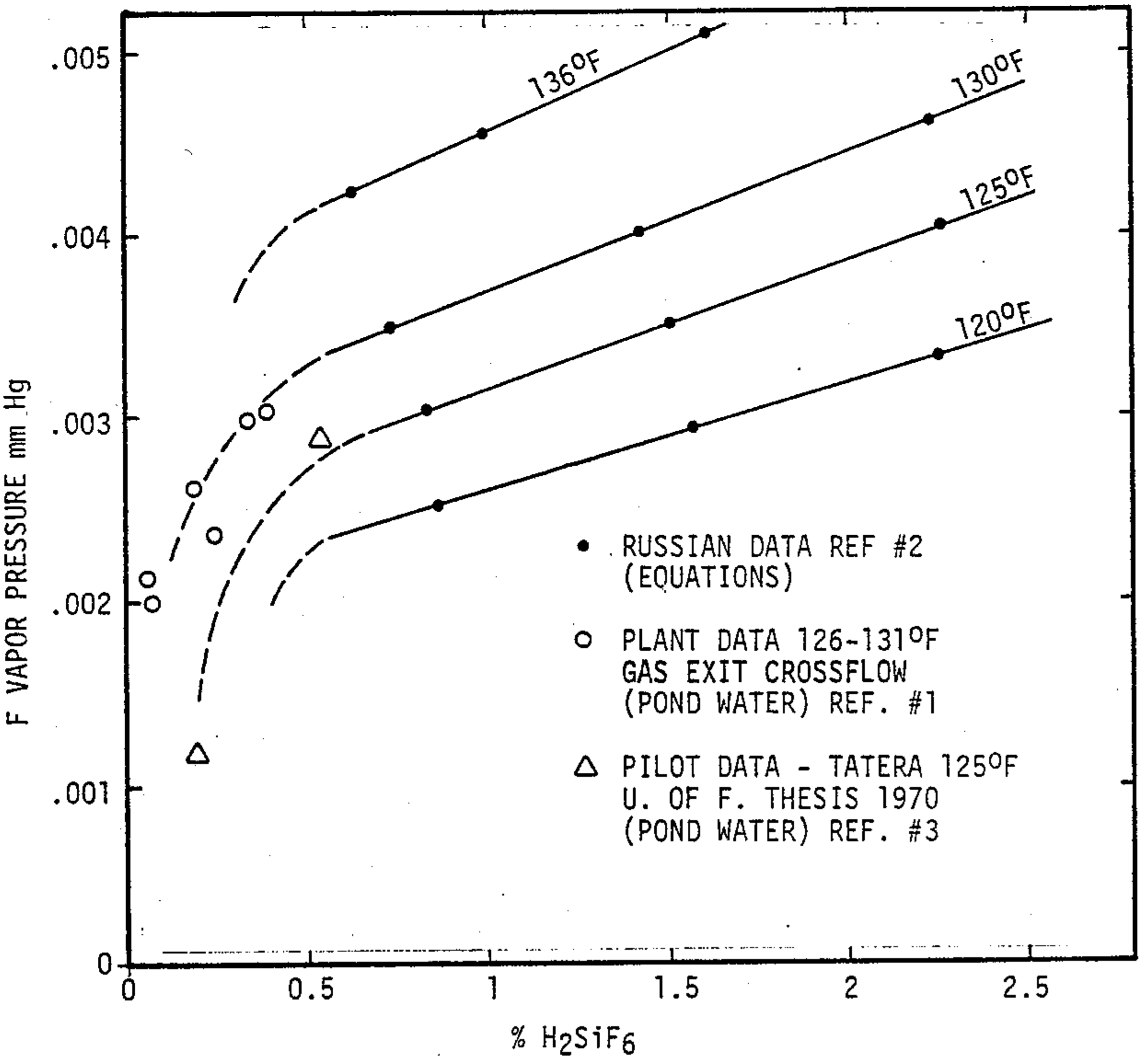
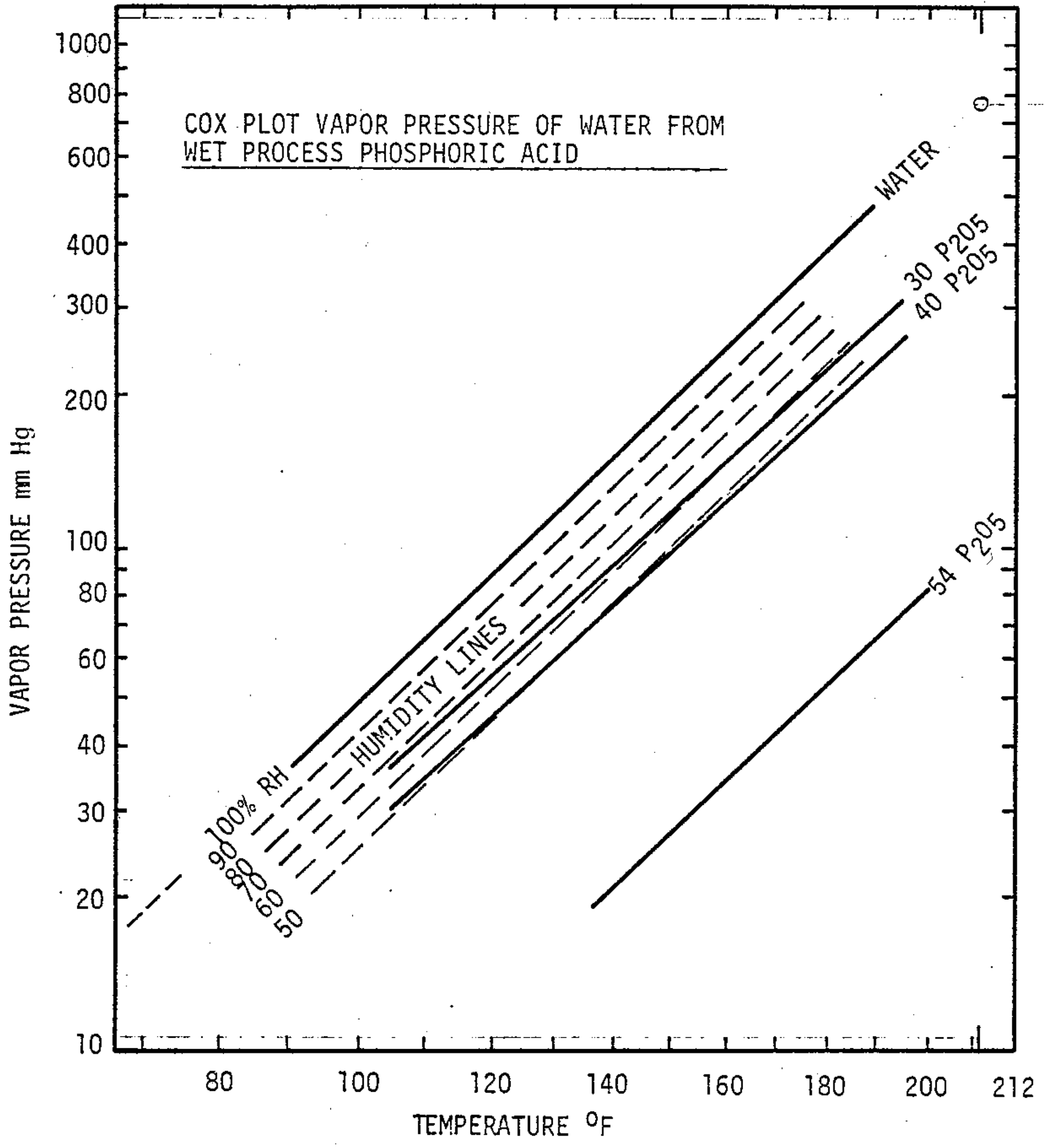


FIGURE #15


COX PLOT VAPOR PRESSURE OF WATER FROM WET PROCESS PHOSPHORIC ACID
VAPOR PRESSURE mm Hg
1000
800
600
400
300
200
100
80
60
40
30
20
10
TEMPERATURE °F
80
100
120
140
160
180
200
212
WATER
30 P205
40 P205
54 P205
HUMIDITY LINES
100% RH
90
80
70
60
50

If the acid is partly ammoniated or slightly more dilute, the equilibrium relative humidity may be somewhat higher. What this means is that the gas stream leaving each primary scrubber is not likely to exceed 65-70% humidity. If we ignore this fact and assume the air to be saturated for design purposes, we may find that the plant can only produce 70% of "design" capacity or that the scrubber system is operating 20-30°F hotter than intended. This causes operating problems and environmental problems.

Note that 40% P_2O_5 has about 50% humidity. Use of this strength acid reduces the amount of water that can be removed in the primary scrubbers, thereby possibly reducing plant capacity.

Sample Calculations

Sample calculations for determining the number of transfer units are shown on Figure 16.

For dust recovery in Calc. #1, there are no back pressures involved, and the required NTU equals the log of the inlet divided by the outlet loadings.

Sample Calc. #2 illustrates an impossible design where there is too much vapor pressure of ammonia in the scrubbing liquid.

Sample Calc. #3 illustrates a reverse type calculation for obtaining scrubbing efficiency with a specified NTU.

FIGURE #16

SAMPLE CALCULATIONS

Sample Calculation #1:

A 1000 lbs/hr of dust enter a scrubbing system. It is desired that a maximum of 10 lbs/hr leave. How many NTU required?

$$NTU = \ln \frac{(1000)}{10} = 4.6 \text{ ANS}$$

Sample Calculation #2:

A dryer gas containing 0.94 mol % NH_3 is to be scrubbed with an ammophos solution MR = 1.35 at 160°F. How many NTU for 95% efficiency?
Inlet gas is -27" W.C. (710 mm Hg abs.)

$$P_1 = 710 \times 0.94/100 = 6.67$$

$$P_2 = 5\% \text{ of } P_1 = 0.33$$

$$P^* = 0.33 \text{ from Figure \#9}$$

$$NTU = \ln \frac{(P_1-P^*)}{(P_2-P^*)} = \ln \frac{(6.67-.33)}{(.33-.33)} = \infty \text{ Ans.}$$

JOB CANNOT BE DONE

Sample Calculation #3:

What is maximum efficiency above case if 3.0 NTU are available?

$$P_2 = \frac{(P_1-P^*)}{(e^{NTU})} + P^* = \frac{(6.67-.33)}{(e^3)} + .33 = 0.646$$

$$\text{Efficiency} = \frac{(6.67-.646)}{6.67} 100 = 90\% \text{ Ans.}$$

Dust Particle Size versus Energy

Figure 17 provides a good correlation between dust particle size and energy input of a venturi scrubber. Dust collection is covered very slightly in this paper because of the many published articles available such as references #16, #18, and #22.

NTU versus Energy

Figure 18 is a highly useful reference for general scrubber design work, although for high accuracy, it is always better to obtain data as close to plant operating conditions as possible. Venturi Curve #2 (top curve) is suggested for venturi scrubbers as an adequate basis for design for ammonia (DAP) and fluoride (TSP) scrubbing and DAP dust collection. For all practical purposes, all of the horsepower is supplied by the gas stream.

A typical DAP vendor quote will provide flow data and an 8-10" venturi pressure drop which calculates to 1.4-1.6 hydraulic horsepower per 1000 CFM via the following standard fan equation:

$$\text{HHP Gas} = \frac{\text{ACFM x Inches } H_2O\ \Delta P}{6356}$$

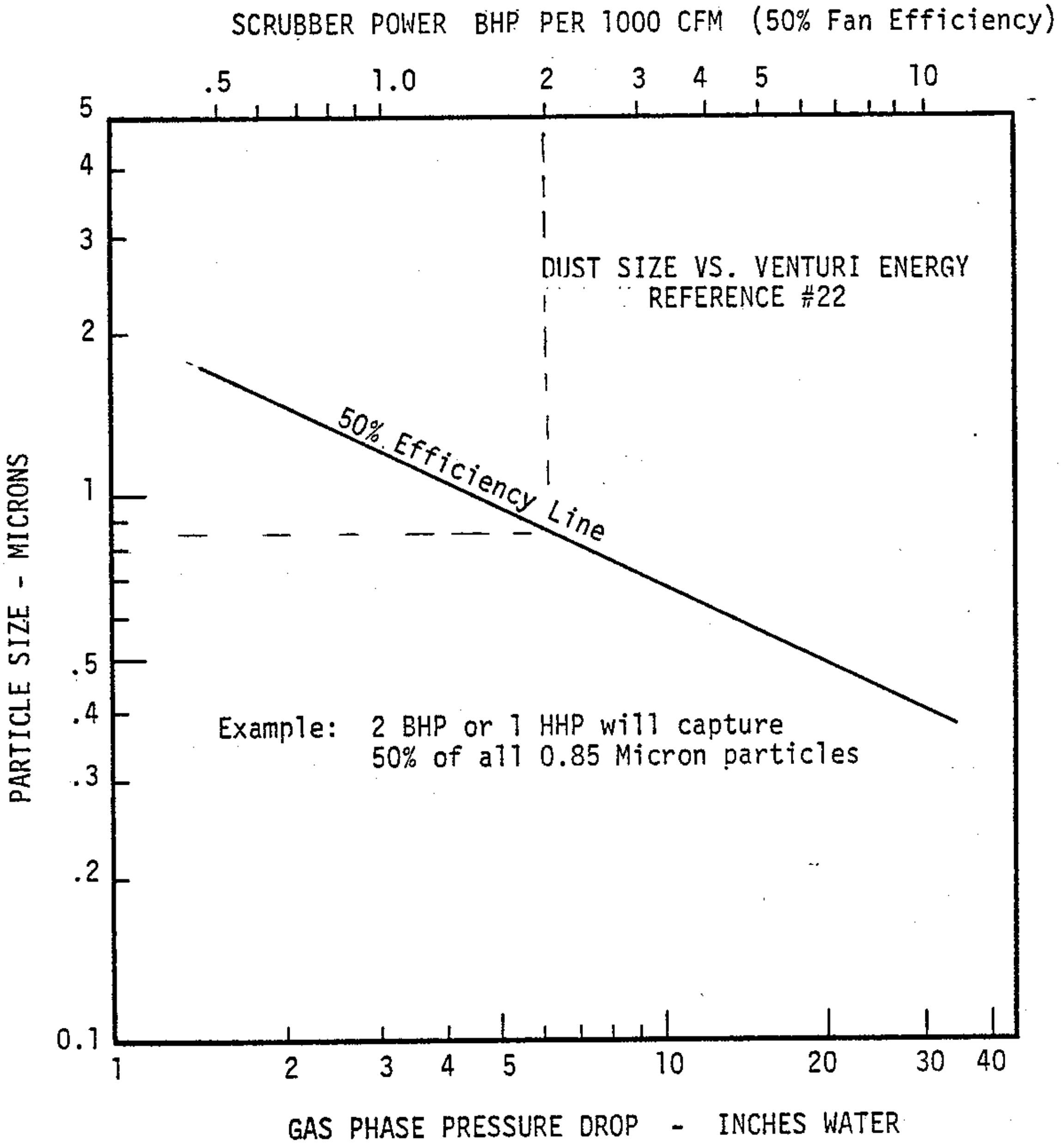
$$\text{Gas HHP} = \frac{1000 \text{ x } 10}{6356} = 1.6 \text{ (approx, 2.3 NTU)}$$

For liquid at 10 gals per MCF and 10 PSIG, the liquid HHP is negligible.

$$\text{Liquid HHP} = \frac{\text{GPM x PSI}}{1713}$$

$$\text{Liquid HHP} = \frac{10 \text{ x } 10}{1713} = 0.06$$

FIGURE #17

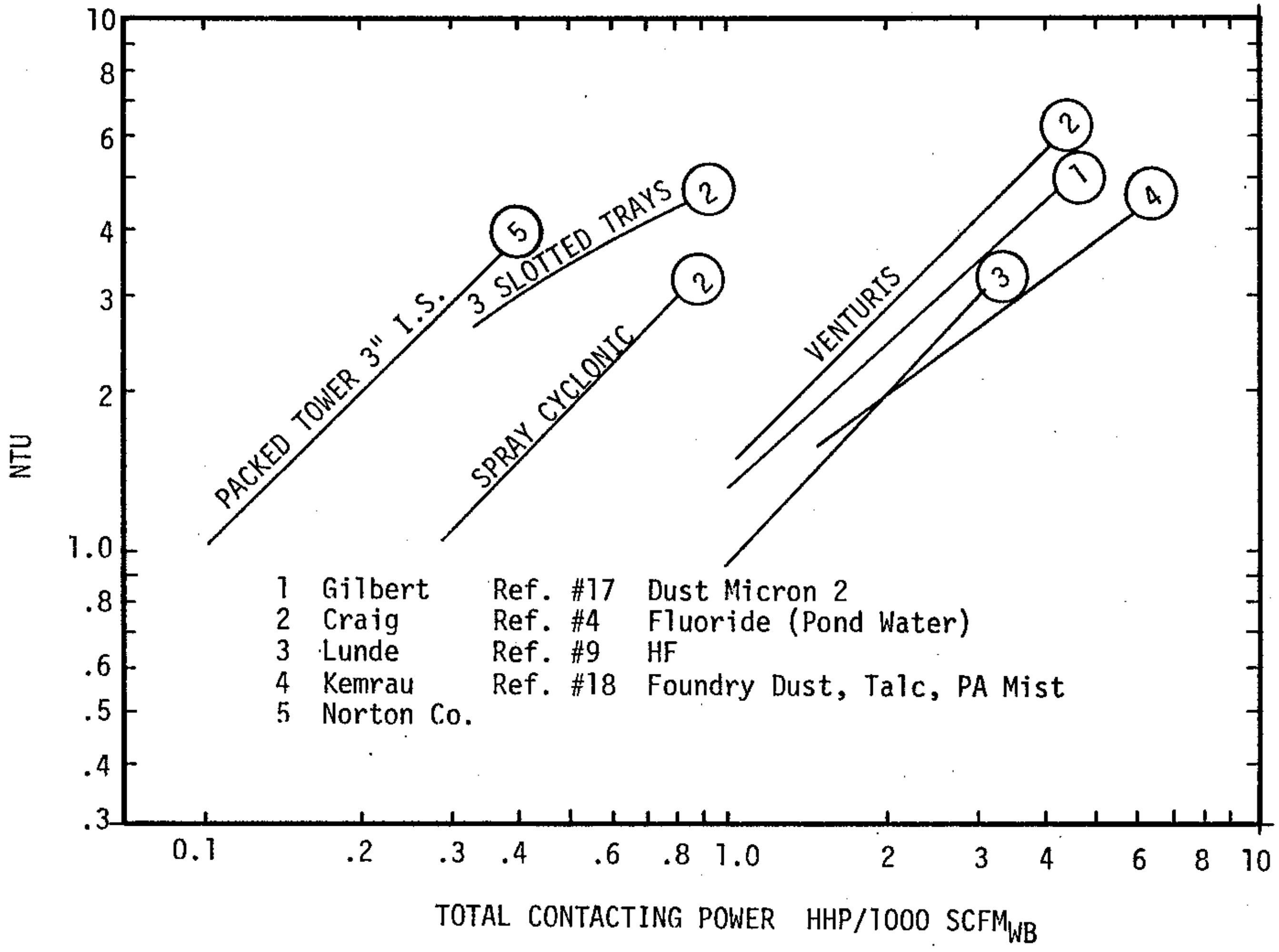


DUST SIZE VS. VENTURI ENERGY
REFERENCE #22

Example: 2 BHP or 1 HHP will capture 50% of all 0.85 Micron particles

FIGURE #18

CONTACT ENERGY VS NTU



At 130 feet per second throat velocity, liquid flow in gallons per 1000 cubic feed of gas has the following effect on venturi pressure drop (inches water) =

FLOW	Δ P
0	2
8	8
10	10
12	11

Changing the liquid flow provides a way of controlling the venturi pressure drop. Another way is by installing a damper or hinged plate which is relatively inexpensive.

Spray Cyclonic

Note that this type scrubber uses about one fifth as much energy as the venturi. The liquid horsepower is higher and accounts for from 10-50% of the total.

Packed Tower

The packed tower requires the least energy of all types.

Slotted Tray

The slotted tray or sieve tray type has not been used in granulation plants to any significant extent. They are used on some phosphate rock dryers. This type should be re-examined because energy usage is low, liquid requirements are low, and they should be fairly easy to clean.

Spray Chamber

This type is not shown. They are relatively inefficient and probably the energy requirements are slightly less than a spray cyclonic.

Solubility of Primary Scrubber Liquids

Most of us are familar with this solubility chart for ammonium phosphates. (Figure 19). Zone A (low mole ratio) is the operating area for most plants. Zone B (high mole ratio) reduces the fluoride problem but increases the ammonia loss problem and also precipitates a lot of solids which cause plugging. Zone C is avoided because of low solubility.

Figure 20 shows that ammonium sulfate enhances the solubility of MAP. This may explain why some plants prefer adding sulfuric acid to the scrubber tank instead of the reactor.

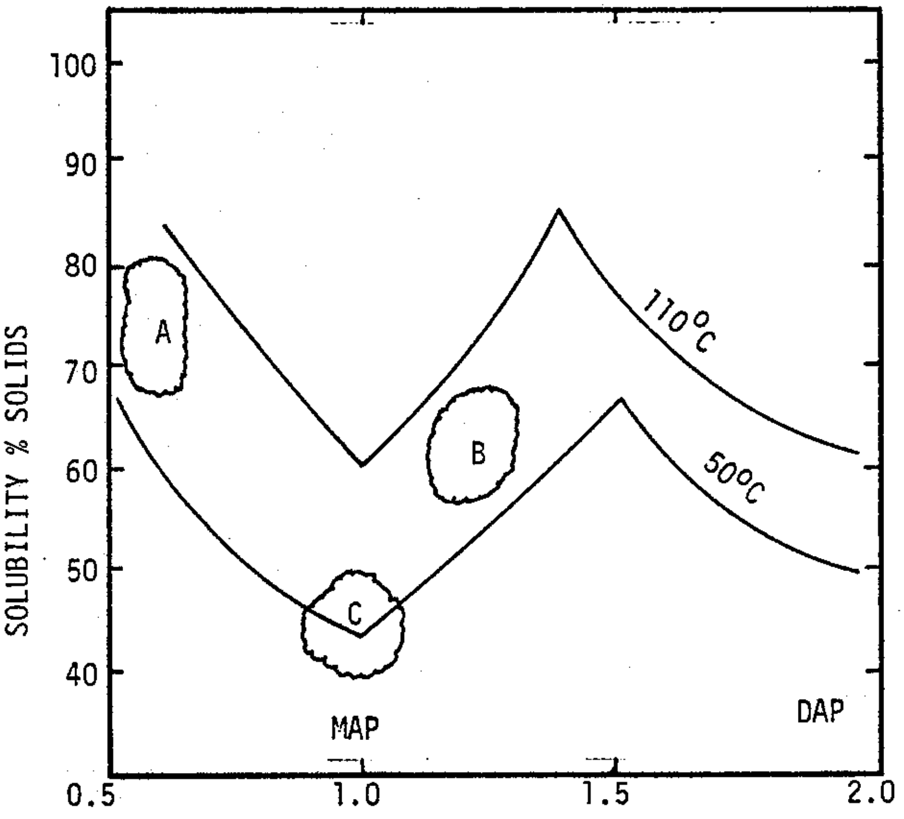
Another interesting point is that ammonium sulfate reduces the ammonia vapor pressure from ammo-phos solutions. If we were to boil a pure DAP solution in the laboratory, the addition of 5% ammonium sulfate would greatly reduce the rate of release of ammonia. The addition of gypsum has a similar effect.

Separate Pond for DAP - Figure 21

About four years ago, I was able to avoid a problem with the EPA by use of a small pond as shown. I think that a 10 acre pond could handle an 80 TPH DAP plant.

FIGURE #19

SOLUBILITY OF AMMONIUM PHOSPHATE



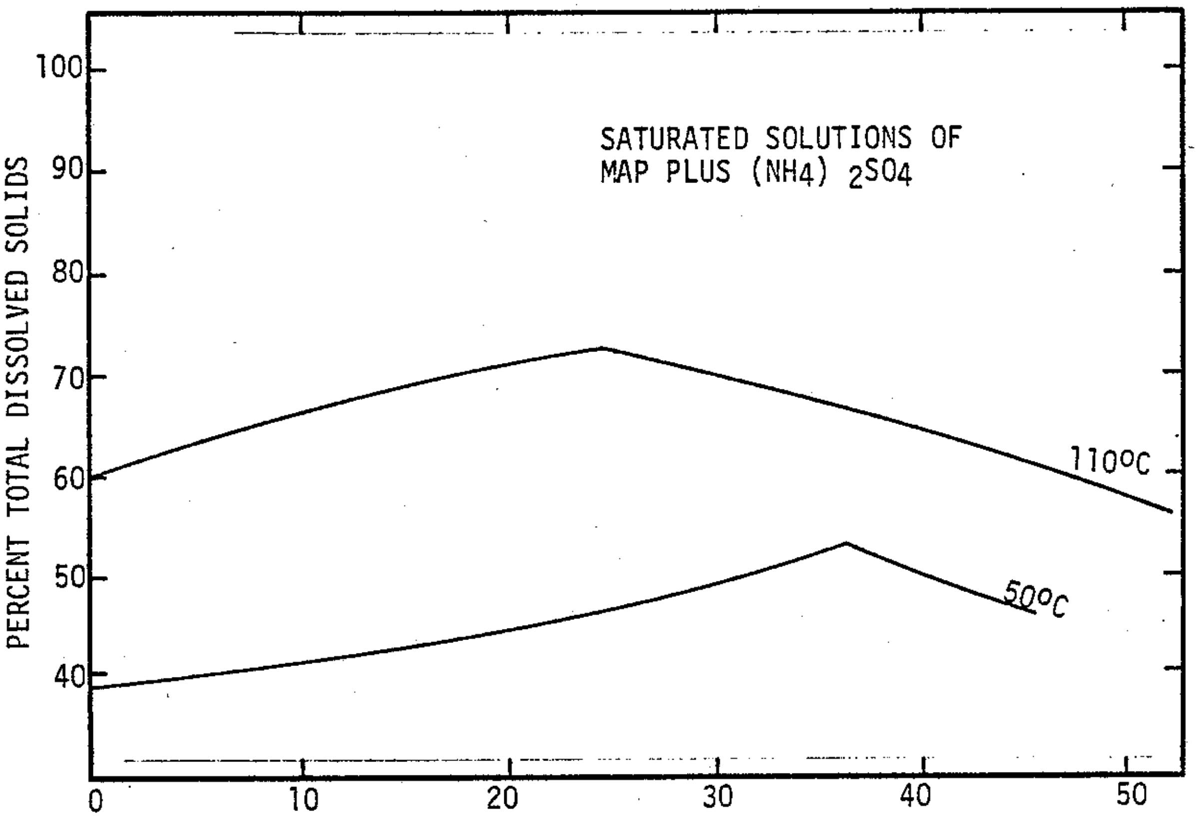
MOL RATIO NH_3/H_3PO_4

OPERATE PREFERABLY IN ZONE A

SECOND CHOICE IS ZONE B

FOR PRIMARY DAP SCRUBBERS

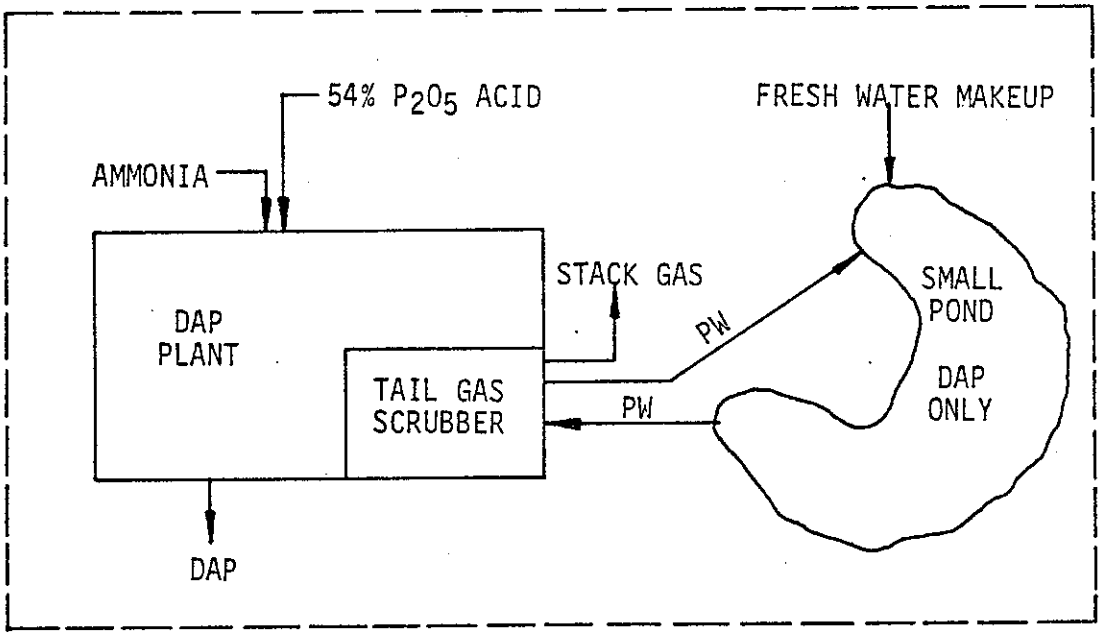
FIGURE #20



PERCENT $(NH_4)_2SO_4$ IN SOLUTION

FEEDING SULFURIC ACID TO DAP PRIMARY SCRUBBER SYSTEM IMPROVES SOLUBILITY SLIGHTLY.

FIGURE #21



USE OF A SMALL COOLING POND OF FRESH WATER ON TAILGAS SCRUBBER.

ADV.
a) A cooler cleaner stack.
b) No liquid effluent
c) No ammonia contamination of phos acid pond - separate contaminant
d) Better plant effluent control
e) Easier permit requirements

DIS.
a) Requires stronger phos acid feed

3.0 FINAL SELECTION - CONSIDERATIONS

Venturi Design - Figure 22

At one time a low pressure (12 psig) spray of pond water was installed above a venturi. Some time later severe erosion-corrosion occured at the throat. It was learned later that this could have been avoided by a liquid film as shown.

Note that dust buildup at the top of the venturi can be avoided as shown.

The bottom elbow plugup problem has been eliminated by use of the flooded elbow concept as shown.

Cyclonic Design - Figure 23

This figure shows some problem areas and corrective design steps on a cyclonic scrubber.

Scrubber Seal Tank - Liquid Flow

a) A minimum of one half hour retention time recommended to provide time for noting trends and taking corrective action.

b) An agitator is desired to prevent settling and improve sampling.

c) Install flow indicators on liquid lines to each venturi.

d) Locate a sample line near the control room.

Process Design and Operating Check List

a) Monitor fan amperage and scrubber pump amperage. Record every 2 hours.

b) Check scrubber pressure drops daily.

FIGURE #22

VENTURI

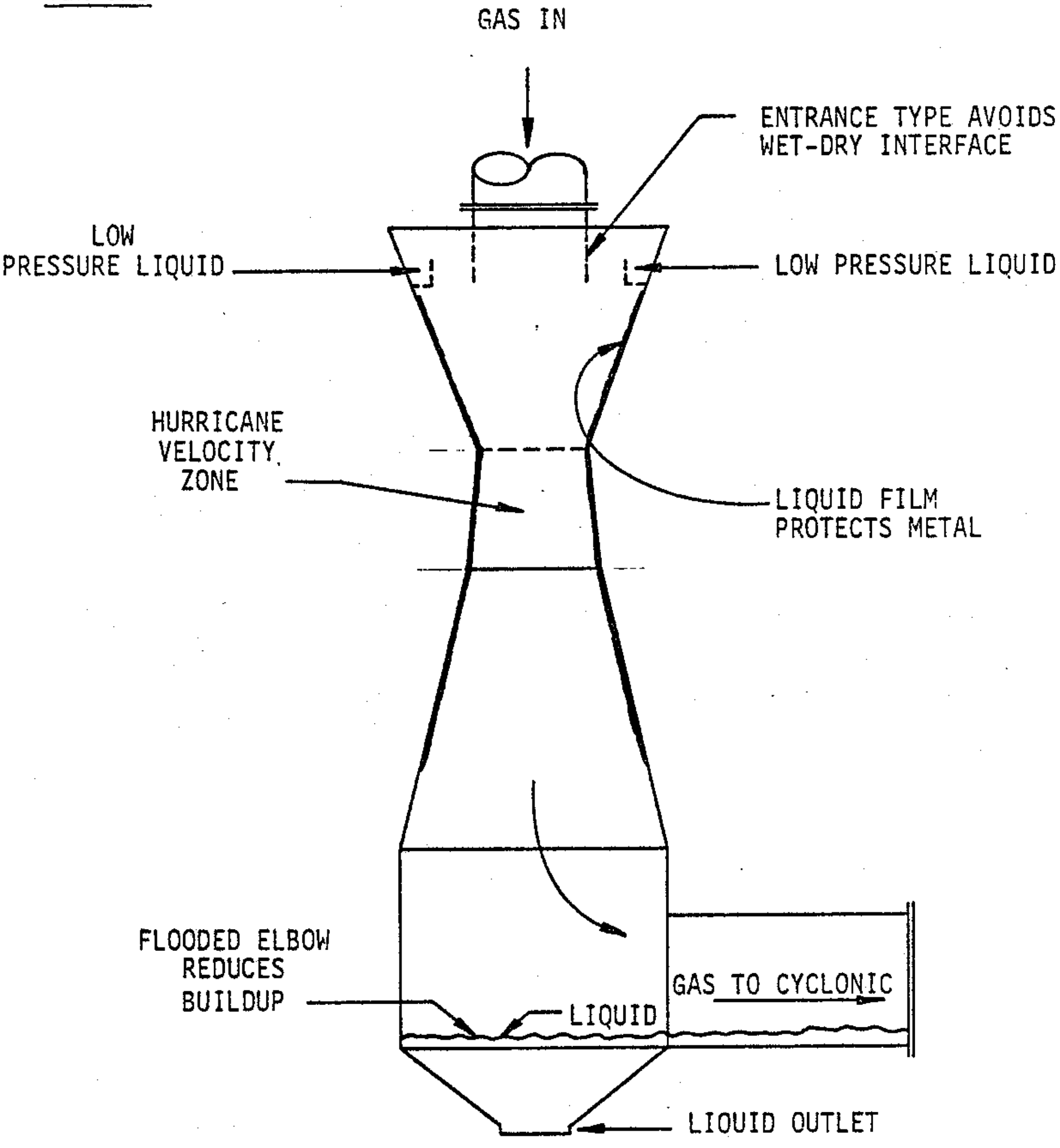
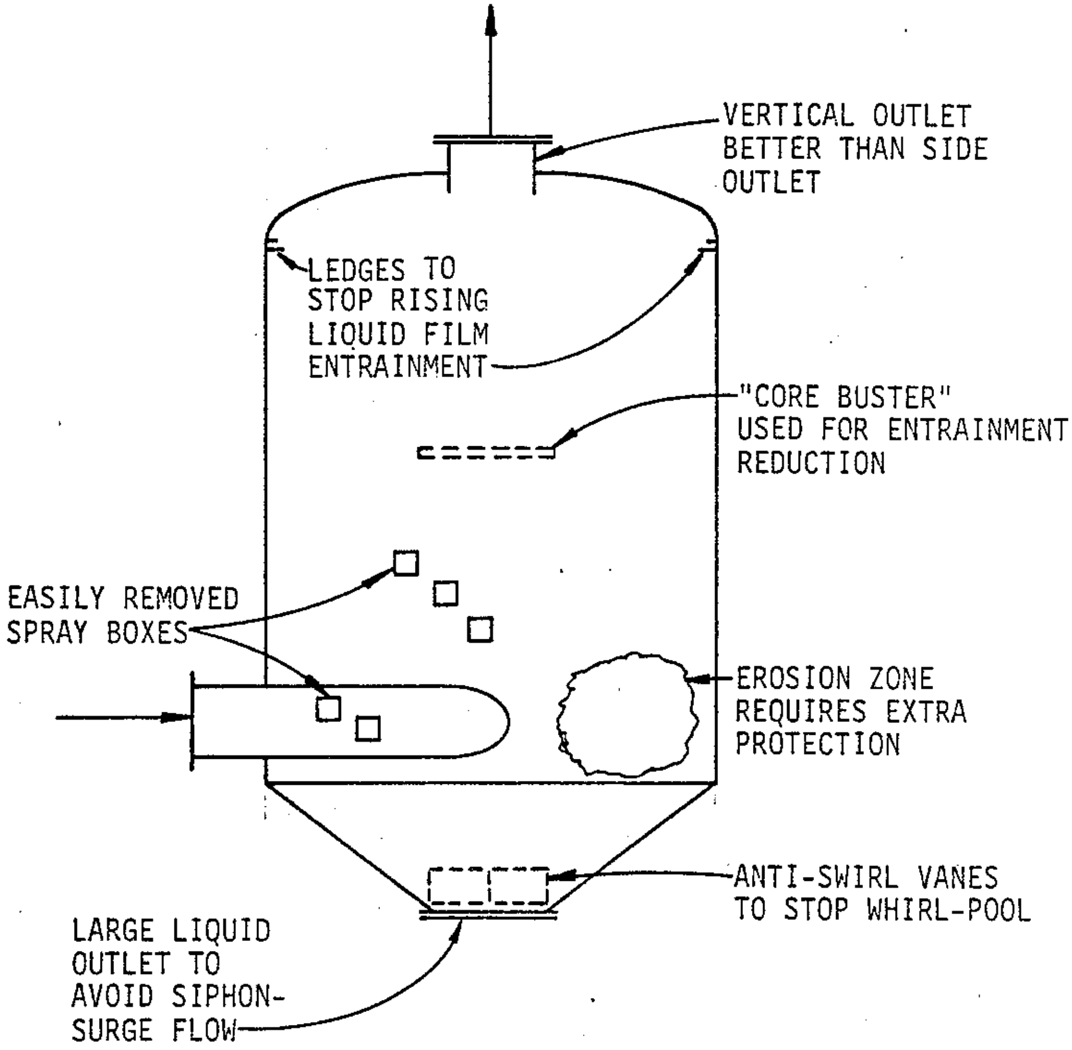


FIGURE #23


VERTICAL OUTLET BETTER THAN SIDE OUTLET
LEDGES TO STOP RISING LIQUID FILM ENTRAINMENT
"CORE BUSTER" USED FOR ENTRAINMENT REDUCTION
EASILY REMOVED SPRAY BOXES
EROSION ZONE REQUIRES EXTRA PROTECTION
ANTI-SWIRL VANES TO STOP WHIRL-POOL
LARGE LIQUID OUTLET TO AVOID SIPHON-SURGE FLOW

c) Inspect scrubber internals - weekly.

d) Check for plugged sprays - shift.

e) Record damper position - daily.

f) Measure air flows exit each scrubber - weekly.

g) Check and clean pond water filter-screens - daily.

h) Check for algae, barnacles, debris from sea water, if used - shock chlorinate when required.

i) Monitor defoamer flow to scrubber acid - as required.

j) Turn on fan wash sprays every shift and check housing drainage.

k) Hose down ductwork - weekly.

l) Remove and clean packing - 6 months.

m) Remove and clean demisters - monthly.

n) Monitor total ammonia flow and total acid flow to maintain stoichiometry.

o) If 40% acid must be used, a 40% blend from 30% and 54% acids is much better than 40% P_2O_5 from evaporators.

Vendor Data - Figure 24

Badger has recently engineered two 60 TPH DAP plants in the Middle East. Each plant has a reactor granulator scrubber, dryer scrubber, cooler-vent scrubber and a tailgas scrubber. Bids were received by 5 vendors - 2 French and 3 Americans, one German firm declined to bid.

The vendors were supplied with inlet loadings liquid compositions, required efficiencies and were told only the type scrubbers desired. It is noted that the equipment sizes and the energy usages were fairly close. The figure shows data on the dryer scrubber and the tailgas scrubber.

FIGURE #24

	VENDOR				
	A	B	C	D	E
	FRENCH	USA	USA	USA	FRENCH
DRYER SCRUBBER					
Gas in ACFM	60000	60000	60000	60000	60000
VENTURI					
GPM Liquid	581	484	598	704	*
PSIG Liquid	15-45	3	10	3	
ΔP Gas " W.C.	11.8	15	12	12	5.9
CYCLONIC					
GPM Liquid	610	240	418	603	*
PSIG Liquid	45	51	40	16	
Δ P Gas " W.C.	3.1	4	6	2	6
Diameter, Inch	134	138	126	132	120
Total Height, Inch	531	282	361	390	285
TAILGAS SCRUBBER					
Gas in AcFM	187,200	196,000	174,750	213,640	195,400
Gas Temperature, ^{o}F	136	145	131	153	154
Gas " W.C. ΔP	6.7	5	5	4	3
Liquid GPM	4620	1962	5280	2807	2640
Diameter, Inch	315	270	312	282	276
Total Height, Inch	524	585	684	551	386
Packing, Height, Inch	118	120	144	96	118

*Total Venturi plus cyclonic 941 GPM (79' Head Pump)

Cost of Scrubbing - Figure 25

This figure has some suggested cost factors for estimating the cost of a scrubber. The factors were arrived at from a large number of recent equipment quotations.

Quoted (Basis February 1980) cost ranges per CFM of gas (corrected to 70°F) are as follows:

Venturi-cyclonic = $1-$1.70
Packed Tailgas Scrubbers = $1-$1.55

4.0 SUMMARY

It is hoped that all or part of this paper will be of use to the operating people in the audience. We will be more than happy to discuss some of the items in greater details with you this weekend or anytime.

We at Gulf Design/Badger are currently assessing several different scrubber systems and lower cost approaches. The high energy cost of venturis, of centrifugal liquid separation, and spray type tail-gas scrubbing are becoming prohibitive.

In many cases, they are overdesigned due to 2 or 3 layers of design safety factors.

Several innovations have been developing in the plants including the use of plastic mesh packing and dry fluoride collection. Perhaps this work will be covered in next year's meeting.

This concludes our paper. Thank you for your attention.

FIGURE 25

SUGGESTED COST FACTORS FOR SCRUBBER COST ESTIMATES

(February 1980 Basis, Local Shop. Supplied with Design Drawings)

1. SCRUBBER SHELL	(DENSITY)	
a) Carbon Steel	493 pcf	= 1.50 $\$/\mathrm{lb}$
b) 316L SS	493 pcf	= 5.00 $\$/\mathrm{lb}$
c) 317L SS	493 pcf	= 6.00 $\$/\mathrm{lb}$
d) Rubber Lining (1/4")	95 pcf	= 12.00 $\$/\mathrm{ft}^2$

2. Add 10-20% to shell to include flanges, stiffeners, manways, sprays, spray valves.

3. a) Packing 3" I.S. Polyprop = 4.20 $\$/\mathrm{ft}^3$

   b) Packing Support, Holddown, Distributors (316 SS) = 8.00 $\$/\mathrm{ft}^3$ packing

4. For design, engineering, bond, guarantee, and sales commission - add 30-40% for scrubber vendor.

BIBLIOGRAPHY

REF. NO.	REFERENCE
1.	Personal Files - A. Hansen
2.	Partial Pressures of HF, SiF_4 Over H_2SiF_6 Solutions W.V. Illanionev ET AL, Zhumal Prikladnoi Khimll Vol. 36 No. 2 PP 237-241, February 1963
3.	Parameters of Fluoride Emission From Gypsum Ponds B.S. Tatera, PhD Thesis, University of Florida, 1970
4.	Fluoride Removal From Phosphoric Acid Reactor Gases John M. Craig, PhD Thesis, University of Florida, 1970
5.	Mechanics of Mass Transfer, J. Osborn, Chem. Eng. 4/21/58, PP 161-165
6.	Transfer Unit Simplities Calculations, J. Osborn Chem. Eng. 8/11/58, PP-147-150
7.	Calculation of Diffusional Processes, A.P. Colburn IEC Vol. 33 No. 4, PP 459-466
8.	Control of Gaseous Fluoride Emissions, A.J. Teller Chem. Eng. Prog. Vol. 63 No. 3, PP 75-79, March 1967
9.	Performance of Equipment for Control of Fluoride Emissions, K.E. Lunde, IEC Vol. 50, No. 3, PP 243-248 1958
10.	Spray Type Absorbers - Performance, R.L. Pigford IEC Vol 43, No. 7, PP 1649-1662, July 1951
11.	Experiments on an Industrial Venturi Scrubber J. Brink (Monsanto) IEC Vol. 50, No. 8, PP 1157-1160 August 1958
12.	Engineering Data for Packed Towers - DC-10R Norton Co.

BIBLIOGRAPHY

REF. NO.	REFERENCE
13.	Problems in the Granulation of 18-46-0, S.M. Kullfay (Monsanto) ACS Talk New York 9/12/66
14.	Ammonia - Phos Acid - Water System, F.H. Lenfesty TVA #265
15.	Perry's Handbook - Mechanical Separation Section 15. Entrainment - Othmer Chart
16.	Power vs. Efficiency - Dust Scrubbers IEC Vol. 50 No. 11 PP 1615-1620
17.	Upgrading Existing Particulate Scrubbers, S. Calvert ChE 10/24/77 P 143
18.	Correlation of Dust Scrubber Efficiency, K. Semrau JAPCA 10, No. 3, June 1960 P 204
19.	"The Chemistry of Fluorine, etc", I.G. Ryss, Moscow 1956 (USDC) P54
20.	The Separation of Liquids with Cyclones, A. Polloch Trans. ASME 1942 64 P 31
21.	Wire Mesh Demister Efficiency, C. Carpenter A.I.ChE, 1 No. 4, P 549 (1955)
22.	Upgrading Dust Scrubbers, S. Calvert Chem. Eng. 8/29/77 P 67

SPEAKER BIOGRAPHY

Arthur O. Hansen
Gulf Design/Badger

Art Hansen started in the phosphate industry when prime interest rates were below 5%.

He has a BCHE from New York Poly, an MCHE from New Jersey Institute of Technology, and has Professional Engineering licenses from New York and Florida.

His career has been divided at about 1/3 R&D, 1/3 plant operations and 1/3 contractor process design. He has been directly involved in the basic design of 14 granulation plants and several other types of plants involving a large variety of scrubbing problems.