PHOSPHATE PLANT SCRUBBERS

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Design Review

This paper is intended to focus primarily on the correction of scrubber problems in existing plants.

To do this, we have to understand scrubber behavior and the design basis. Accordingly, we will briefly review design aspects which are covered fairly thoroughly in previous papers by the writer (ref.1 & ref.2). These papers in turn list many additional references, and are obtainable from Badger Engineers and Constructors Inc.

Since most of the engineering data for scrubbers originated in the '40's and '50's, we have revised very little, if any, of the design bases - and we are reusing some of the slides from reference 1. Actually, there have been no significant changes in scrubber designs in the past ten years - but there has been frequent recurrance of old problems. I recall the words of a retired Wellman Lord executive " Please bring me some NEW mistakes!"

Figure 1 - Scrubber Design Inputs

This slide shows the basic flow of information leading to final scrubber design.

Flow sheets have not changed much in the past 20 years. Larger plants and expanded plants have increased the number of equipment items.

Heat and Material Balances are perhaps more accurate because of more and better input data, and the greater use of computers. Instrumentation, process control, record keeping, etc. have improved greatly.

Designs are tighter and more competitive. New granular plants are going to operate at perhaps 110% rather than 150% of design. Existing plants operating at increasing rates have higher scrubber loadings requiring additions and modifications.

Fluoride vapor pressure data are still based on early work by Illanionev, Tatera, Craig, Parish, and others.

The next **Figure 2** provides some useful equations for estimating the number of transfer units (NTU) required for design.

Let us now briefly review the gases we are dealing with in the phosphate industry.

I prepared **Figure 3** for discussion purposes- most of us are very familiar with these gases. Trace gases and dust content are not listed. Some comments are offered as follows:

a) Phos acid scrubbing is fairly simple. The designer assumes SiF_4 to be the problem on dihydrate acid and usually ignores the HF content. Air and CO_2 are listed since they have a major effect on the mass transfer coefficient - because of the resistance of the gas film at the interface where the scrubbing is taking place. This gas film resistance is minimized in vacuum type isothermal reactors and evaporators.

b) The 42% acid is largely free of dissolved silica. I believe this is part-cause of DAP plant fume problems. A blend of 28% and 54% to make 42% is considered better in this regard than straight 40-42% evaporator acid -but we prefer to avoid it.

c) Granulation plants can be designed with a negative water balance - if we are willing to use high strength 52% acid. We have designed and started up three of this type - with fewer scrubber problems,better stacks, and better product quality and capacity. There is no place for the P_2O_5 to go except in the product - hence no loss - a major sales point! Also,stack fluoride in a Jordan DAP plant never exceeded one kilogram per day.

d) For DAP plants, the addition of an ammonia pre-scrubber or "Dual-mole-ratio" system has been adopted by most plants. I helped develop this at a Bartow plant 15 years ago. The efficiency is kept low (65%) for process reasons - more on this later.

The prescrubber becomes an additional stage <u>fluoride</u> scrubber in MAP and ASP (ammonia sulfate-phosphate) or 16-20-0 production - good for these multi-product plants.

e) In NPK plants, the designer must be aware of nitrous oxide gas problems. There were several incidents in the '60's of the laughing-gas chain reaction in storage buildings, and granulator fires, which caused major safety-environmental-product loss problems. I spent over a year on this subject.

f) Normal Super is still an important product overseas-especially Australia -my first job on day #1 in Fla.. This was USA's major phosphate product in the '50's. Falling film towers were used for 14% FSA recovery -silica was a headache. The recovered acid was used for a variety of fluosilicate salts production.

SCRUBBER LIQUIDS - Figure 3 cont'd

g) Pond water -no comments -except that we like to see the water percolate through miles of gypsum to bring down the fluoride content.

h) At least one local plant uses recirculated 'fresh' water from a small pond - with good results.

i) Use of sea or ocean water requires the use of chlorine injection to control marine growth.

j) Medium strength 42% P205 acid is desireable in cold weather plants -from a storage/handling viewpoint- because its freezing point is over 100 degrees lower than 28 or 54% acids. In recent years, use of 42% evaporator acid may have caused the ammonium fluoride fume problem to reappear at a Western US and a Western Canadian complex.

k) The use of ammonium phosphate (AP) solutions in DAP plants may be discussed in three categories -- low, medium, and higher pH - these correspond roughly to mole ratios N/P of (.5-.8), (.9-1.1), and (1.2-1.6) respectively.

The low pH solution is good for ammonia scrubbing but fluoride is stripped and sent to the tail-gas scrubbers.

The high pH solution stops fluoride evolution but results in ammonia loss to the tail-gas scrubber.

The medium pH solution is an ideal compromise, but requires some process dilution with water to keep MAP from crystallizing out. This ultimately requires a stronger P205 acid (higher than combined average input 40% P205) and more phos acid evaporation capacity in the complex.

An alternate approach is to operate an ammonia prescrubber at a high temperature 210 F and high pH ----followed by the regular primary system at low pH.

A combination of both approaches provides even better flexibility and improved operation. I chose this combination for a Western plant about 5 years ago.

SOLIDS PLUGGING PROBLEMS

A variety of chemical reactions contribute to buildup and equipment plugging:

- the reaction of silicon tetrafluoride with water to form silica.
- the reaction of an alkali such as ammonia with gypsum pond water to form SiO_2 and CaF_2 solids.
- the reaction of ammonia with wet process phosphoric acid to form insoluble iron/aluminum/sodium/calcium/potassium-fluoride compounds.

GAS GENERATION PROBLEMS

Salts of a weak acid and a weak base are relatively unstable. For example, process heat can decompose commercial DAP or MAP and increase scrubber loadings. Commercial DAP and MAP contains appreciable ammonium fluoride:

$$NH_4HF_2 + heat \rightarrow NH_3 + 2HF$$
$$NH_4F + heat \rightarrow NH_3 + HF$$
$$(NH_4)_2HPO_4 + heat \rightarrow NH_4H_2PO_4 + NH_3$$

SBRUBBER TYPES AND PROBLEMS

Cross-Flow Packed Scrubbers - see Figure 4A.

A large number of these scrubbers were installed in the '60's and '70's - for phosphoric acid plants and for secondary or 'tail-gas scrubbers' on granulation plants.

Problems:

a) Solids buildup at point "A", caused by chemical reactions and dust.
b) Bypassing of gas flow with entrainment at point "B".
c) The inherent lower efficiency of a cross-flow vs. countercurrent scrubber.
d) The use of small size (plugging-prone) packing.

Remedies:

a) Minimize NH_3 in feed gas "C" if present, and replace packing with plastic mesh cloth for easier cleaning.
b) Revise baffles to prevent bypassing.

In general, the design is poor since it is not self-cleaning.

Liquid Venturi - Jet - see Figure 4B.

Here is another type system recently installed in a phosphoric acid plaant being prepared for hemi-hydrate mode operation. Air flow is obtained by a fan supported by liquid induced venturis. The unit appears to be functioning well.

Problem: Client complained of high entrainment and fluoride evolution from stack.

Field Check: Noticed a cyclical pattern of one-hour wet stack followed by one-hour dry stack (with aid of sophisticated tool-a broom handle). Requested a shutdown and scrubber inspection.

Cause: Demister "A" had two back layers of very fine cloth which was blinded by very fine silica. Operator had instructions to turn on pond water sprays on demister when pressure drop indicator on control board showed high. This caused a one hour accumulation of pond water at "B".

Remedy:
a) Replace fine mesh pads with coarser pads.
b) Install drain system at point "C".
c) Cleanout blocked drain at "D".

Note: Although the unit has performed well, this type scrubber is more applicable to liquid-film controlling mass-transfer than air-film controlling.

Venturi Scrubber - see Figure 5.

This drawing is self-explanatory. Some designs have an elbow at the bottom which tends to build up with solids. It is a good idea to have an adjustable throat to permit some velocity control. A velocity of 130 feet per second is good. These adjustable accessories reduce efficiency and increase pressure drop slightly.

Coaxial Venturi - see Figure 6.

Several coaxial scrubbers have been installed in granulation plants. They have performed very well. The design eliminated the elbow buildup problem and reduced entrainment by what I call the "tornado effect" in the cyclonic section - because of the annular path. The unit can have either top or bottom gas discharge to save on ductwork.

The bottom drawing shows one of my first designs (1973). Two of these were installed on triple-super plant/storage -at about 40% cost of quoted units. This permitted us to stay within budget at the time. The design combines a venturi, an impingement section, and a packed tower in one vessel. There were mechanical problems with packing support and holddowns, lack of a gas flow damper - which were corrected. Process efficiency was very high.

Cyclonic Scrubber - see Figure 7.

This type is often connected in series with a venturi. Some vendors design high velocities in the tangential inlet which improves efficiencies but increases pressure drop and erosion at point "A".

Problem:

In a Jordan DAP plant, a large piece of rubber lining (2 sq.yds.) fell off at point "A" at a very inoppertune time - the eve of a test run. This jeopardized a large incentive bonus to the prime contractor for getting the acceptance test run done on time.

Causes:

a) Prolonged exposed storage of equipment in the desert
b) Use of unauthorized Japanese antifoam not listed in job specifications.
c) Lack of extra rubber lining at erosion zone.
d) Possible use of poor bonding agent by US vendor.

Temporary Remedy:

Operate scrubber at a non-corrosive pH range 5.9-6.1 and a 1.26 specific gravity -maintain ammonia stack loss under 2% as per contract. Complete test run at excess of design rate.

Remedy (permanent)

Strip and reline scrubbers. (neoprene used by German vendor). Use double thick liner in erosion zone. Use acceptable antifoam.

Vertical Packed Tower -see Figure 8.

I installed the first of this type in a Florida GTSP plant in 1970 - which is still in operation. This was of typical standard design used in other industries at the time. We used the largest (3" I.S.) plastic packing available, and equipped it with a circulating pump.

Some comments on this drawing are as follows:

Point A) Bottom of unit sloped for sludge cleanout.
B) Emergency overflow provision.
C) Packing supports must have greater open area (i.e.100%) than packing itself (i.e.94%) - secure to vessel.
D) Packing of 3" Intalox Saddles for efficiency and low buildup characteristics.
E) Hold-down mesh to keep packing in place.
F) Low pressure (0-15 psig) liquid distributor to avoid entrainment - weir type preferred.
G) Demister

H) Demister cleanout sprays
J) Inlet elbow
K) Adequate number and size of manways.

Problem#1 -

Scrubber filled up with water causing elbow "J" to break with drainage of packing over a wide area - and plant shutdown

Cause:

a) Failure of level controller.
b) Packing supports not secured

Remedy:

a) Replace level controller.
b) Install emergency overflow "B"
c) Secure packing supports at "C"
d) Install new elbow and replace packing

Note: This was a case where the exit water required pumping to a distant pond - with some flow control of liquid to the primary scrubber.

Problem#2

A rapid drop in circulating pump amperage and liquid level occurred - a warning of future trouble.

Cause:

Foaming

Remedy:

Add antifoam. Type used must be stable under process pH conditions and will not deteriorate rubber lining.

Problem#3 - west Mexico

Phone call -top of packing plugged up with solids ------analysis $CaCO_3$.

Cause:

Marine organisms -barnacles?

Remedy:

a) Clean up packing - use dilute acid.
b) Install chlorination system as earlier requested.

Spray Scrubber (FSA - Swift type)

Many of these scrubbers are in service. They are used to scrub evaporator vapors to prepare fluosilicic acid (FSA) and to reduce fluoride loading to the plant cooling pond. The units are expensive and equal in size to phos acid evaporators.

After study of data from various plants our conclusion is that these units are extremely overdesigned. In all cases the vapor leaving was in equilibrium with the liquid leaving the unit. The reason for this is the near absence of air or non-condensibles which would otherwise have a profound effect on mass transfer due to gas film resistance. Poor performance of these units in some plants is due to incorrect operating conditions, and in some cases a low cost two-stage system is indicated.

TROUBLE-SHOOTING CHECK LIST

It is important to have or secure adequate data to diagnose a problem when it occurs. For example, the presence of P205 in a stack sample indicates a mechanical problem (entrainment) instead of a process or chemical problem.

A suggested starter list is as follows:

Hourly - this would include normal process information on the log sheets such as:

a) Flows, Temps, Levels, SG's, pH, mole ratios, pressures
b) Fan and pump amperage
c) Check dust discharge rate from dry cyclones

Shift

a) External inspection of equipment
b) Check for plugged sprays
c) Check for leaks
d) Turn on fan sprays and check fan drain
e) Analyses where required

Daily

a) Static pressures and delta P's -scrubbers, fans, cyclones
b) Record damper positions
c) Check and clean pond water screens

Weekly

a) Inspect scrubber and fan internals - clean
b) Vibration check on fans
c) Analyze stack samples

Periodic

a) Clean demisters - as needed
b) Clean packing - 6mos.?

CLOSING REMARKS

The author thanks AIChE for the opportunity of giving this paper and hopes that it is of some value to the attendees and has stimulated some new ideas.

SUMMARY

This paper has reviewed scrubber operating variables, design data, design features, and problem areas - relating to the phosphate industry. Several case histories from operating plants are described. A preventive check list is discussed.

---AIChE Clearwater,Florida May 1991

RELATED PAPERS BY SPEAKER

1) "The Design and Selection of Scrubbers for Granulation Plants" AO Hansen ------AIChE Clearwater, Florida 1980

2) "Scrubbers for Phosphoric Acid Plants" AO Hansen & RJ Danos, Chem Eng.Progress , March 1982 pp 40-45

3) "Changing Technology in Fertilizer Granulation Plants" AO Hansen & RJ Danos, ACS 1982 Meeting Aug.23,1983 NY,N

4) "DAP Plant Startup at AQABA " A Hansen, IFA Middle East Technical Seminar Oct.25-27, 1983 , Aqaba,Jordan

SPEAKER BIOGRAPHY

The writer has been in the phosphate industry for 40 years ranging from laboratory to farm application . A decade of R&D supervision covered subjects from lawn products, bulk blending, liquid NPK, and detergents. Plant work involved phosphorus, fluorides, sulfuric acid, 6 initial startups in 4 countries of AP,GTSP,PhosAcid. As a senior process design engineer he has designed many plants. He has been with four major phosphate and three major engineering companies.

The writer's services are available for plant studies, technical audits, or laison work. For questions call (813)646-4926.

FIGURE
1

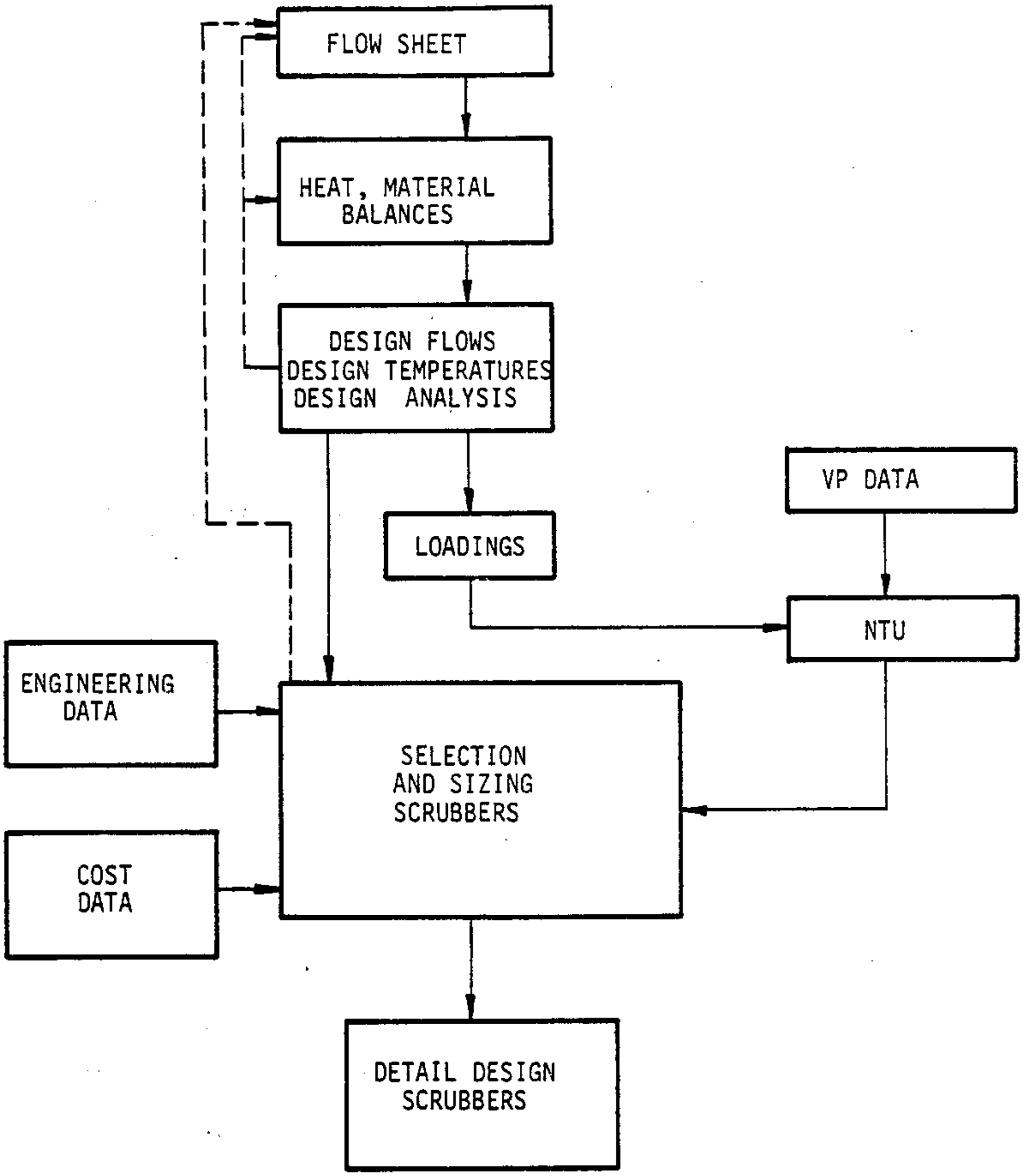
FLOW SHEET
HEAT, MATERIAL BALANCES
DESIGN FLOWS
DESIGN TEMPERATURES
DESIGN ANALYSIS
VP DATA
LOADINGS
NTU
ENGINEERING DATA
SELECTION AND SIZING SCRUBBERS
COST DATA
DETAIL DESIGN SCRUBBERS

Figure 2
USEFUL NTU EQUATIONS

Venturi-Cyclonic Scrubber *

NTU = 1.5 x P/Q   where: P = hydraulic horsepower
Q = MSCFM wb (thousands of standard cubic feet per minute- wet basis)

Spray Tower *

NTU = 4.0 x P/Q   where: see above

Vertical Packed Tower - with 3" Intalox Saddles

NTU = 0.36 x H   where: H = feet of packing height

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* calculated from doctorate thesis: J.Craig, Univ.Fla. 1970

Note: The Spray Tower uses considerably less energy. It is limited to about 3 NTU. Performance on dust collection is poor.

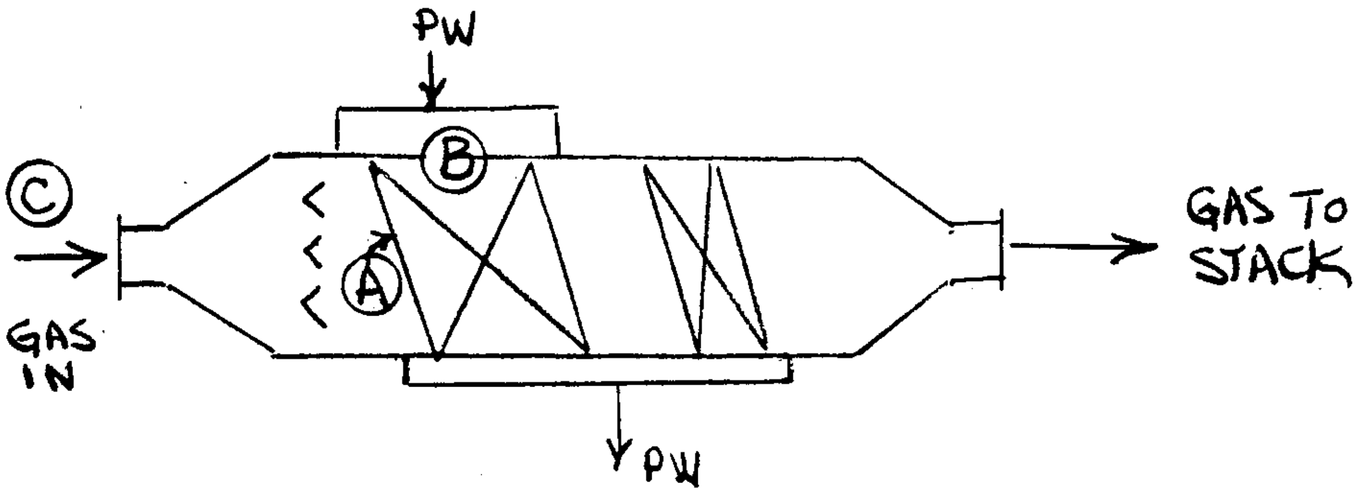
Figure 3

CONTENT OF GASES EXIT PROCESS TO SCRUBBERS

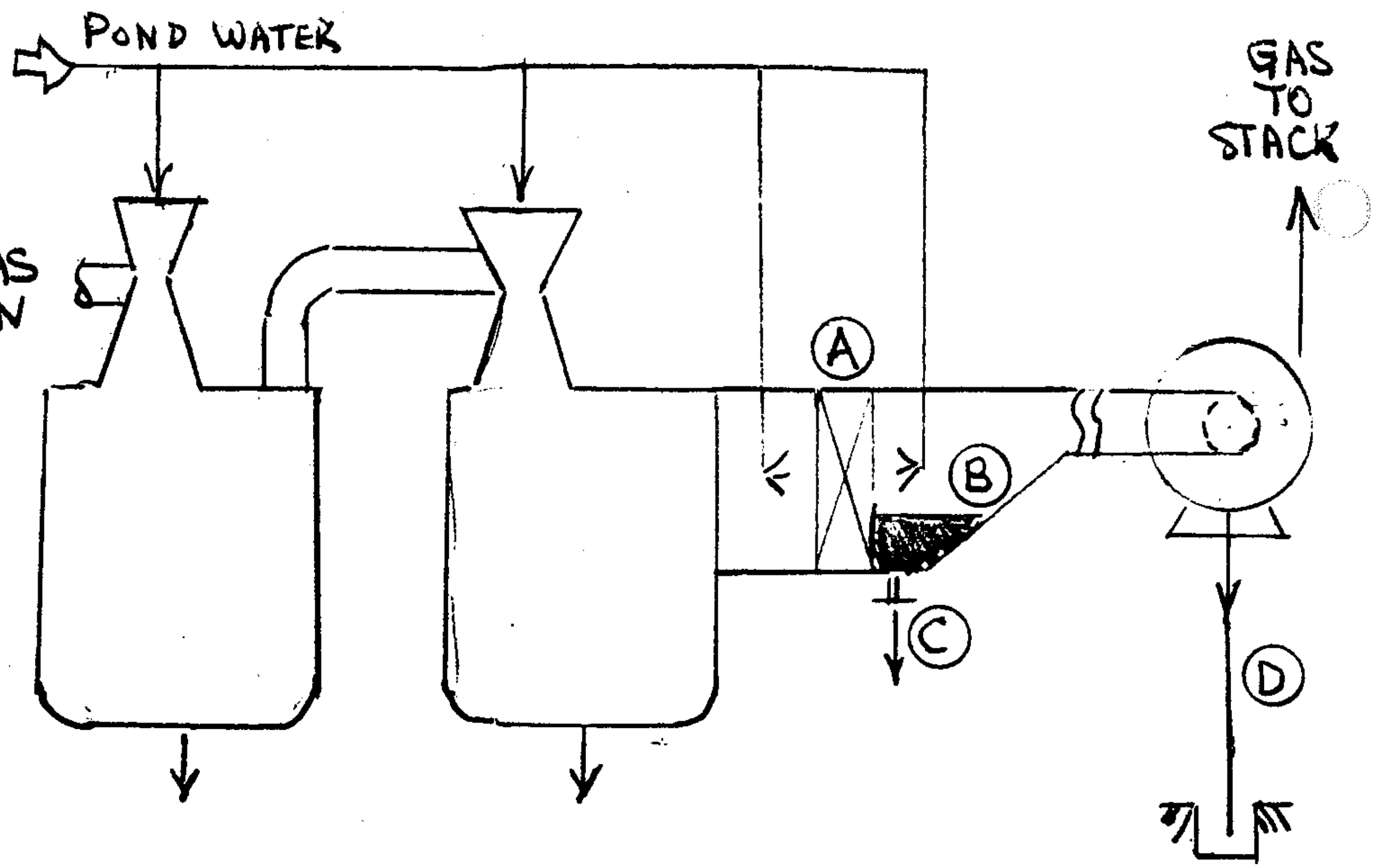
Phos Acid 28%P2O5------------	SiF_4, CO_2, H_2O, air
Phos Acid 40%P2O5------------ (hemihydrate)	SiF_4, HF, CO_2, H_2O, air
Phos Evap,28->42%------------	SiF_4, HF, H_2O
Phos Evap,42->54%------------	HF, H_2O
Phos Evap,54->68%------------	HF, H_2O
Normal Super 20%P2O5---------	SiF_4, HF, H_2O, air
GTSP 46%P2O5-----------------	SiF_4, HF, H_2O, air
DAP--------------------------	NH_3, HF, H_2O, air, (fume)
MAP--------------------------	HF, SiF_4, (NH_3), H_2O, air
ASP (16-20-0)----------------	HF, SiF_4, (NH_3), H_2O, air
NPK--------------------------	NH_3, HF, H_2O, air, (N_2O)
Defluorinated Phos Rock------	HF, SiF_4, CO_2, air
Phos Rock Dryer--------------	H_2O, air,

GASES FROM SCRUBBER LIQUIDS

Gyp Pond Water---------------	HF, SiF_4, H_2O
Ammophos Sol'n pH 0-3 -------	SiF_4, HF, H_2O, (fume)
Ammophos Sol'n pH 4-5 -------	H_2O (requires low SG=1.26 to avoid crystals)
Ammophos Sol'n pH 6-8 -------	NH_3, H_2O



CROSS FLOW FIG. 4 A



LIQUID-VENTURI

FIG. 4 B

FIGURE
5

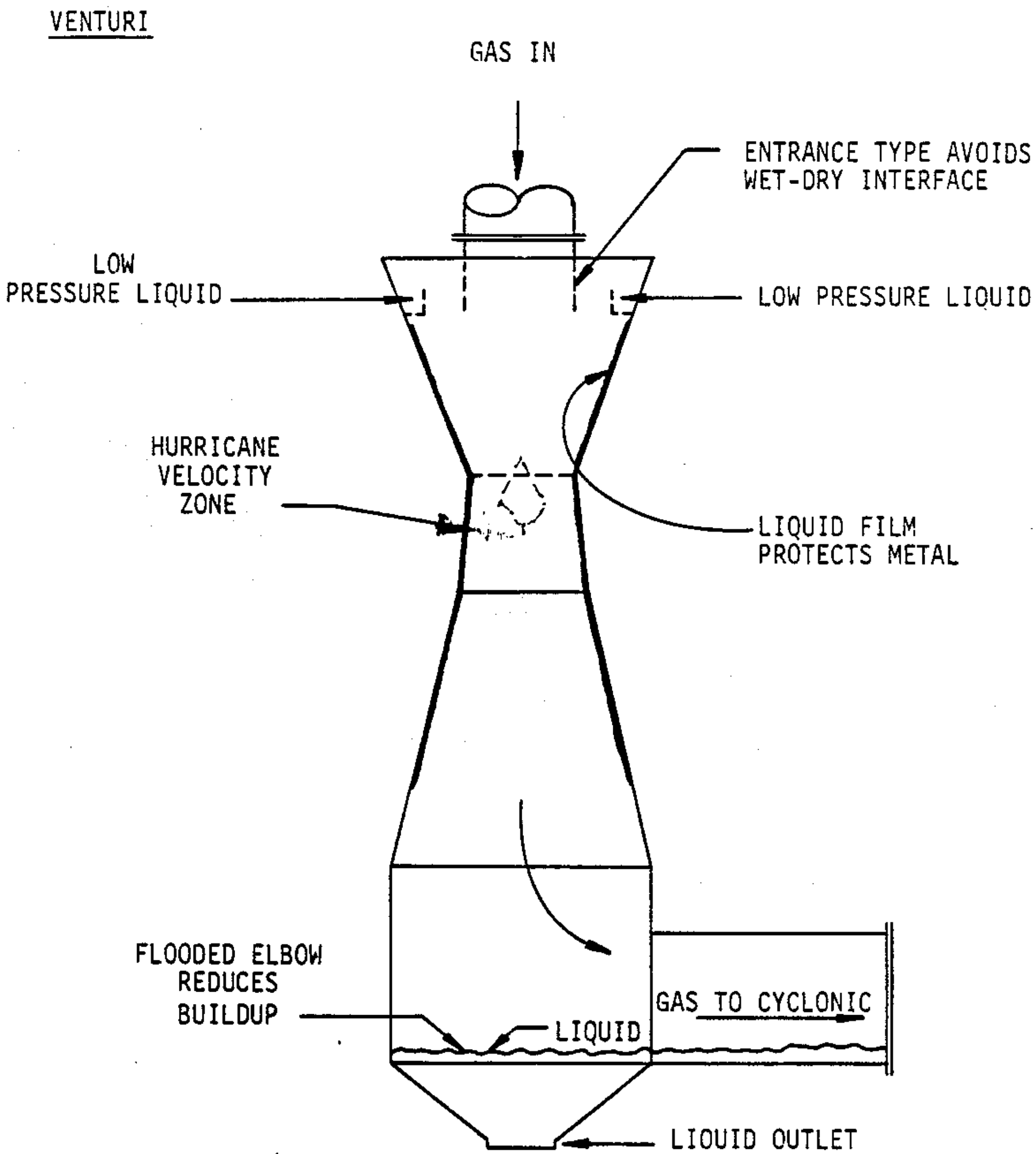
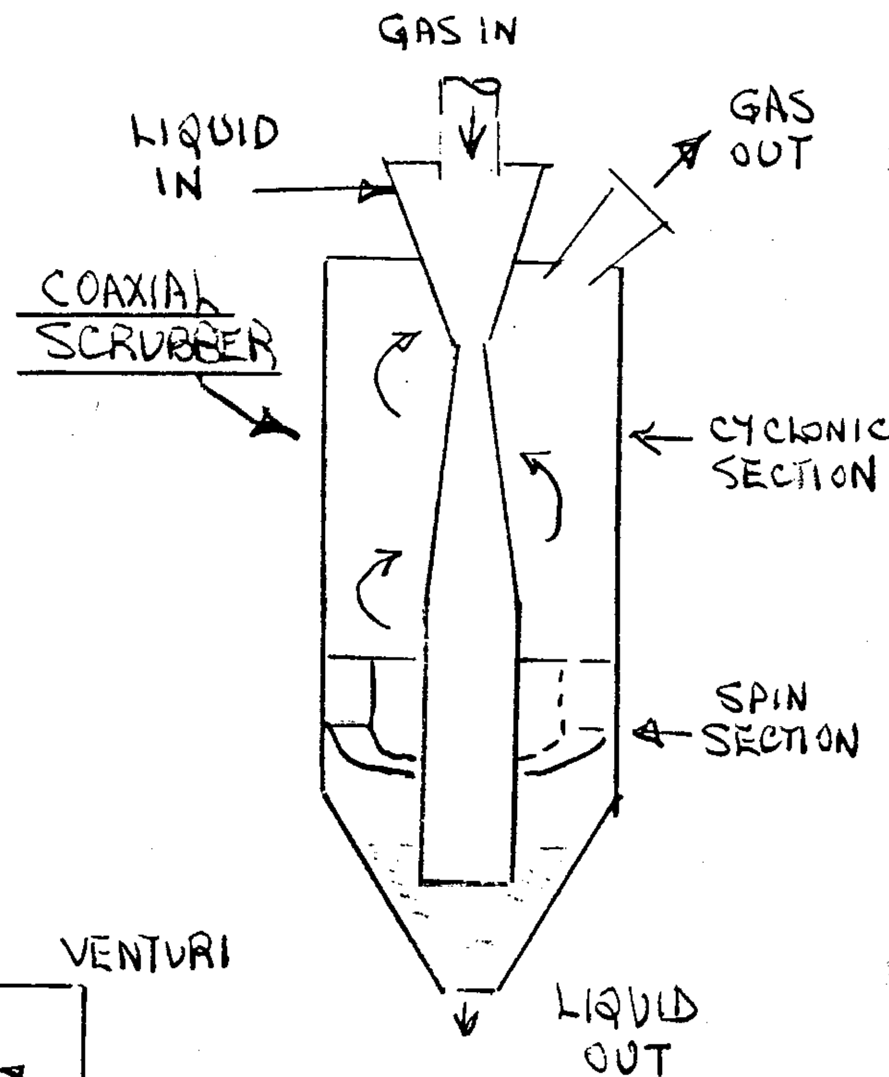
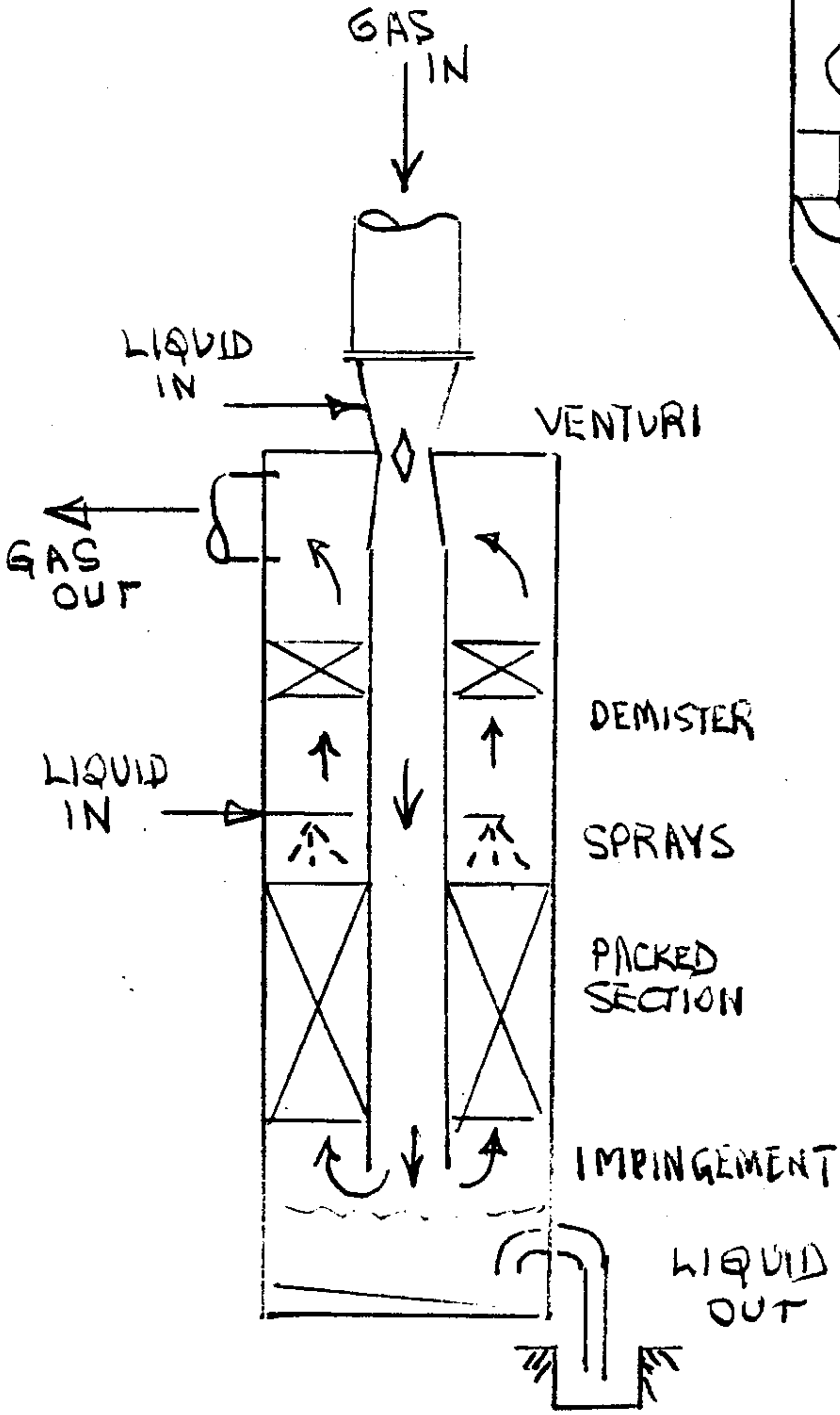

VENTURI
GAS IN
ENTRANCE TYPE AVOIDS
WET-DRY INTERFACE
LOW
PRESSURE LIQUID
LOW PRESSURE LIQUID
HURRICANE
VELOCITY
ZONE
LIQUID FILM
PROTECTS METAL
FLOODED ELBOW
REDUCES
BUILDUP
LIQUID
GAS TO CYCLONIC
LIQUID OUTLET

FIGURE 6.



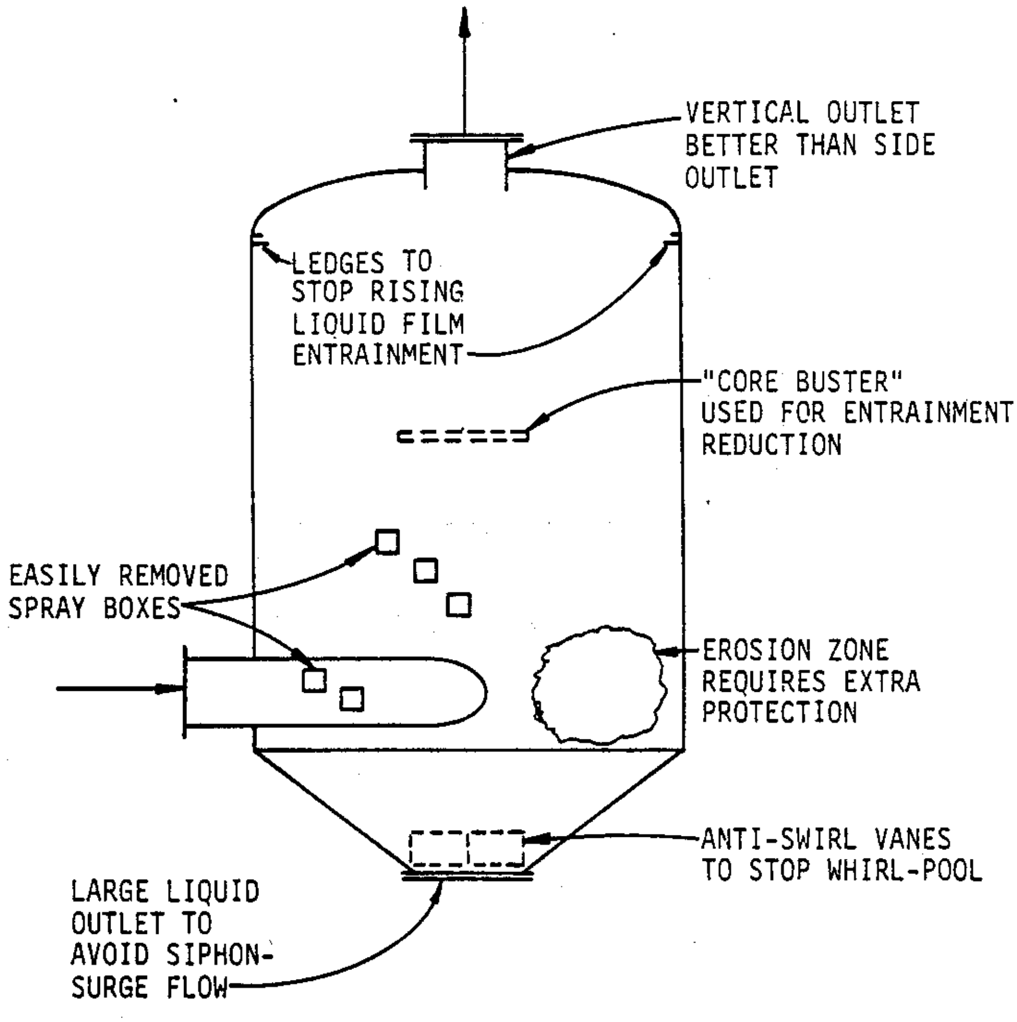


LOW COST COMBINATION SCRUBBER

8-9 NTU

FIGURE

7


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

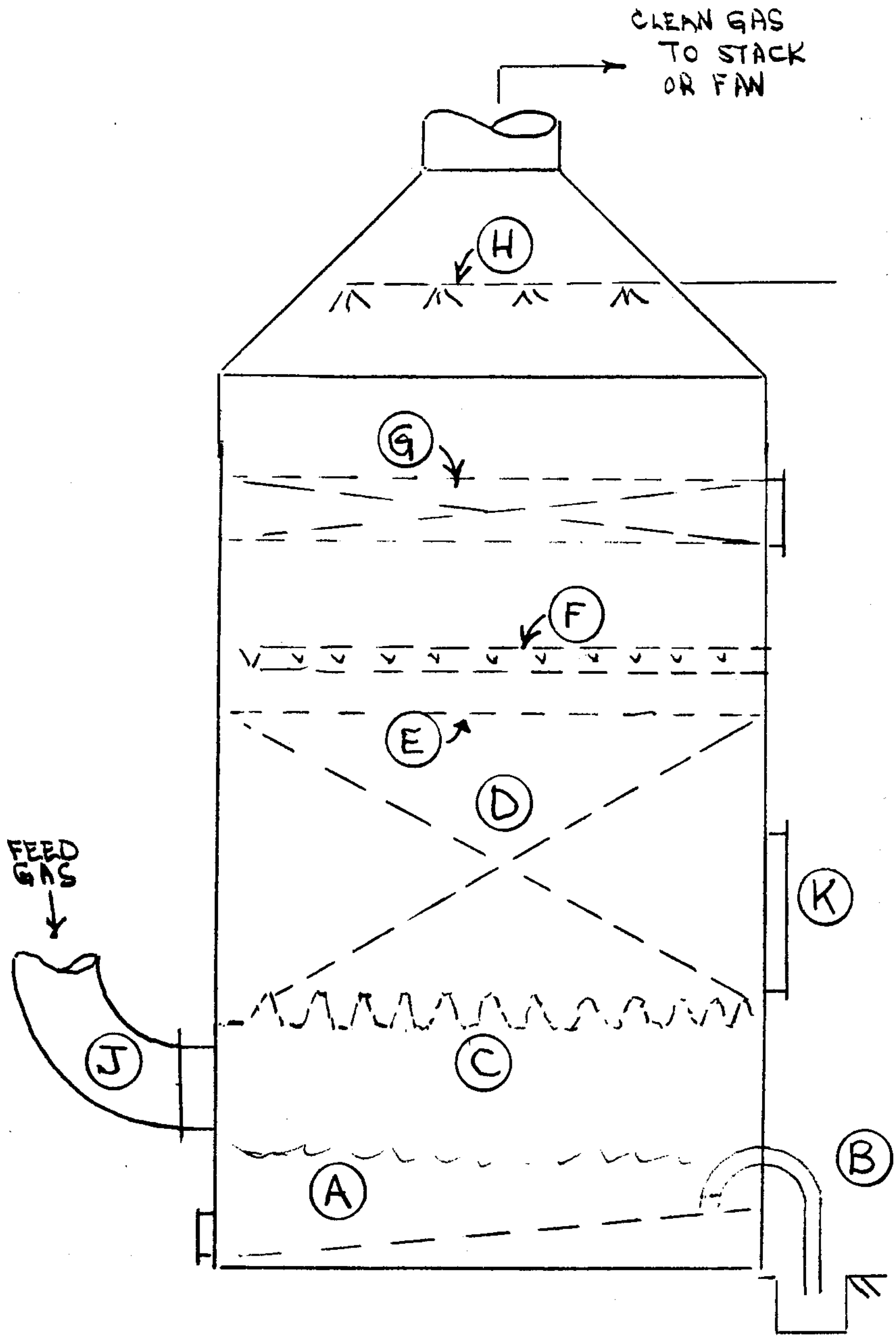


FIGURE 8