Stationary Source Enforcement Series

July 1979

Draft

ENFORCEMENT WORKSHOP ON PLANT INSPECTION AND EVALUATION PROCEDURES

VOLUME VII
CONTROL EQUIPMENT OPERATION AND MAINTENANCE - WET SCRUBBERS

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF ENFORCEMENT
OFFICE OF GENERAL ENFORCEMENT
WASHINGTON, D.C. 20460

REFERENCE MATERIAL FOR TECHNICAL WORKSHOP ON EVALUATION OF INDUSTRIAL AIR POLLUTION CONTROL EQUIPMENT OPERATION AND MAINTENANCE PRACTICES

Volume VII
Operation and Maintenance of
Wet Scrubbers

Compiled by
PEDCo Environmental, Inc.
505 S. Duke Street
Durham, North Carolina 27701

Contract No. 68-01-4147
PN 3470-2-O

Prepared for
U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Enforcement
Division of Stationary Source Enforcement
Washington, D.C. 20460

May, 1979

FOREWORD

The following document is a compilation of selected technical information and publications on the evaluation of industrial air pollution control equipment operation and maintenance practices. The reference manual is intended to be an instructional aid for persons attending workshops sponsored by the U.S. Environmental Protection Agency Regional Offices.

TABLE OF CONTENTS

VII-1

WET COLLECTORS:

SECTION VII, CONTROL OF PARTICULATE EMISSIONS
TRAINING COURSE MANUAL IN AIR POLLUTION

U.S. Public Health Service

March 1977

I Wet collectors increase particle removal efficiency by two mechanisms.

A Re-entrainment of the collected particles is prevented by trapping them in a liquid film or stream and then washing the liquid (and trapped particles) away.

B Fine particles are "conditioned" so that their effective size is increased, thus enabling them to be collected more efficiently.

II PARTICLE CONDITIONING

Particle conditioning in wet collectors involves the process of increasing the effective size of the fine particles so that they may be more readily precipitated. The effective size may be increased by:

Forcing precipitation of fine particles on liquid droplets, or

Promoting condensation upon fine particles (which act as nuclei) when the water vapor in a gas passes through its dewpoint.

A Conditioning by Forcing Precipitation of Particles on Liquid Droplets

1 An example:

An example is the attachment of a 5-micron dust particle to a liquid droplet 50-microns in diameter thereby increasing its apparent mass 1000 fold for collection purposes.

2 Effect of wetting agents in resisting redispersion

Collision of solid particles with liquid droplets is inelastic and because of Van der Waal's forces, the agglomerates resist redispersion. Therefore, the addition of wetting agents does not significantly increase removal efficiency.

3 Effect of solubility of particles

Solubility of the particles in the droplets is not a factor in effectiveness. (An exception is the case of concentrated mist droplets, such as sulfuric acid. These droplets may grow in size by absorption of moisture when passing through a humid chamber).

B Conditioning by Promoting Condensation upon the Particle Surface

If the liquid spray causes the gas to pass through its dewpoint, condensation will take place upon the surface of the particles when the particles act as nuclei. Thus, the effective size of the particles is increased under such conditions. This mechanism is important for initially hot gases containing relatively small dust concentrations (say less than 1-grain/cf).

III OPERATING PROBLEMS OF WET COLLECTORS

A Corrosion

1 All water scrubbers have the inherent problem of corrosion.

a Even when no chemically corrosive constituent may be contained in the carrier gas stream, the carbon dioxide present contributes to corrosion.

b When corrosive agents are contained in the gas stream (SO_2, chlorides, fluorides, nitric acid, etc.), will occur on wet metallic surfaces.

B Erosion

1 Wet collectors that remove insoluble, abrasive materials have troubles due to erosion especially if removal is dependent upon impingement velocities or centrifugal action.

C Wet-Dry

1 Scrubbers are faced with problems at wet-dry junctions, particularly at the entrance of an installation.

a When dust concentrations and gas temperature are high, there may be a zone where dust build-up can occur (by reason of moist dust layers).

D Mist Elimination

1 In all scrubbers, entrainment eliminators are important to prevent carry-over of droplets.

2 Many scrubbers have mist eliminators built into their design.

3 When not incorporated in the design, mist elimination is accomplished by means of additional separators.

E Slurry Handling

1 For all scrubbers, a method must be provided for handling the liquid effluent. Slurries may be treated by means of:

a Settling tanks

b Filters

c Liquid cyclones

d Further chemical or recovery methods

e Disposal to sumps, streams, rivers

f Others

2 All these effluent handling methods have their own unique engineering problems.

COLLECTION OF PARTICLES ON CYLINDRICAL AND SPHERICAL OBSTACLES

Particulates transported by a carrier gas through a depth of cylindrical (fibers) or spherical (granules) obstacles tend to be precipitated upon the surface of the obstacles. Van der Waal's and electrical forces cause the particulates to adhere to the surfaces of the obstacles resulting in the removal of the particulates from the gas stream.

I MECHANISMS OF PARTICULATE REMOVAL

A Screening (or sieving) is not the principal mechanism

It can be shown that the sizes of the gas passages through the depth of obstacles are very much larger than the sizes of the particulates collected.

B The principal mechanisms by which particulates are brought into contact with the obstacles include:

1 Interception

2 Gravitation

3 Impingement

4 Diffusion

5 Electrostatic

6 Thermal

II INTERCEPTION

Particulates being carried by a flow of gas tend to follow the streamlines around an obstacle. By chance, a particle on one of the streamlines may make contact with the obstacle if the streamline passes the obstacle at a distance less than the radius of the particle. This type of removal is called direct interception, and depends solely on the position that a particle has in the gas stream.

III GRAVITATION

As a particle passes by an obstacle, it may fall (under the influence of gravitational force) from the streamline along which it is being carried and settle upon the surface of the obstacle.

IV ELECTROSTATIC

Since a force of attraction exists between bodies possessing electrostatic charges of opposite polarity, it is possible for a charged particle to be removed from the gas stream by an oppositely charged obstacle. However, when only the particle or obstacle is charged, a charge may be induced upon the uncharged component resulting in a polarization force that can also effect particle removal.

The effect of the electrostatic mechanism of particle removal from a gas stream may be significant when the charge on the particle or obstacle is high, and when gas velocity is low. The significance of particle size and obstacle size varies, depending on whether the electrical attraction originates from Coulomb or polarization forces.

The mechanism involved in a bed of fibers or granules depends principally on the characteristics of the particulates and obstacles in the bed, and on the gas velocity.

V IMPINGEMENT TARGET EFFICIENCY

A The meaning of impingement target efficiency

When an obstacle is placed in the path of a particulate-laden gas stream (Figure 1) the streamlines will diverge and pass around the obstacle. The particles, how ever, tend to leave the streamlines (along which they are being carried) at the beginning of the curvature and may impinge upon the obstacle.

If like particles, initially within a cross-section of the carrier-gas stream having a radius of $\frac{D'}{2}$ (measured from the central streamline) strike a cylindrical obstacle of diameter D_o, then D' is termed the "impingement target diameter" of the obstacle for the particular particles being considered.

The ratio $\left[\frac{D'}{D_o}\right]$ is called the "impingement target efficiency" and is symbolized η_I. In other words, it is the ratio of the cross-sectional area of the gas stream cleaned of particles (all of which are alike) to the projected area of the obstacle.

If it is assumed that all particles are alike and equally dispersed throughout the gas stream, the "impingement target efficiency" is the ratio of the weight of particulate collected by the obstacle to the weight of particulate that would pass on if the obstacle were not there. Therefore, "impingement target efficiency" is the efficiency of removal by weight of like particles by one obstacle.

B The Mathematical Expression

Impingement target efficiency (η_I) is a function of the dimensionless ratio,

$$\left[\frac{D_o\, g}{v_{p/o}\, f_{p(s)}}\right]$$

where:

η_I = impingement target efficiency for uniformly dispersed like particles and for one obstacle.

D_o = diameter of the obstacle

$v_{p/o}$ = relative velocity of the particle (in the approaching gas stream) to the obstacle

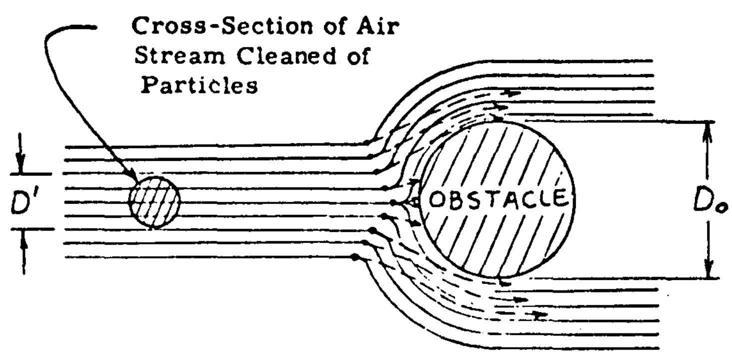
$f_{p(s)}$ = Stokes' settling velocity

C Impingement Target Efficiency Curves (Figure 2)

Figure 2 demonstrates the relationship between impingement targe efficiency (η_I) and the dimensionless ratio

$$\left[\frac{D_o\, g}{v_{p/o}\, f_{p(s)}}\right]$$

Note that there are two curves; one for spheres and one for cylinders. The impingement target efficiency for spheres is higher than that for cylinders because the streamlines diverge more sharply around spheres.



Impingement on a Spherical Obstacle

Figure 1

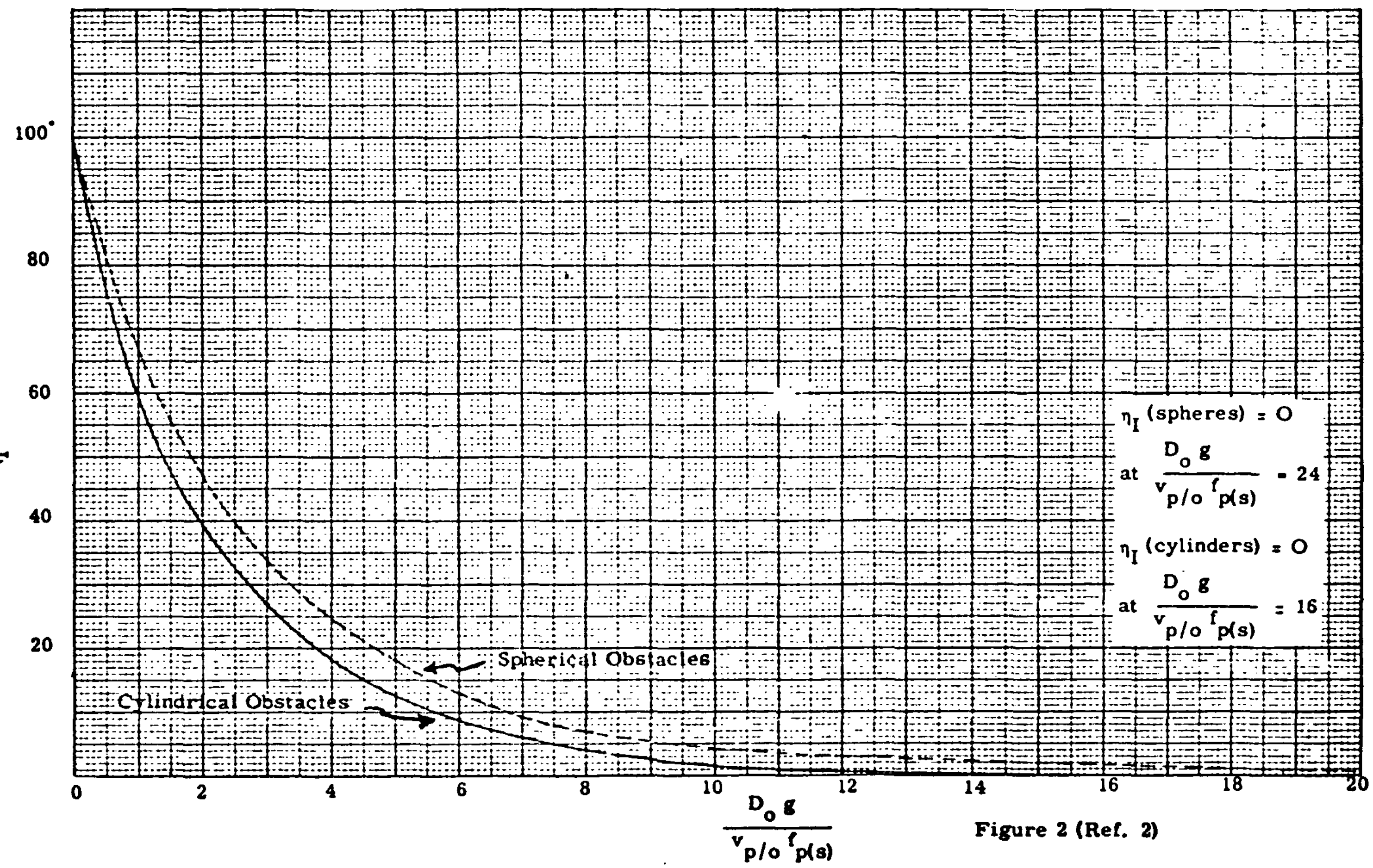
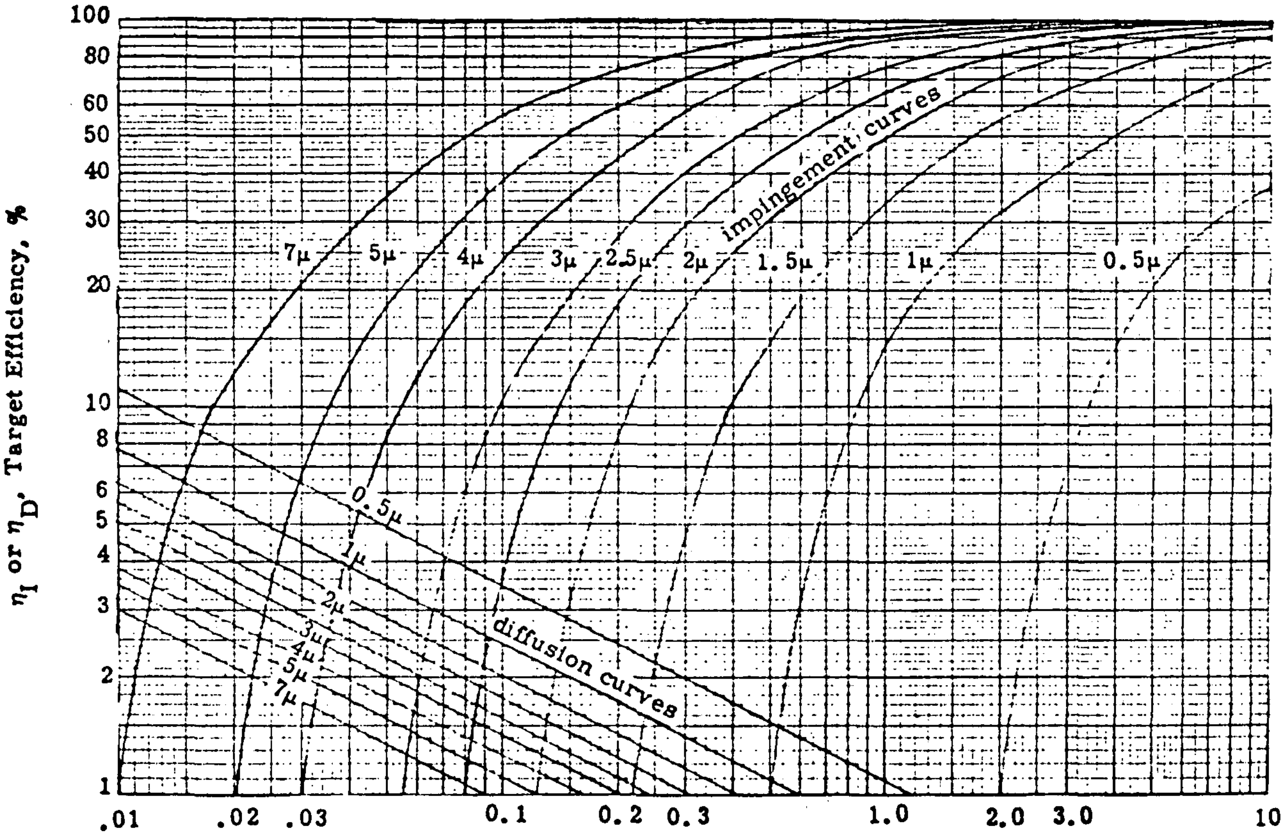


Figure 2 (Ref. 2)



Impingement and Diffusional Target Efficiencies at Various Air Velocities for Different Diameter Dust Particles (Ref. 2)

(ρ_p = 2.0) (Fibre Diameter = 10μ) (Viscosity = $1.8(10)^{-4}$ poises)

Figure 3

Figure 2 shows that small obstacles (D_o) and high relative velocities ($v_{p/o}$) are essential if high impingement target efficiencies (η_I) are to be achieved for a given particle.

VI DIFFUSIONAL TARGET EFFICIENCY FOR CYLINDRICAL OBSTACLES

In addition to impingement, another important mechanism of particle precipitation on obstacles in a gas stream is diffusion. However, the diffusion mechanism plays little part in the separation of particles from a gas stream except for the very finest ones. It is of special interest where very high overall efficiencies of removal are required, and where there are low velocities.

A The Mathematical Relationship[2]

1 The general equation

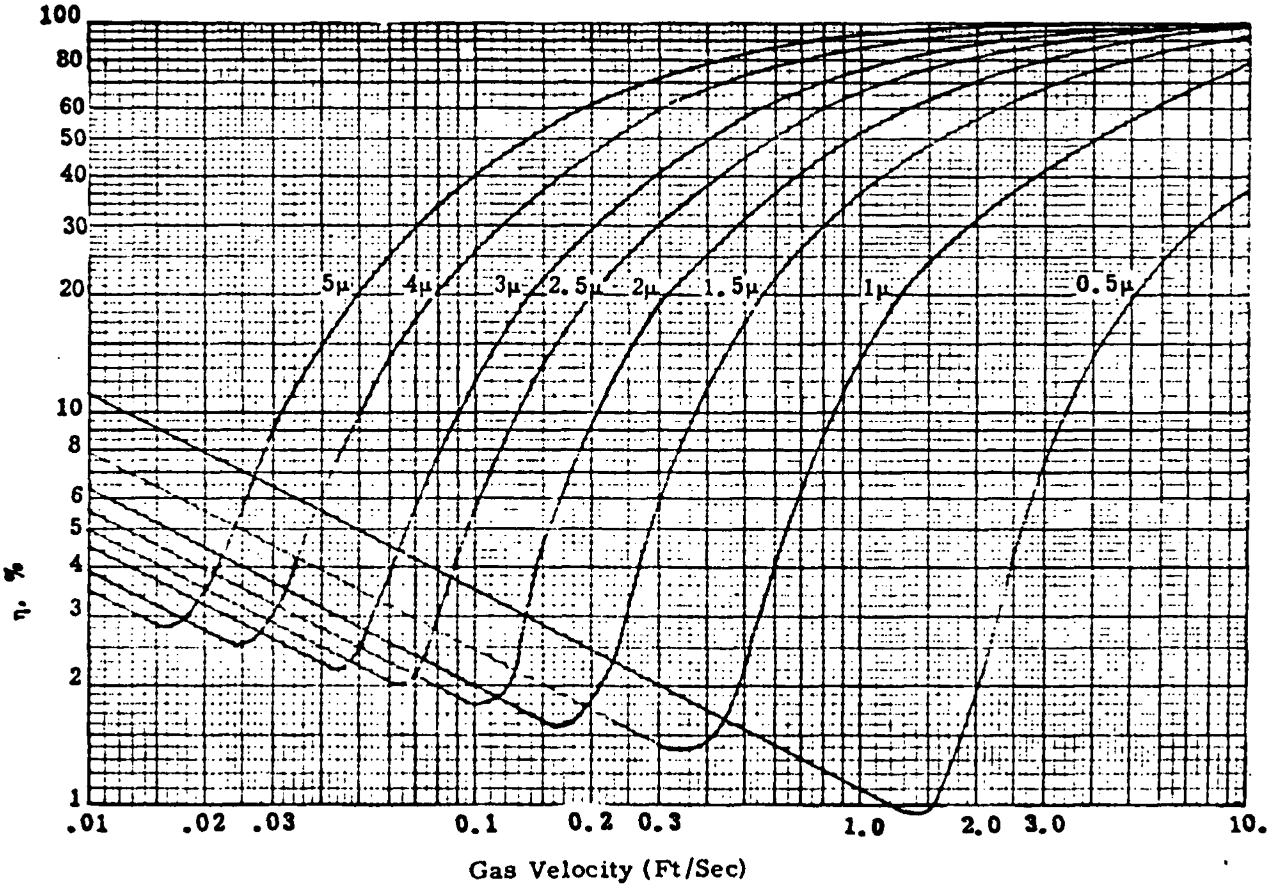
$$\eta_D = \sqrt{\frac{8K}{v_{p/o}\, D_o}} \qquad (2)$$

where:

η_D = diffusional target efficiency for uniformly dispersed like particles and for one obstacle.

D_o = obstacle diameter (cm)

$v_{p/o}$ = relative velocity of the particle (in the approaching gas stream) to the obstacle (cm/sec)



Target Efficiency at Various Air Velocities for Different Diameter Dust Particles (Ref. 2)

(ρ_p = 2.0) (Fibre diameter 10μ) (Viscosity = $1.8(10)^{-4}$ poises)

K = a constant depending on the temperature, viscosity, and particle diameter (cm^2/sec)

$$K = 1.45(10)^{-17} \left[\frac{T}{\mu D_p} \right]$$

where:

T = absolute temperature (°K)

μ = absolute viscosity of the gas (poise)

D_p = particle diameter (cm)

2 For air below 100°C

$$\eta_D = \left[\frac{2.45}{\sqrt{v_{p/o} D_p D_o}} \right] \quad (3)$$

where:

η_D = diffusional target efficiency for like particles and one obstacle when gas stream is air below 100°C (%)

$v_{p/o}$ = relative velocity of the particle (in the approaching gas stream) to the obstacle (ft/sec)

D_p = diameter of the particle (microns)

D_o = obstacle diameter (microns)

B Remarks

The above equations show that if target efficiency due to diffusion (η_D) is to be high, then the relative velocity ($v_{p/o}$) must be low. This is opposite to the requirements for high impingement target efficiency (η_I) which demands high relative velocity. This leads to a velocity zone for a given obstacle where the efficiency of removal will be low for a given particle-size; that is, where conditions are poor for both impingement and diffusion.

This is evident by observing the low portions of the curves in Figure 4.

VII SIZE-EFFICIENCY

A The equations for target efficiencies provide information on the removal of like particles by only one obstacle, or, let's say, removal of like particles by one "treatment" of the gas stream. Since in the actual course of filtration through a bed of fibers or granules the gas stream meets a number of obstacles and is therefore "treated" a number of times before it exits, an efficiency equation taking all "treatments" into account is necessary.

B The general equation for size-efficiency

$$E = 1 - (1 - \eta)^{S_o}$$

where S_o is small [as in spray devices ($S_o \approx 5$) and old cloth ($S_o \approx 2$)] (4)

$$E = 1 - e^{-\eta S_o}$$

where S_o is large [as in packed fiber or granular beds and new cloth filters ($S_o \approx 50$)] (5)

where:

E = efficiency of removal of a given particle-size (size-efficiency). The particle size is identified in

e = natural logarithmic base = 2.718

S_o = number of "treatments" received by the gas stream

$$S_o = \frac{\text{Total projected area of all obstacles in the filter}}{\text{Cross-section of filter normal to the gas flow}}$$

η = target efficiency of the individual obstacles

C Size-efficiency for a bed of spherical granules

$$E = 1 - e^{-\eta \alpha L \left(\frac{3}{2}\right)\left(\frac{1}{D_o}\right)} \qquad (6)$$

$$E = 1 - e^{-\eta S_o} \qquad (7)$$

where:

E = efficiency of removal of a given particle-size by a bed of spherical obstacles. The particle-size is identified in η.

e = natural logarithmic base = 2.718

η = target efficiency of the individual shperical granules in the bed

L = depth of the bed

α = volume of the spherical granules per unit volume of bed

D_o = diameter of the spherical granules

S_o = number of "treatments" received by the gas stream as it passes through the bed

$$S_o = \frac{\text{Total projected area of all obstacles in the bed}}{\text{Cross-section of the bed normal to the gas flow}}$$

D Size-efficiency for a bed of cylindrical fibers

$$E = 1 - e^{-\eta \alpha L \frac{4}{\pi D_o}} \qquad (8)$$

$$E = 1 - e^{-\eta S_o} \qquad (9)$$

where:

E = efficiency of removal of a given particle-size by a bed of cylindrical obstacles. The particle size is identified in η.

α = volume of fibers per unit volume of bed

e = natural logarithmic base = 2.718

η = target efficiency of the individual fibers in the bed

L = depth of bed

D_o = diameter of the fibers

S_o = number of "treatments" received by the gas stream as it passes through the bed

$$S_o = \frac{\text{Total projected area of all obstacles in the bed}}{\text{Cross-section of the filter normal to the gas flow}}$$

VIII PARAMETERS OF COLLECTION EFFICIENCY

Using the following theoretical relationships, a qualitative evaluation of the relative importance of the various collection mechanisms may be derived

Mechanism	Parameter
Direct interception	$D_p \sim / D_o$
Gravitation	$\frac{D_p^2 \rho_p g}{18 \mu D_o}$
Impingement	$\frac{D_p^2 \rho_p v_{p/o}}{18 \mu D_o}$
Diffusion	$\frac{RT}{\mu v_{p/o} D_o D_p}$

where:

D_p = diameter of the particle removed from the gas stream

D_o = diameter of the obstacle

ρ_p = density (mass) of the particle

g = local acceleration due to gravity

μ = viscosity of the gas

$v_{p/o}$ = velocity of the approaching gas stream with respect to the obstacle

R = universal gas constant

T = absolute temperature of the gas

REFERENCES

1 Lapple, C. E. Fluid and Particle Mechanics. U. of Delaware. 1956.

2 Stairmand, C. J. Dust Collection by Impingement and Diffusion. Paper read at Midland Branch of A. Inst. P. Birmingham, England. Oct. 14, 1950.

3 Dallavalle, J. M. Micromeritics. Pitman Publishing Corp. N. Y. 1948.

4 Miller, J. S. and Traxler, R. N. Annual Asphalt Paving Conference. The Asphalt Institute, pp 315 - 23. (Discusses physical properties of mineral filters).

THE GRAVITY SPRAY TOWER

I IMPINGEMENT OF GRAVITATIONAL SPRAY DROPS

A In a gravitational spray unit, there are a number of liquid spherical obstacles (droplets) falling in an empty tower by the action of gravity in the path of rising particles.

B The relationship between impingement target efficiency (η_I) and $\left[\frac{D_o g}{v_{p/o}\, f_{p(S)}}\right]$ is shown in Figure 1.

1 $\left[v_{p/o}\right]$ in gravitational spray towers, is the difference in the free-falling velocities (Stokes') of the droplets and the particle.

2 In practice, since the free-falling velocity of the particle is small compared to the droplet, $\left[v_{p/o}\right]$ may be taken as the free-falling velocity of the droplet.

C From Figure 1, it is evident that for high collection efficiency by impingement there must be a small obstacle (D_o) and a high relative velocity $\left[v_{p/o}\right]$ between the obstacle and particle.

1 In gravitational spray towers, these conditions tend to be mutually incompatible. (Small droplets have small free-falling velocities)

2 Therefore, there is an optimum droplet size (for a given particle size) for maximum impingement target efficiency. (See Figure 2.)

a Inspection of Figure 2 shows that as droplet size diminishes to the range 500 - 1000μ, the target efficiency increases. However, a further decrease in droplet size, decreases the impingement target efficiency.

b It is seen that the maximum efficiency for the smaller particle sizes (say less than 5μ) occurs for droplet size of about 800μ: and that for larger particle sizes, the efficiency varies little over the range of droplet sizes 500 to 1000μ.

Thus in gravitational spray towers, there is little point in using very fine spray sizes even if such were available.

II EFFICIENCY

A Inspection of Figure 2 shows that the efficiency of a gravitational spray tower is very low for particles below 1 - 2 microns.

B Figure 3 illustrates a size-efficiency curve for a large industrial spray tower handling 70,000 cfm. The tower is 22 ft in diameter, 66 ft high. Pressure drop is less than 1" water.

III DUST CONCENTRATIONS

A There are no fine clearances for the passage of dust-laden gases. Therefore, it can handle relatively high dust concentrations without fear of chokage.

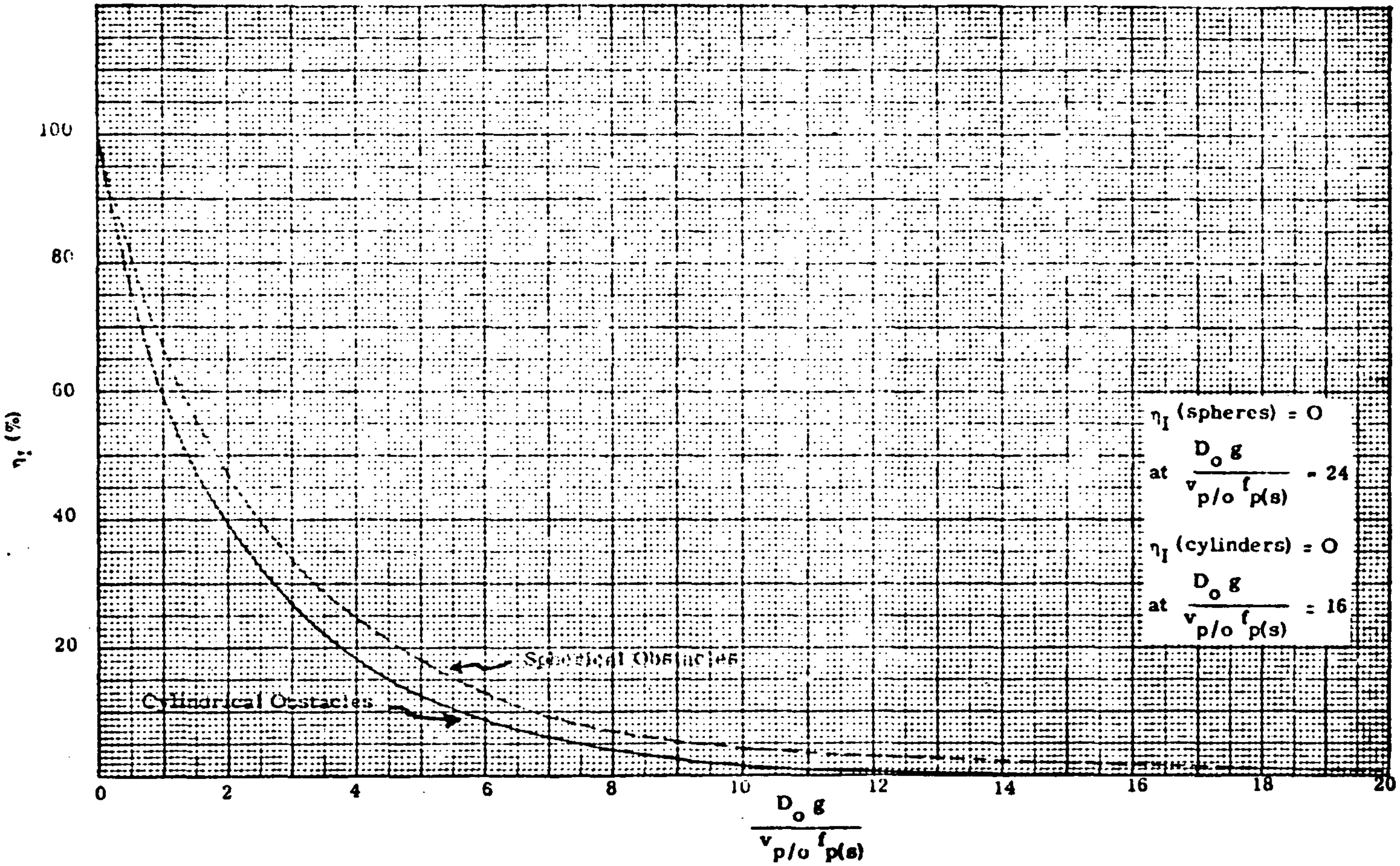
IV GAS VOLUME

A It is capable of handling large quantities of gas.

B It is often used as a pre-cooler where large quantities of gas are involved (as in blast furnaces).

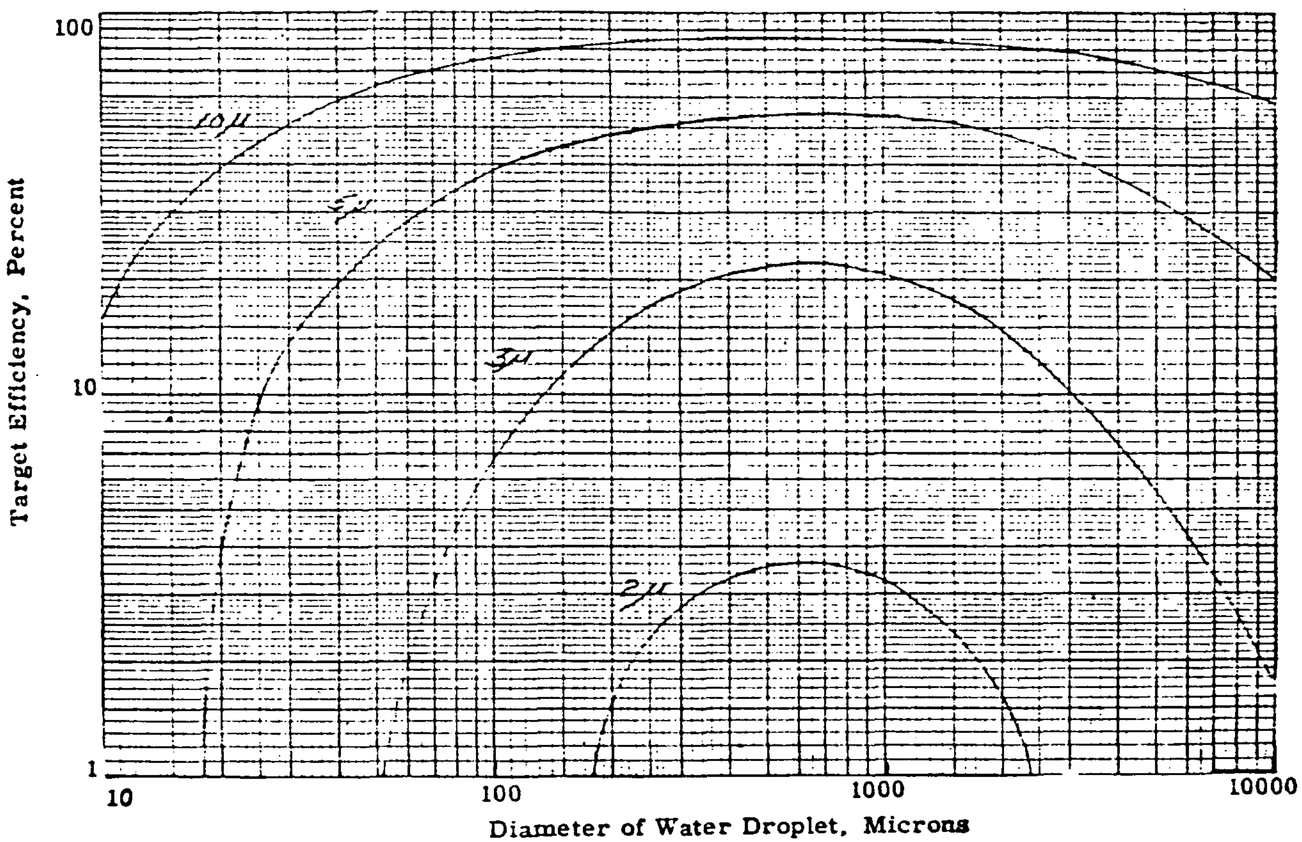
V RECIRCULATION OF WATER

A Since very fine droplets are not employed, the spray generators need not have fine jets.



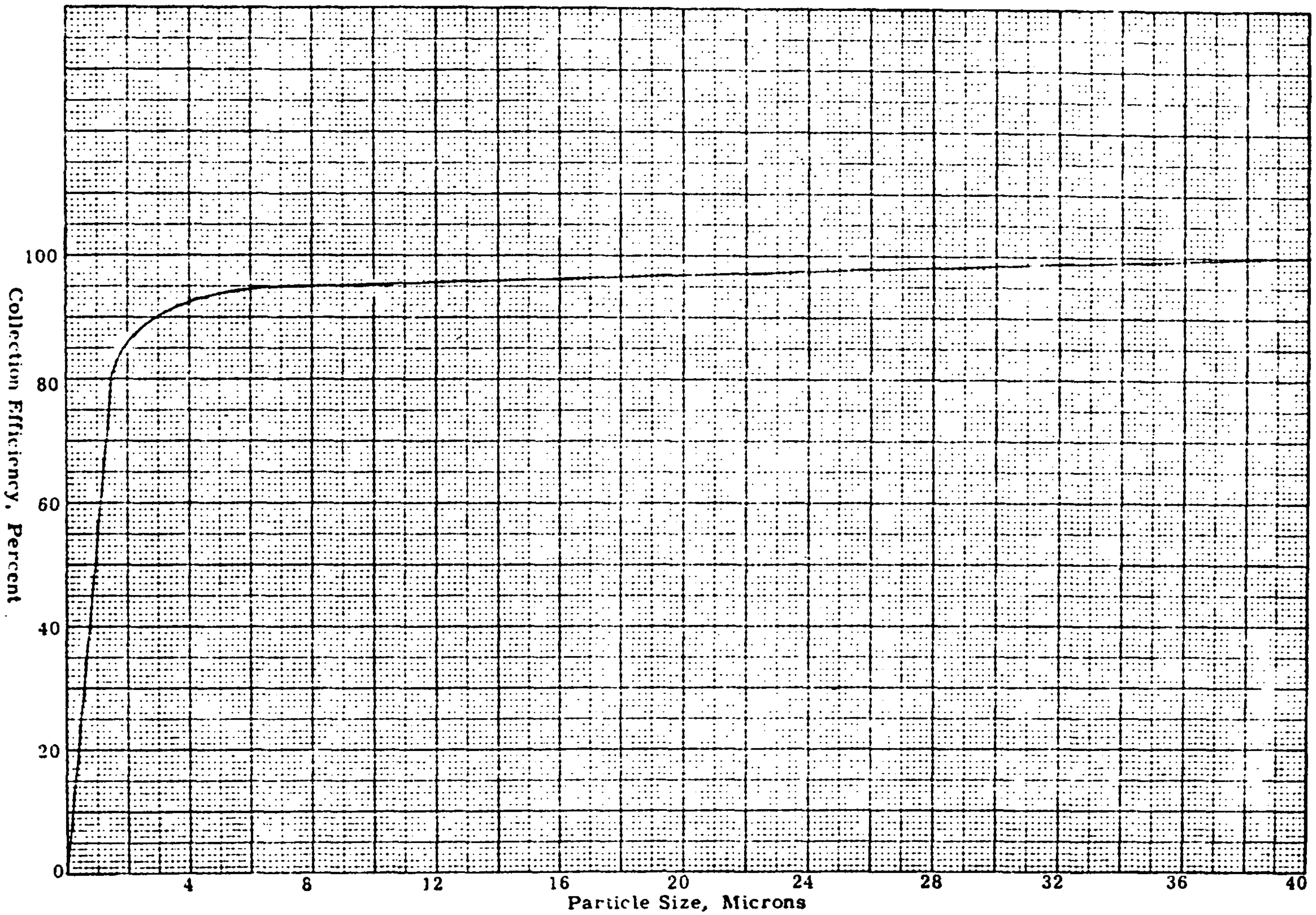
100
80
60
40
20
η_I (%)
0
2
4
6
8
10
12
14
16
18
20
$\frac{D_o g}{v_{p/o} f_{p(s)}}$
η_I (spheres) = O
at $\frac{D_o g}{v_{p/o} f_{p(s)}}$ = 24
η_I (cylinders) = O
at $\frac{D_o g}{v_{p/o} f_{p(s)}}$ = 16
Spherical Obstacles
Cylindrical Obstacles

Figure 1



Relation Between Collection Efficiency and Droplet Size for A Gravitational Spray Tower (Ref. 1)

Figure 2



Size-efficiency Curve for Spray Tower

Figure 3

1 Hence, the dirty water may be recirculated until it contains quite a high concentration of trapped dust particles.

a Therefore, there is a saving of water, and perhaps a simplification of effluent treatment and ultimate waste disposal.

VI PRESSURE DROP

A The pressure drop is very small (less than 1 in. w.g.)

VII PERFORMANCE DATA

Gas flow	over 70,000 cfm
Gas temperature	often used as pre-cooler. Gas temperature over 2000°F may be reduced to 275°F.
Gas velocity	about 3-5 fps
Treatment time	about 20-30 seconds
Draft loss	less than 1" w.g.
Efficiency	very low for below 1-2μ
Particle concentrations	relatively high (over 5 gr/cu ft)
Particle composition	solid, liquid. Some problems with corrosion.
Water usage	about 18 gal/1000 cu ft

REFERENCES

1 Stairmand, C. J. Dust Collection by Impingement and Diffusion. Paper read at the Inaugural Meeting of the Midland Branch of A. Inst. P. Birmingham, England. October 14, 1950.

2 Stairmand, C. J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before the A. Inst. P. London. November, 1955.

VENTURI SCRUBBERS

I MECHANISM OF PARTICLE REMOVAL

A Since for high collection efficiency of fine particles by impingement there must be a small obstacle (D_o) and high velocity of approach of the gas stream relative to the obstacle ($v_{p/o}$), attempt is made to approach this ideal by:

1 An arrangement in which very small water droplets (upon which the particles impinge) are formed by the gas flow so that the droplets are initially at rest at the time of impact with the particles. Even during the period of acceleration of the droplet, high relative velocities will be maintained since the particles move at the velocity of the gas stream.

a Such an arrangement is incorporated in the Venturi scrubber. See Figure 1.

II OPERATION (Figure 1)

A Collection of Particles upon the Droplets

1 In the Venturi scrubber, the particulate-laden gas passes through a duct which incorporates a Venturi scrubber.

2 At the throat, high gas velocities of the order of 200-600 fps are attained.

3 Coarse water spray is injected into the throat by way of radial jets in quantities of 5 to 7 gpm per M cfm of gas.

4 The high gas velocities at the throat immediately atomize the coarse water spray to fine droplets (about 50 microns).

5 Since, at their genesis, these fine droplets are initially at rest relative to the particles in the gas stream, it is at this moment that collection efficiency is at its maximum. ($v_{p/o}$) is maximum.

a The atomized droplets, being fine, rapidly accelerate to the velocity of the carrier gas; but even during this short period, relative velocities will be high and effective collision between droplet and particle will take place.

It is during the period before the droplets attain the same velocity as the gas stream that any relative velocity between the droplets and particle is obtained. For example, a 100-micron droplet introduced into a gas stream moving at 100 fps would accelerate to 90% of the gas velocity in 16 inches; a 20-micron droplet would reach 90% of the gas velocity in 2 inches.

B Removal of the Dirty Droplets

1 As the gas decelerates after passing through the throat, agglomeration of the particle-laden droplets takes place.

2 The large agglomerates are readily removed by a cyclonic separator.

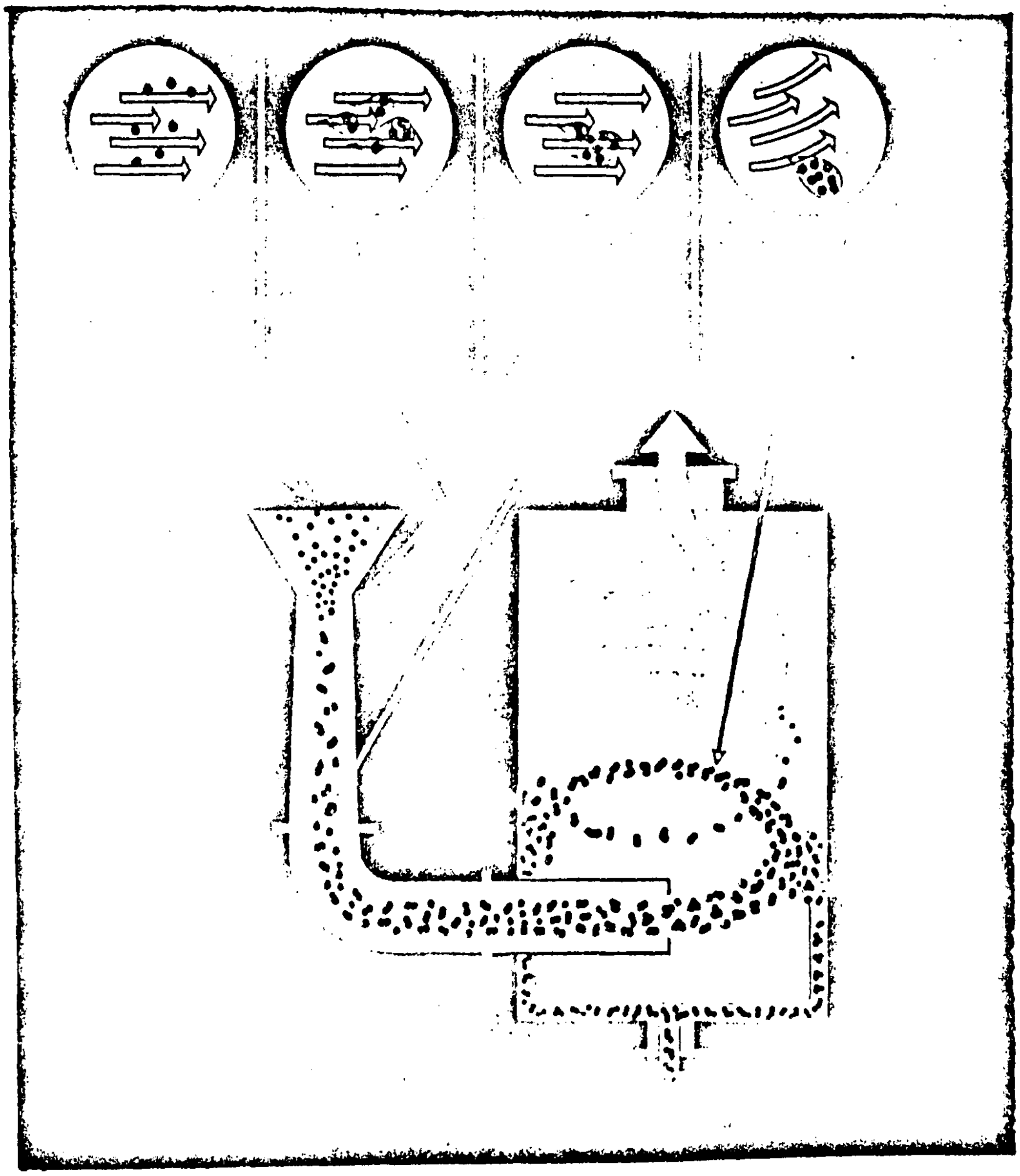
III EFFICIENCY

A Effect of Pressure Drop on Efficiency

1 The higher the pressure drop, the higher the removal efficiency of particles. See Figures 2 and 3.

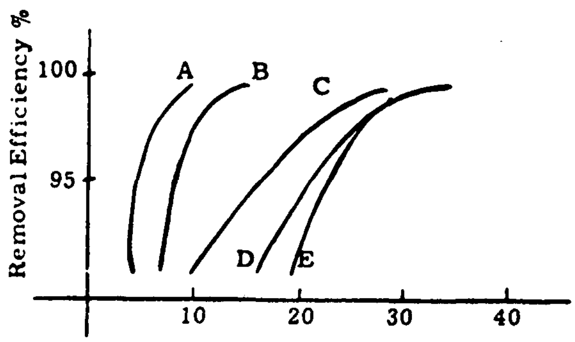
2 Pressure drops across the Venturi of 25-30 inches of water gage may be expected.

3 Pressure drop can be increased (and hence efficiency can be increased) simply by increasing the gas velocity and/or the water injection rate. See Figure 4.



Chemical Construction Corporation

Figure 1



Venturi Pressure Drop (in. w. g.)

Curve A: Rotary iron powder kiln

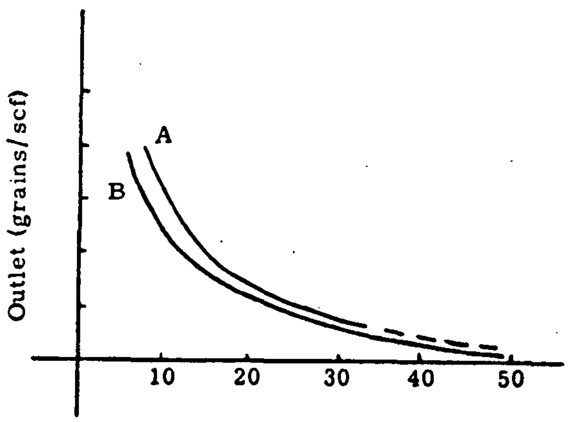
B: Lime kiln, asphalt plant

C: Iron cupola

D: Phosphoric acid plant (acid mist)

E: Incinerator (sodium oxide fumes)

Figure 2[5]

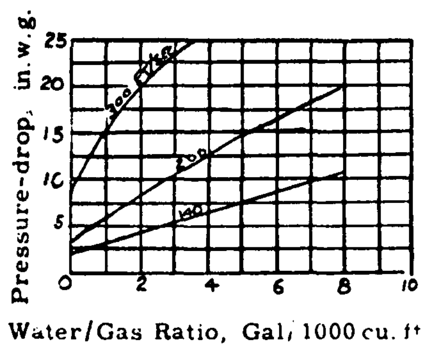


Venturi Pressure Drop (in.w. g.)

Curve A: Cupola gases

B: Blast furnace gases

Figure 3[5]



Relation Between Pressure-loss and Water Usage in Venturi Scrubber

Figure 4

4 When gas cleaning requirements change, the only adjustment necessary to the Venturi scrubber, in most cases, is in the flow of scrubbing liquid to increase the pressure drop. Thus higher cleaning efficiency is accomplished without modification or addition.

B Effect of Particle Concentration on Efficiency

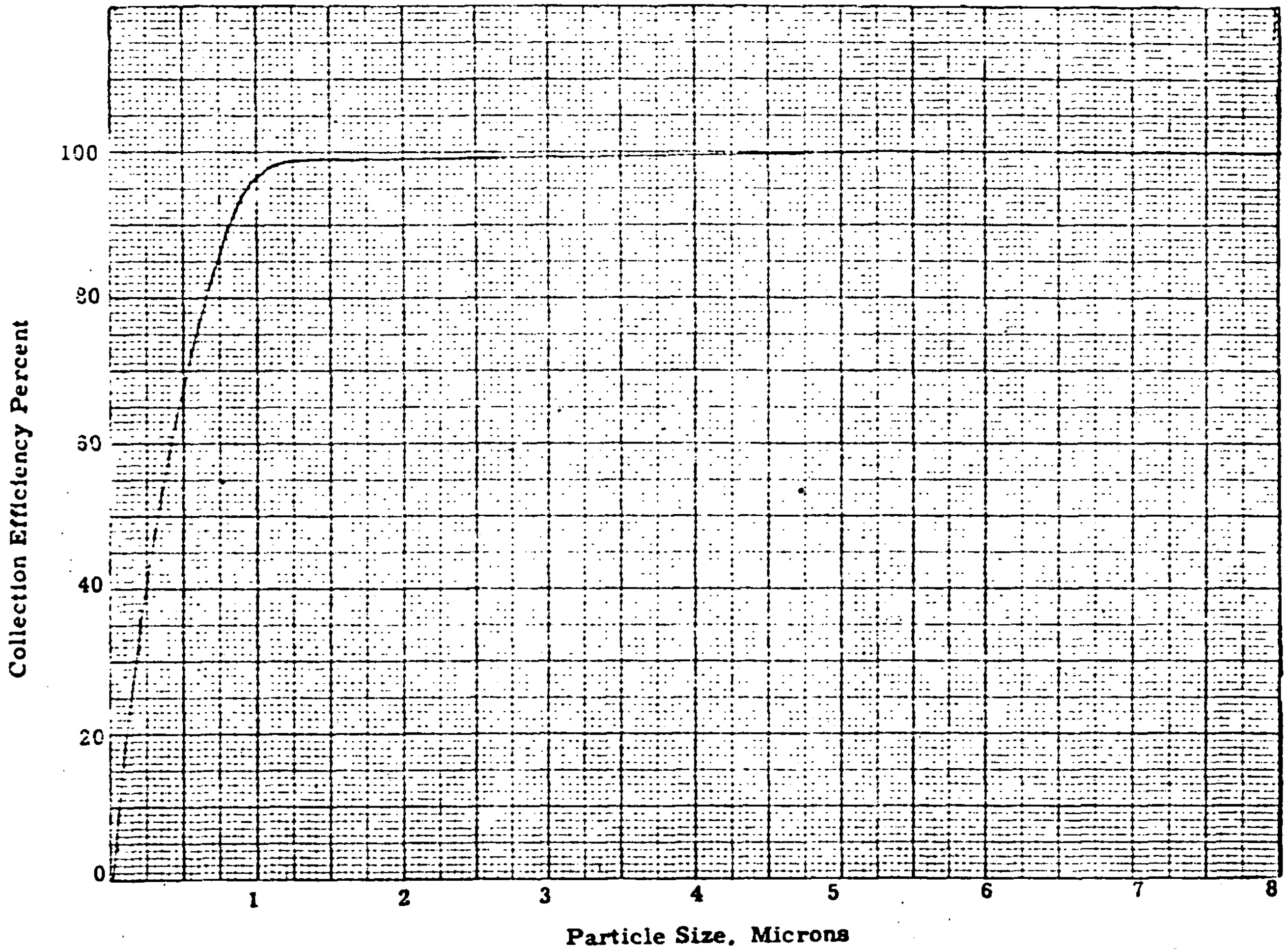
1 If the number of water droplets is held constant and the number of particles (concentration) is increased, the number of collisions would be expected to increase. In other words, collection efficiency should increase as loading increases.

2 This increase, however, is due not only to the increased chances of particle collision with droplets, but also due to collisions between the particles themselves.

C Size-Efficiency

1 The Venturi scrubber approaches 100% for all particles larger than 1.5 to 2 microns.

2 Figure 5 shows a size-efficiency curve for a Venturi scrubber[1]. Sizes above 2-microns were obtained on special



Size-efficiency Curve for Venturi Scrubber (6-in. throat)(3,500 cfm gas)

Figure 5

TABLE 1

TYPICAL PERFORMANCE DATA FOR VENTURI SCRUBBER[5]

Source of Gas	Contaminants	Approximate Size Range (Microns)	Loading (Grains/ cf) Inlet	Loading (Grains/ cf) Exit	Average Removal Efficiency (%)
IRON & STEEL INDUSTRY					
Gray Iron Cupola	Iron, Coke, Silica Dust	1-10	1-2	.05-.15	95
Oxygen Steel Converter	Iron Oxide	5 2	8 10	05-08	98 5
Steel Open Hearth Furnace (Scrap)	Iron & Zinc Oxide	.08-1	.5-1 5	.03-.06	35
Steel Open Hearth Furnace (Oxygen Lanced)	Iron Oxide	5-2	1-6	.01-.07	99
Blast Furnace (Iron)	Iron Ore & Coke Dust	.5-20	3-24	.008-.05	99
Electric Furnace	Ferro-Manganese Fume	.1-1	10-12	.04-.08	99
Electric Furnace	Ferro-Silicon Dust	.1-1	1-5	.1-.3	92
Rotary Kiln—Iron Reduction	Iron, Carbon	.5-50	3-10	.1-.3	99
Crushing & Screening	*Taconite Iron Ore Dust*	.5-100	5-25	.005-.01	99.9
CHEMICAL INDUSTRY					
Acid—Humidified SO_3	H_2SO_4 Mist				
(a) Scrub with Water		—	303*	1.7*	99.4
(b) Scrub with 40% Acid		—	406*	2.8*	99.3
Acid Concentrator	H_2SO_4 Mist	—	136*	3.3*	97.5
Copperas Roasting Kiln	H_2SO_4 Mist	—	198*	2.0*	99
Chlorosulfonic Acid Plant	H_2SO_4 Mist	—	756*	7.8*	98.9
Dry Ice Plant	Amine Fog	—	25*	2.0*	90+
Wood Distillation Plant	Tar & Acetic Acid	—	1080*	58.0*	95
$TiCl_4$ Plant, TiO_2 Dryer	TiO_2-HCl Fumes	.5-1	1-5	.05-.1	95
Spray Dryers	*Detergents, Fume & Odor*	—	—	—	95
Flash Dryer	Furfural Dust	.1-1	1-1.5	.05-.08	95+
Phosphoric Acid Plant	H_3PO_4 Mist	—	192*	3.8*	98+
NON-FERROUS METALS INDUSTRY					
Blast Furnace (Sec Lead)	Lead Compounds	.1-1	2-6	.05-.15	99
Reverberatory Lead Furnace	Lead & Tin Compounds	.1-.8	1-2	.12	91
Ajax Furnace—Aluminum Alloy	Aluminum Chloride	.1-.9	3-5	.02-.05	95
Zinc Sintering	Zinc & Lead Oxide Dusts	.1-1	1-5	.05-.1	98
Reverberatory Brass Furnace	Zinc Oxide Fume	.05-.5	1-8	.1-.5	95
MINERAL PRODUCTS INDUSTRY					
Lime Kiln	Lime Dust	1-50	5-10	.05-.15	99+
Lime Kiln	Soda Fume	.3-1	.2-5	.01-.05	99
Asphalt Stone Dryer	Limestone & Rock Dust	1-50	5-15	.05-.15	98+
Cement Kiln	Cement Dust	.5-55	1-2	.05-.1	97+
PETROLEUM INDUSTRY					
Catalytic Reformer	Catalyst Dust	.5-50	.09	.005	95+
Acid Concentrator	H_2SO_4 Mist	—	136*	3.3*	97.5
TCC Catalyst Regenerator	Oil Fumes	—	756*	8.0*	98+
FERTILIZER INDUSTRY					
Fertilizer Dryer	Ammonium Chloride Fumes	.05-1	.1-.5	.05	85+
Superphosphate Den & Mixer	Fluorine Compounds	—	309*	5.5*	98+
PULP & PAPER INDUSTRY					
Lime Kiln	Lime Dust	.1-50	5-10	.05-.15	99+
Lime Kiln	Soda Fume	.1-2	2-5	.01-.05	99
Black Liquor Recovery Boiler	Salt Cake	—	4-6	.4-.6	90
MISCELLANEOUS					
Pickling Tanks	HCl Fumes	—	25*	2.3*	90+
Boiler Flue Gas	Fly Ash	.1-3	1-2	.05-.08	98
Sodium Disposal Incinerator	Sodium Oxide Fumes	.3-.1	.5-1	.02	98

* Milligrams per cubic ft

Note: The efficiencies shown above are average values for a particular plant or group of installations operating under a specific set of conditions.

5

silica dust powders and those for the smaller sizes on dispersed non-pathogenic bacteria. This size-efficiency curve suggests a very high efficiency for a comparatively simple piece of equipment.

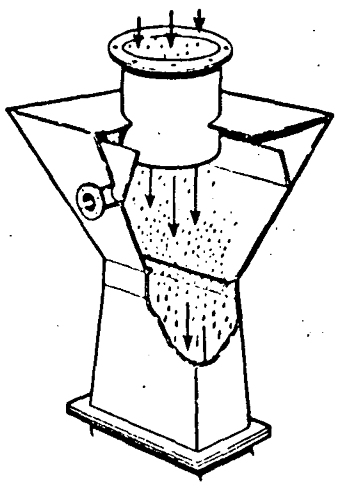
D Overall Efficiency

Table I shows some efficiencies of collection experienced by various installations.

IV ENERGY USAGE

A Since pressure drops of 30 inches water gage correspond to 120 kwh per million cubic feet of gas cleaned, efforts have been made to reduce the pressure drop. However, if pressure drop is reduced, there is a tendency to reduce the efficiency also.

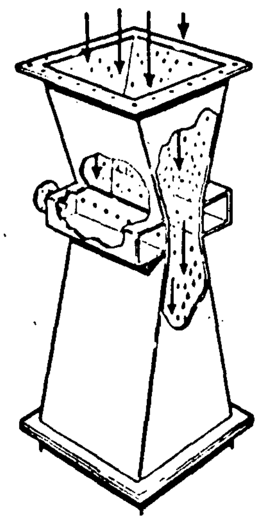
B Additional high energy usage results from the method of injecting water into the Venturi throat. See Figure 6.



THE TYPE S-F VENTURI

The Chemico Type S-F Venturi Scrubber is particularly recommended for these hard-to-handle situations: removal of "sticky" solids from gases; recycling of heavy slurries where water supplies are limited; and recovery of process materials in concentrated form.

In the S-F Venturi, scrubbing liquid is introduced through troughs at the top of the unit. The liquid flows downwardly in a continuous film along the sloping walls to the deflecting lips, which direct it across the throat of the Venturi to be atomized by the force of the high velocity gas.



THE TYPE P-A VENTURI

The Chemico Type P-A Venturi Scrubber is most effective in the very difficult applications requiring efficient removal of sub-micron dust, fume, and mist particles.

Chemical Construction Corp.

Figure 6

V PERFORMANCE DATA

Gas flow	200 to over 145,000 cfm
Gas velocity through throat	200-600 fps
Pressure loss	up to 25-30 in. water gage
Gas temperature	"unlimited"
Overall efficiency	usually high (97 - 99+%)
High efficiency on dusts with mass median size greater than	0.5-2μ
Humid air influence on efficiency	none
Water usage	5-7 gpm of water per M cfm gas

REFERENCES

1 Stairmand, C. J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before A. Inst. P. London. November, 1955.

2 Nicklen, G. T. Some Recent Developments and Applications of Scrubbers in Industrial Gas Cleaning. Proceedings APCA, 52nd Annual Meeting APCA. Los Angeles. June, 1959.

3 Jones, W. P. Development of the Venturi Scrubber. Ind. Eng. Chem. Nov. 1949.

4 Basse, B. Gases Cleaned by the Use of Scrubbers. Blast Furnace and Steel Plant. Nov. 1956.

5 Chemico Gas Scrubbers for Industry. Bulletin M-104, Chemical Construction Corporation, 525 West 43rd Street, N. Y. 36, N. Y.

6 Venturi Scrubbers for Industry, Bulletin M-103A, Chemical Construction Corporation, 525 West 43rd St. N. Y. 36, N. Y.

COLLECTORS WITH SELF-INDUCED SPRAYS

I MECHANISM OF PARTICLE COLLECTION

A In this equipment, the particle collection zone is a spray curtain which is induced by the gas flow itself through a specially designed orifice. (The spray curtain is followed by a spray eliminator).

B The Collection of Particles

1 Normal gas velocity of about 50 fps creates droplets about 320μ.

2 Collection of particles is mostly by impingement on the droplets during the free-falling period of the droplets and also during the period of the acceleration of the droplets from rest (when high relative velocities are available).

II APPLICATION

A Since there is an absence of ledges, moving parts, and restricted passages, these units are especially adapted to materials like:

1 Magnesium and explosive dusts

2 Sticky or linty materials like metallic buffing exhausts

III PERFORMANCE DATA

Efficiency -	See Figure 3
Water usage -	10-40 gal/1000 cfm gas cleaned (Much or all of this water may be recirculated).
Sensitivity - to cfm change	not particularly sensitive (at least within ± 25% of the design rate)
Concentration-	high concentrations (40 grains/ft^3) (There are no fine clearances to cause chokage)
Pressure drop-	$2\frac{1}{2}$ - 6 in. w.g.
Maintenance -	The whole apparatus is well irrigated and periodic hosing-down of the interior is easily done. There is an absence of moving parts. There may be corrosion difficulties.

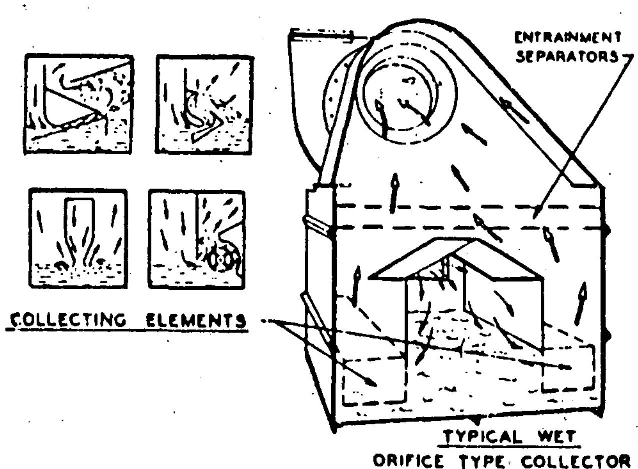
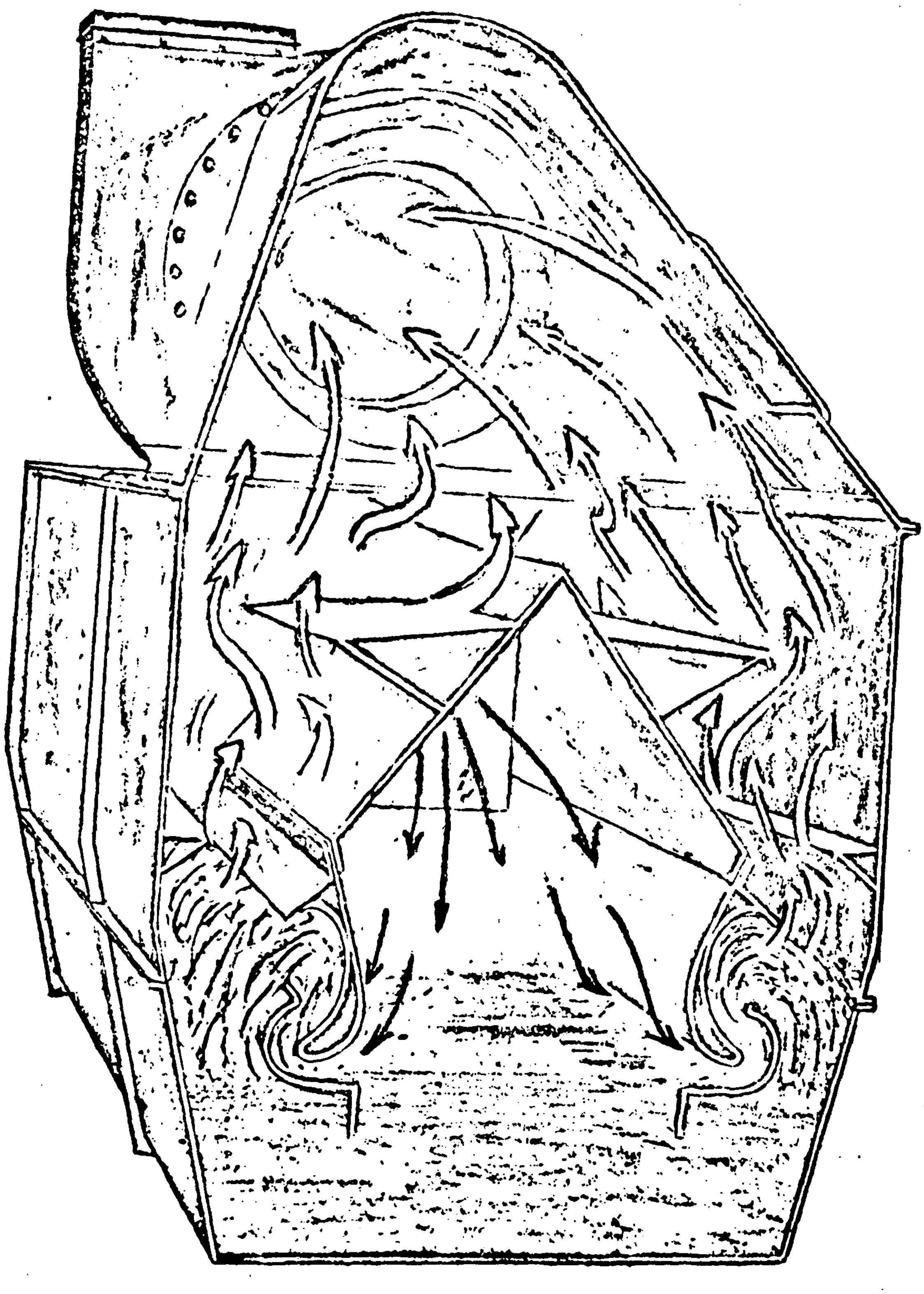
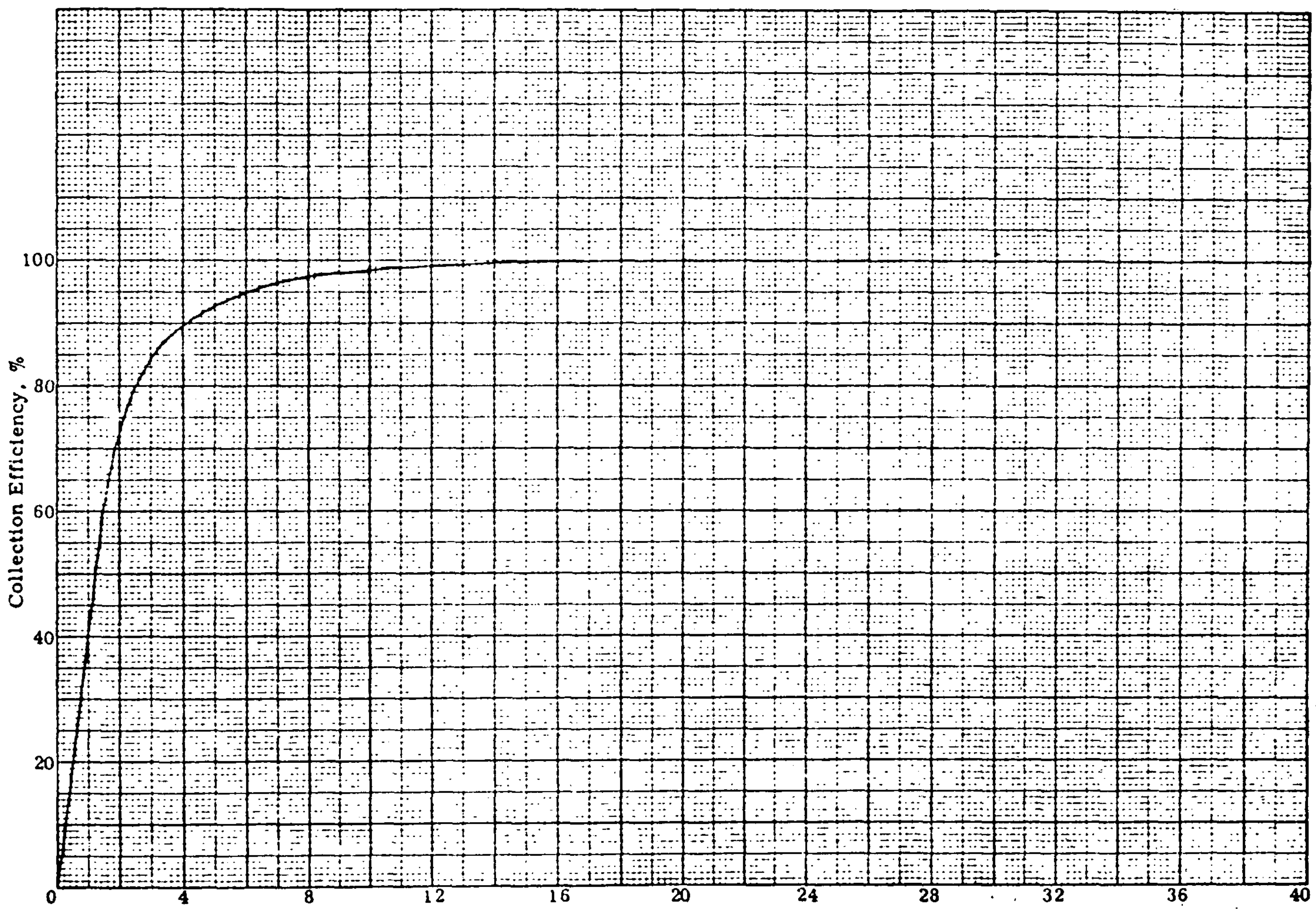


Figure 1



2



Size-Efficiency Curve for Self-Induced Spray Collector
Figure 3

55).

3

REFERENCES

1 First, M., et. al., "Performance Characteristics of Wet Collectors," NYO-1587 Waste Disposal, Harvard University. 1953.

2 Stairmand, C. J. "Mist Collection by Impingement and Diffusion," paper read at the Inaugural Meeting of Midland Branch of A. Inst. P., Birmingham, England. Oct. 14, 1950.

3 Stairmand, C. J. "The Design and Performance of Modern Gas-Cleaning Equipment," paper read before the A. Inst. P., London. November, 1955.

4 Kane, J. M. "Operation, Application, and Effectiveness of Dust Collection Equipment," Heating and Ventilating Aug. 1952.

5 Nicklen, G. T. "Some Recent Developments and Applications of Scrubbers in Industrial Gas Cleaning," Procceedings APCA, 52nd Annual Meeting, Los Angeles. June, 1959.

6 Magill, P. L. Air Pollution Handbook, McGraw-Hill Book Co., Inc. 1956.

4

WET DYNAMIC PRECIPITATOR

I OPERATION (Figure 1)

A Wet dynamic precipitators combine the dynamic forces of a rotating fan to cause the particles to impinge upon numerous specially shaped blades.

B A film of water is maintained on the blades by spray nozzles.

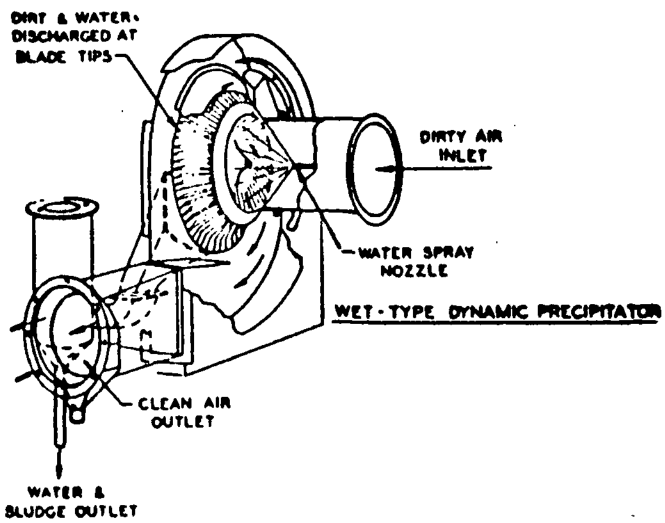


Figure 1

II PERFORMANCE DATA

Pressure drop. . . . . . a function of mechanical efficiency Usually less than 1-in. w. g.

Pressure drop sensitivity to cfm change. . . . . a function of mechanical efficiency.

Particle concentration. .less than 1 grain/ft^3. (For heavy loading, a pre-cleaner may be used to lighten the load on the unit).

High efficiency on particles with mass median greater than. . . . .1 - 2μ

Efficiency sensitivity to cfm change . . . . .no

Water usage. . . . . .0.5 to 1 gpm/1000 cfm gas

REFERENCES

1 First, M., et al. Performance Characteristics of Wet Collectors. NYO-1587 Waste Disposal. Harvard University. 1953.

2 Stairmand, C. J. Mist Collection by pingement and Diffusion. Paper read at the Inaugural Meeting of Midland Branch of A. Inst. P., Birmingham, England. October 14, 1950.

3 Stairmand, C. J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before the A. Inst. P. London. November, 1955.

4 Kane, J. M. Operation, Application, and Effectiveness of Dust Collection Equipment. Heating and Ventilating. August, 1952.

5 Nicklen, G. T. Some Recent Developments and Applications of Scrubbers in Industrial Gas Cleaning. Proceedings APCA, 52nd Annual Meeting, Los Angeles. June, 1959.

6 Magill, P. L. Air Pollution Handbook. McGraw-Hill Book Co., Inc. 1956.

DISINTEGRATOR SCRUBBERS

I MECHANISM OF PARTICLE COLLECTION

A Since for high collection efficiency there must be a small obstacle (D_o) and a high relative velocity between the obstacle and particle ($v_{p/o}$), attempt is made to approach this ideal by:

1 Shooting water drops at the particles so that a high relative velocity ($v_{p/o}$) will be obtained (even if such velocities are maintained for short periods) and arranging that this be done so that a very large number of impacts will be achieved.

B Such action is incorporated in the disintegrator scrubber (Figure 1).

II OPERATION

A A disintegrator scrubber consists of an outer casing containing alternate rows of stator and rotor bars, the relative velocity between adjacent bars being of the order of 200 - 300 fps.

B Water is injected axially and is effectively atomized into fine droplets (say 25μ) by the rapidly rotating vanes.

C The dust-laden gas also enter axially and passes through the dense spray zone where the particles are subjected to intense bombardment by the water droplets.

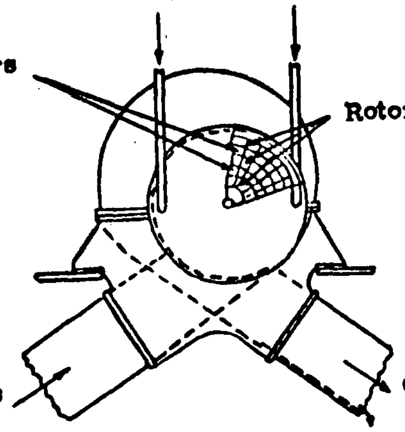
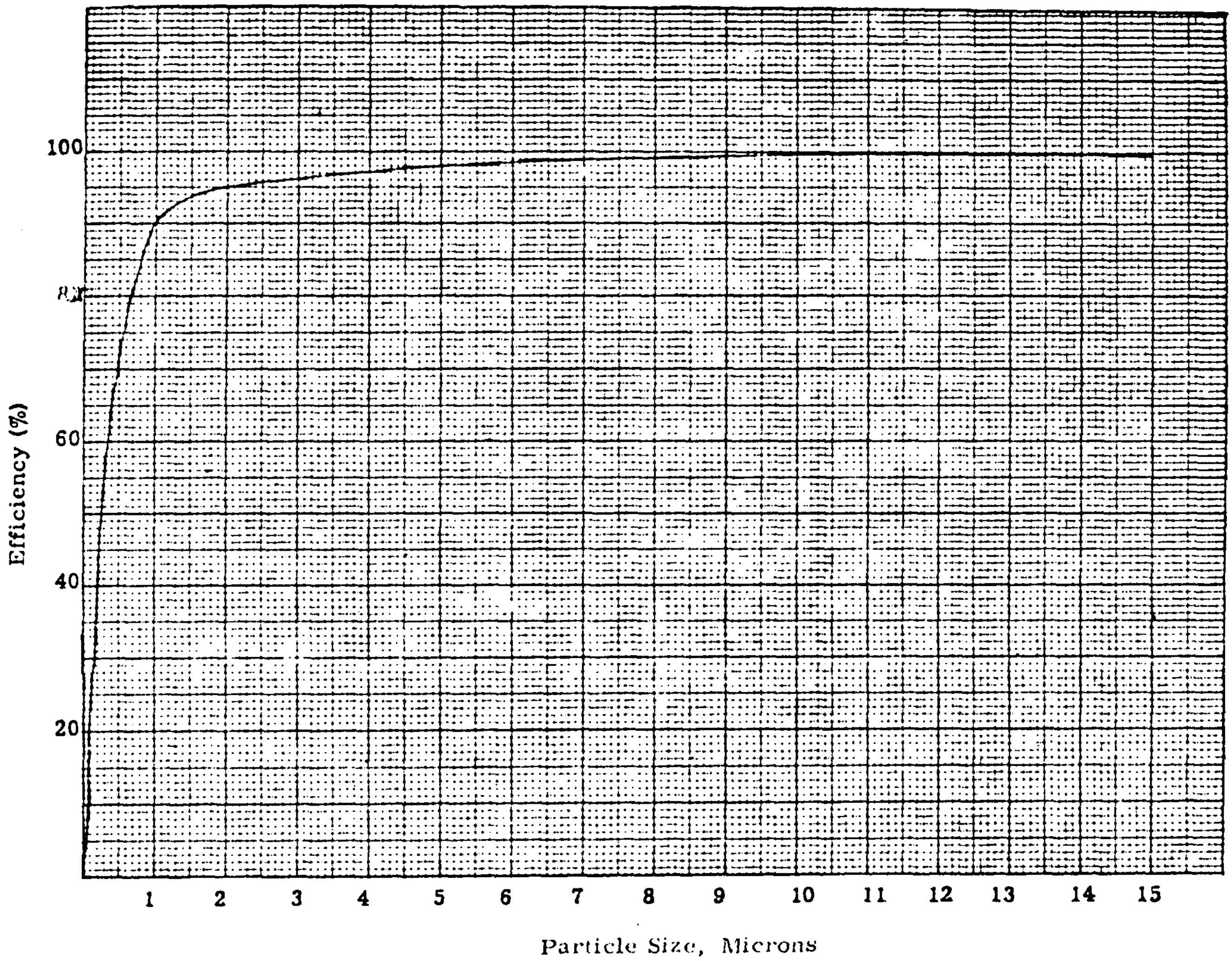


Figure 1



Size-Efficiency Curve for Disintegrator Scrubber

Figure 2

REFERENCES

1 First, M., et al. Performance Characteristics of Wet Collectors. NYO-1587 Waste Disposal, Harvard University. 1953.

2 Stairmand, C.J. Mist Collection by Impingement and Diffusion. Paper read at the Inaugural Meeting of Midland Branch of A. Inst. P. Birmingham, England. October 14, 1950.

3 Stairmand, C.J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before the A. Inst. P. London. November, 1955.

4 Kane, J.M. Operation, Application, and Effectiveness of Dust Collection Equipment. Heating and Ventilating. August, 1952.

5 Nicklen, G.T. Some Recent Developments and Applications of Scrubbers in Industrial Gas Cleaning. Proceedings APCA, 52nd Annual Meeting. Los Angeles. June, 1959.

6 Magill, P.L. Air Pollution Handbook. McGraw-Hill Book Co., Inc. 1956.

III. PERFORMANCE DATA

Efficiency	**highly efficient. See Figure 2 for a size-efficiency curve.**
Pressure drop	less than 1-in. w.g.
Energy usage	high power requirements. Total power consumption may be 16-20 HP per 1000 cfm gas cleaned. This power is largely expended in atomizing and accelerating the water.
Water consumption	extremely high.
Concentration	usually preceded by conventional collectors as cyclones and scrubbers to insure that low concentrations of the order of $\frac{1}{4}$ to $\frac{1}{2}$ grains per cu. ft. are presented to the unit. These precautions are necessary to avoid build-up in the disintegrator, which, running at high speed with fine clearance, is particularly susceptible to trouble if operated under unsuitable conditions.

IMPINGEMENT TYPE SCRUBBING TOWER

I TYPES OF SCRUBBING TOWERS

A There are two types of scrubbing towers commonly used:

1 Those employing impingement target plates

2 Those employing beds of spherical obstacles

II TOWER WITH TARGET PLATES (Figure 1)

A Construction and Operation

1 This type of scrubber is a tower consisting of a vertical shell in which are mounted a large number of equally spaced, circular, perforated (orifice) plates.

a At one side of each orifice plate, a conduit, called a downspout, is provided to pass the liquid to the plate below.

b At the opposite side of the orifice plate, a similar conduit feeds liquid from the plate above.

2 Over each hole (about 3/16" diameter) in the orifice plate, a target plate is positioned.

a The motion of the gas past the edge of the holes in the orifice plate results in the formation of spray droplets (about 100μ). These droplets are initially at rest and provide an effective relative velocity between particle and droplet for good impingement.

b The particle-laden gas passes through the holes in the plate and the particles impinge upon the atomized droplets and on the target plates.

B Particle Concentration

1 An important feature of this design is freedom from chokage in spite of the small holes in the orifice plates. This is due to:

a The very violent circulation induced below the targets by the air jets, and

b A preliminary spray zone which helps to keep the orifice plate free from deposits.

2 Concentrations of 40 grains/ft^3 can readily be handled.

C Efficiency

1 An example of a size-efficiency curve is shown in Figure 2.

D Pressure Drop

1 Each plate imposes a pressure drop of 3 in. w. g.

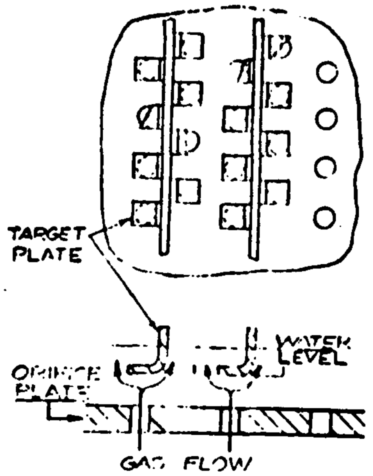
III TOWERS WITH BEDS OF SPHERES

A Construction and Operation

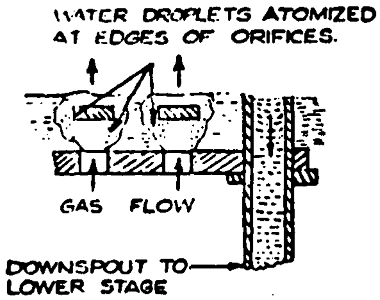
(An example of a scrubbing tower with beds of spheres is shown in Figure 3)

1 Large particles are removed by impingement on wet surfaces and contact with water spray in an area below the filter bed.

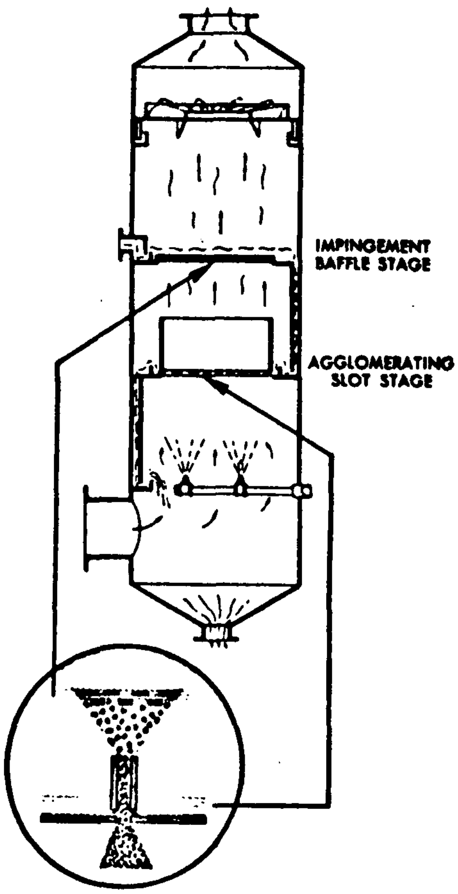
2 Particle-laden gas then passes upward through a bed of spheres. In the interstices of the bed, the particles are subjected to increased velocities which results in their efficient impingement upon the surfaces of the spheres.



ARRANGEMENT OF "TARGET PLATES" IN IMPINGEMENT SCRUBBER.

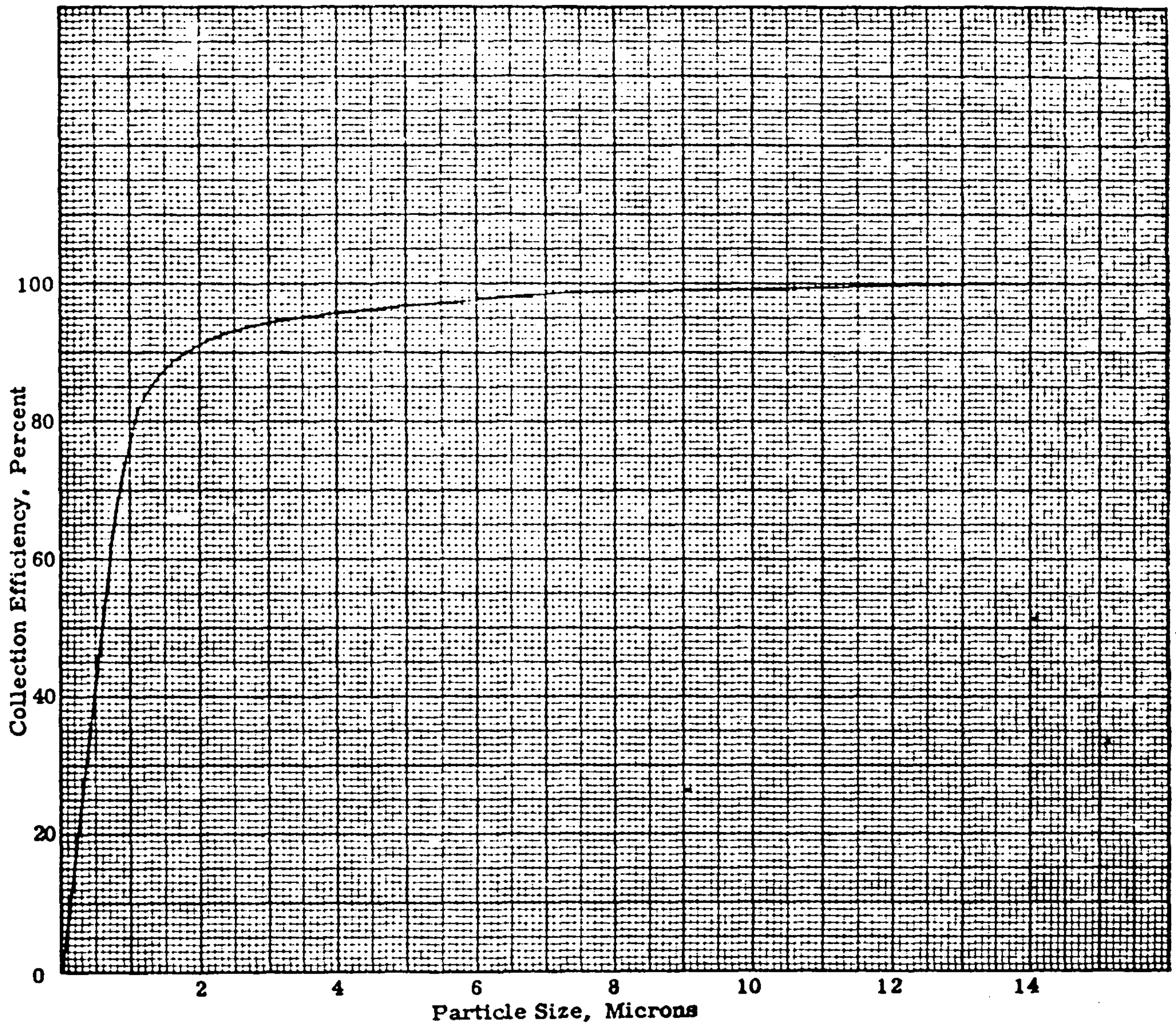


MECHANISM OF IMPINGEMENT SCRUBBER.



Peabody Engineering Corp.

Figure 1



Size-efficiency Curve for Wet-Impingement Scrubber
Figure 2

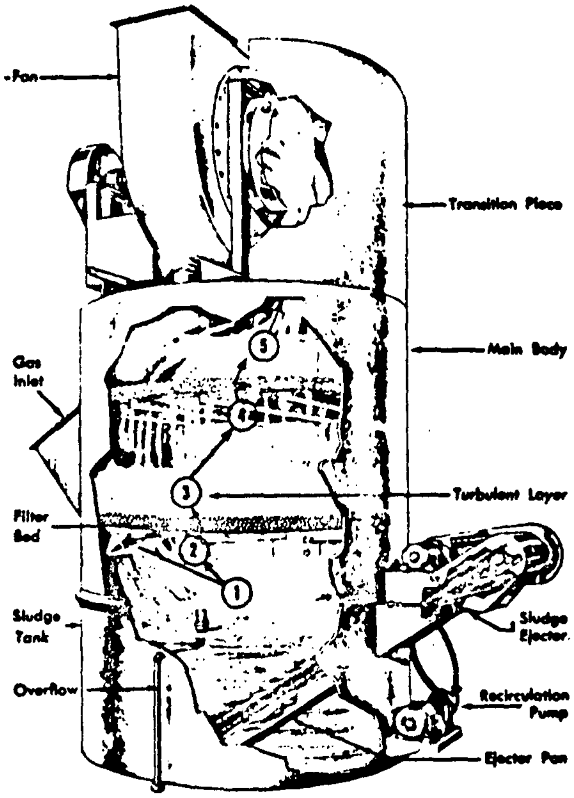


Figure 3

National Dust Collector Corp.

3 The high gas velocity through the interstices of the packed spheres also results in pulling water upward with sufficient force to disintegrate the water streams into a turbulent mist in the zone above the filter bed. Here, ultra-fine particles are trapped by the mist and constantly flushed downward.

4 Mist carried by the upward flowing cleaned gas is removed by passage through a bed packed with porcelain saddles.

B Particle Concentration

1 Such units have self-cleaning action and there is freedom from build-up of solids and ease of cleaning.

2 Concentrations of about 40 grains/ft^3 are readily handled.

C Pressure Loss

1 Pressure loss is 4-6 in. w.g.

D Efficiency

1 Efficiency is high on two micron-sized particles and above.

E Water Consumption

1 Fresh water: ¼gpm per 1000 cfm gas cleaned

2 Recirculated water: 3 gpm per 1000 cfm gas cleaned (Scrubbing liquid can have high solids content).

F Capacity

1 Units handle 500 to 40,000 cfm.

REFERENCES

1 First, M. et al. Performance Characteristics of Wet Collectors. NYO-1587 Waste Disposal, Harvard University. 1953.

2 Stairmand, C. J. Mist Collection by Impingement and Diffusion. Paper read at the Inaugural Meeting of Midland Branch of A. Inst. P. Birmingham, England. October 14, 1950.

3 Stairmand, C. J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before the A. Inst. P. London. November, 1955.

4 Kane, J. M. Operation, Application, and Effectiveness of Dust Collection Equipment. Heating and Ventilating. August, 1952.

5 Nicklen, G. T. Some Recent Development and Applications of Scrubbers in Industrial Gas Cleaning. Proceedings APCA, 52nd Annual Meeting, Los Angeles. June, 1959.

6 Magill, P. L. Air Pollution Handbook, McGraw-Hill Book Co., Inc. 1956.

WET CENTRIFUGAL COLLECTORS

I TYPES OF WET CENTRIFUGAL COLLECTORS

A Irrigated Types

1 These rely upon the throwing of particles against wetted collected surfaces, such as wetted walls or impingement plates by centrifugal action.

B Spray Chamber Types

1 These depend upon impaction of the particles upon spray droplets and the subsequent precipitation of the "dirty" spray droplets upon the wall of the unit by centrifugal action.

II IRRIGATED TYPES (Figure 1)

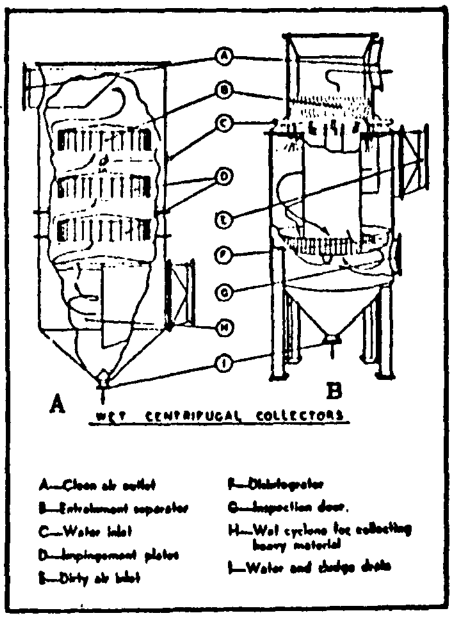


Figure 1

American Air Filter Co.

A The efficiency of a centrifugal collector may be increased by irrigating its walls, if the attendant disadvantages of a wet system can be tolerated.

B Water distribution may be from low pressure nozzles or gravity flow.

C Performance Data

Water rates.	.3-5 gal/1000 cfm of gas treated
Draft loss	$2\frac{1}{2}$ to 6"
Draft loss sensitivity to cfm change	as $(cfm)^2$
High efficiency on particles of mass median greater than. .	1-5μ
Efficiency sensitivity to cfm change.	yes
Humid air influence on efficiency	none
Gas temperature . . .	"unlimited"

III CYCLONE SPRAY CHAMBERS (Figure 2)

A Operation

1 The dust-laden gas enters tangentially at the bottom and spirals up through a spray of high velocity fine water droplets.

2 The dust particles are collected upon the fine spray droplets which are then hurled against the chamber wall by centrifugal action.

3 An unsprayed section above the nozzles is provided so that the liquid droplets containing the collected particles will have time to reach the walls of the chamber before the gas stream exits.

PEASE - ANTHONY CYCLONIC SPRAY SCRUBBER

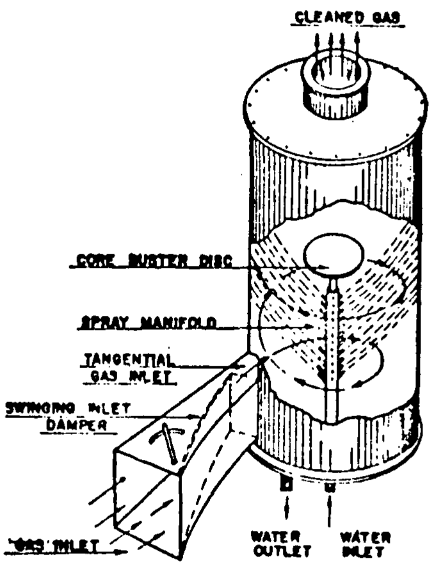


Figure 2

Chemical Construction Corp.

B Efficiency

1 Efficiency of dust removal is given by:

$$E = 1 - e^{-\frac{3\eta \, rWH}{2D_oQ}}$$

where:

- E = efficiency of collection
- η = individual droplet efficiency
- r = radius of the cyclone (the length of the path of the droplet)
- W = volume rate of liquid through the nozzle
- D_o = diameter of the droplets
- Q = volume rate of carrier gas
- H = height of tower (The drops should not be made too small since entrainment may occur, requiring an increase in the height of the tower)

2 Operating Conditions

Gas flow.	500-more than 25,000 cfm
Gas velocity into cyclone	up to 200 fps
Separation factor . . .	50 to 300
Efficiency.	97+% on dust above 1µ
High efficiency on particles of mass median greater than .	0.5 - 5µ
Efficiency sensitive to cfm change	yes
Draft loss	2 - 6" w. g.
Draft loss sensitivity to cfm change	as $(cfm)^2$
Water usage	3-10 gal/1000 cu ft of gas cleaned
Humid air influence on efficiency	none
Gas temperature . . .	pre-cooling of high temperature gases necessary to prevent rapid evaporation of fine droplets.
Power requirements .	1 to 3 HP/1000 cfm of gas

REFERENCES

1 First, M., etal. Performance Characteristics of Wet Collectors. NYO-1587 Waste Disposal. Harvard University. 1953.

2 Stairmand, C. J. Mist Collection by Impingement and Diffusion. Paper read at the Inaugural Meeting of Midland Branch of A. Inst. P. Birmingham, England. October 14, 1950.

3 Stairmand, C. J. The Design and Performance of Modern Gas-Cleaning Equipment. Paper read before the A. Inst. P. London. November, 1955.

4 Kane. J. M. Operation, Application, and Effectiveness of Dust Collection Equipment. Heating and Ventilating. August, 1952.

5 Nicklen, G. T. Some Recent Developments and Applications of Scrubbers in Industrial Gas Cleaning. Proceedings APCA, 52nd Annual Meeting. Los Angeles. June, 1959.

6 Magill, P. L. Air Pollution Handbook. McGraw-Hill Book Co., Inc. 1956.

VENTURI SCRUBBER
OPERATION AND MAINTENANCE

Prepared by

K. C. Schifftner
Peabody Process Systems
Glenbrook, Connecticut 06906

Prepared for

Environmental Research Information Center
Seminar on

Operation and Maintenance of
Air Pollution Equipment for Particulate Control

April 1979

ENVIRONMENTAL RESEARCH INFORMATION CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

E.P.A. SCRUBBER OPERATIONS & MAINTENANCE SEMINAR

Ken Schifftner

A scrubber system is an investment of a peculiar variety. Unlike production equipment whose pay-back can be gauged and plotted, a scrubber system begins its life typically unwanted and follows an often ignored course through its operating life, more a symbol of Government mandate than a willfull, environment protecting device.

Yet an improperly operated scrubber system can destroy profits in a more dramatic fashion than most any commercial factor. It can gobble up operating capital unless controlled, waste energy unless properly maintained, and fail to reach compliance unless efficiently operated. Many of you know this all too well.

We will attempt to disclose as many operating and maintenance suggestions as space will allow so that your "bag of tricks" will be fuller, your confidence reinforced in your ability to keep air pollution control equipment operating effectively and at lowest cost.

Types of Scrubbers:

Wet scrubbers can be divided into approximately six (6) basic types:

Venturi -

Using a high velocity zone of various configurations designed to change fan static pressure into velocity pressure, in doing so creating fine, dust-removing droplets when scrubbing liquid is introduced. The efficiency of these devices vary as the pressure drop across the venturi and the mechanical efficiency of the throat in the creation of the droplets.

Impingement -

These use perforated or slotted plates containing target plates opposite all openings to cause an abrupt change in direction (and acceleration) of contaminant laden air. When flooded with scrubbing liquid, these designs produce a high surface area froth of scrubbing liquid on its top surface and turbulence, both factors contributing to particulate removal and gas absorption.

Packed Tower -

Like the impingement scrubber yet use replaceable packing which extends the surface area of the scrubbing liquid, providing a tortuous path for the contaminated gas and enhancing gas absorption.

Spray Tower -

A gas absorption device developing high liquid surface areas through the use of a spray nozzle(s), hydraulically or pneumatically atomized.

Dynamic Scrubbers -

Utilize a fan, impeller or other motive device to mechanically produce small droplets which enhance gas absorption and particulate removal. These are typically sprayed fans, coupled with droplet removal devices.

Cyclonic Scrubbers -

A spray tower variation in which gas is spun cyclonically in a vessel with scrubbing liquid sprayed concurrantly into the stream.

General Problems:

Before getting to specifics, lets talk about general wet scrubber problems.

Most scrubber problems, assuming the proper unit was selected for the given application, involve spray nozzle plugging, liquid circuit restrictions and entrainment of droplets from the vessel.

Other less common problems are:

Wet/Dry line build-up: the scrubber design improperly allows dry dust laden gas to contact the juncture of the scrubbing liquid and the vessel, causing dust build-up. Good designs prevent this contact by extending ductwork sections sufficiently into the scrubber and thoroughly wetting all scrubber surfaces through reliable means (usually gravity flush and sometimes sprays).

Nozzle Plugging: Nozzles plug through improper selection; too small orifices through which too dense scrubbing liquid must pass; improper header design; drawing off a sump which also settles (and concentrates) solids; erratic pump operation; chemical sealing; and mechanical failure.

Flow Imbalance: The headers external to the scrubber are very important. They must send the manufacturer's required flow to the proper location at the proper rate. Many problems are solved through the simple adjustment of flow using existing valves.

Build-up (scaling): Scaling is the plating out of deposits on a scrubber surface. Usually it is harmless unless the surface in question is a functional one. It is caused by the chemical composition, solubility, temperature and pH of the scrubbing liquid. A difficult problem to diagnose; a good deal of research has been done on calcium based SO_2 scrubber scaling problems. Proper control starts with the scrubber design and process control.

Localized Corrosion: Corrosion is a major factor in shortening the operating life of a scrubber whether properly designed or not. Wells or pockets of liquid should be avoided and points of stress should be adequately flushed. Internal members attacked from two sides should be thicker than the shell.

Instrumentation fitting blockage: One problem which significantly causes other problems is instrumentation blockage. Many times a standard fitting is not adequate in a scrubber, specially designed fittings and connections must be used.

Sump Swirling: Especially on cyclonic devices, the swirling of the scrubbing liquid can cause severe wear and draining problems unless arrested by anti-swirl plates in the scrubber or rapid continuous draining.

Entrainment: Entrainment occurs when the droplet separator is not functioning properly. Nearly all scrubbers produce entrainment, only the good ones remove it prior to discharge.

Re-Entrainment: Re-entrainment occurs beyond the droplet removal device through improper draining or erratic flow patterns. It can also occur in stacks of very high velocity or where fittings protrude into the high velocity air area.

Liquid-Gas Maldistribution: The gas and liquid must be properly distributed for the given application. Each affects the other aggravated by the influence of baffles (needed or accidental), build-up, mechanical failure, wear, scaling in headers or improper design. This is most common in packed and spray towers.

Thermal Shock: Where hot gas meets cold scrubber something has to give. Proper design permits gradual cooling rather than abrupt changes. A typically simple problem to fix through the use of multiple cooling zones, thermal shock is sometimes only discovered too late.

Loss of Seal: All scrubbers run in variation with atmospheric or ambient conditions. The juncture of the liquid circuit with its surroundings is many times a liquid seal. This seal may be at the top of a quencher or from an overflow connection. These lines must have seals able to prevent gas movement to or from the ambient surroundings. Loss of seal can cause entrainment or plugging, and instrumentation malfunction.

Wear: Wear can be tolerated unless it is localized. Unfortunately, a scrubber's functioning parts are also the wear parts. Expect to replace fan wheels if they are constantly sprayed with water (as in dynamic scrubbers) venturi throats on venturi scrubbers and any other high velocity zone.

Wear (Cont'd): Remember, gasses take the path of least resistance (not necessarily the shortest path). When you check for wear, be suspicious of those parts which inhibit this flow (parts directly along the path of least resistance).

Vibration: Most common in wet dynamic scrubbers and with the fans on wet fan venturi or cyclonic systems, it is best controlled by monitoring and scheduled preventive maintenance.

Now let's look at a hypothetical "lemon" system, purchased by some fellow who bought the system from the company 40% below everyone else's price, using ½ the water consumption and 1/3 the energy. Let's investigate some of the problems of this bargain that didn't work.

Please see Figure #1

Here we see a quencher venturi scrubber with a fixed throat, cyclonic separator, tray absorber, vane type droplet eliminator, and, for sake of further discussion a chevron droplet eliminator and a mesh pad. The absorber liquid circuit is separate from the venturi circuit so that a neutralization chemical may be added to the absorber.

Let's follow some 1800°F gas into the quencher through the venturi and out to atmosphere.

Quencher:

The manufacturer of this system apparently calculated the exact amount of water needed to adiabatically saturate this gas flow and introduced it into a single quencher nozzle. Unfortunately the quencher only cooled to 800°F as expected. Why?

Possible Reasons:

A. Low Water Flow: Typically 1½ to 2½ times the theoratical evaporation demand are used spray quenchers. It is a matter of probility that dictates the more droplets available to evaporate, the more will.

Possible Reasons (Cont'd)

B. Poor Distribution: Selecting a cheap hollow cone nozzle, the manufacture made thorough cooling nearly impossible. Full cone nozzles are usually used since evaporation is a surface phenomenon. One must generate a high surface area to adequately evaporate. He should add a full cone nozzle or a double header to adequately quench and cool. At least 2 dia. straight duct dun above the quencher should be used.

C. Low Header Pressure: In the heat of bidding this job, the manufacturer found out that a competition claimed only 10 psig. quencher header pressure. He then changed his pressure to 5 psig. The 5 psig. pressure however only gives him a 60° spray cone angle, not 90° as he needs and the nozzle is producing 1000 micron droplets at 5 psig., not 400 micron or smaller as he needs. Raise the header pressure to 15-30 psig. after checking the spray nozzle characteristics for agreement.

D. Short Length: Evaporation is a surface phenomenon, as we said. It is also time dependent. Evaporation does not occur instantaneously, but progresses at a rate dictated by the evaporating liquid, the humidity, and temperature of the surrounding air and physical factors such as turbulence. Usually 0.15 to 0.25 sec. residence time is used for gases 1000°F and below with 0.2 -0.3 sec. used for hotter gases.

You'll note on figure #1 that the quencher is quite long. The manufacturer had to double the quencher length.

Seal:

Between the bottom of the quencher and the top of the venturi is a liquid seal. When first started up, the "lemon" system sucked all the water out of the seal within seconds. The user was told to fill the seal with sand. The scrubber then sucked the sand out of the seal. Extra height was then added to the seal and it now works fine.

Some seal problems and solutions are:

A. Insufficient height due to suction: Allow at least 4" more free-board height on all liquid seals over and above the manometer effect which will occur naturally. On adjustable venturi scrubbers, with a fan after the scrubber, start-up the venturi with closed so as to restrict flow. On adjustable venturis running under pressure, start (if possible) with the throat open and the fan inlet dampers closed so as to reduce the pressure at the seal.

B. Low flow: Add enough liquid to continually overflow inside the vessel.

C. Poor distribution: Make certain the seal is level and symetrical. A seal at an angle will draw more quickly from the side with the lowest atmosphere to baffle length.

D. Asymetrical liquid flow: Typically one liquid inlet is not enough, multiply inlets should be used.

Please see figure 1A for the revised liquid inlet.

Now we get to the venturi itself. Figure 2A shows an actual adjustable venturi used on a successful industrial application. There are many more like it presently operating well. Problems do occur however.

Let's go through about a dozen potential problems with venturi scrubbers:

A. Distribution pipes insufficient in size or quantity.
As we mentioned about wet/dry line problems, the venturi inlet must have the proper liquid distribution in order to function properly. Many venturis do not have sufficient liquid inlets to cover the approach (hopper-shaped section) of the scrubber. An inspection into this zone usually shows a non-uniform flow pattern or perhaps no flow at all.

Inlet pipes should be no more than about 8'/sec. velocity if tangential type and no more than about 6'/sec. if weir type. This reduces flow imbalance due to splashing.

B. Distributor pipes plugged: This common occurance, especially on limekiln scrubbers can be corrected by placing rod-out connections at all plugging prone locations. Headers should be made in small sub-assemblies to facilitate handling. Many installations outlaw 90^{o} elbows, using two 45^{o} elbows and a coupling instead.

C. Distribution should cover entire approach surface. Additional headers may be needed in the "lemon" system to accomplish full coverage.

D. Poor flow, quantity and pressure: Do what the operating manual says to do. On high solids lines, put the venturi liquid outlet distributor pipe above the venturi, feeding downward from its bottom surface (rather than the top) into the venturi inlets. This permits thorough draining on shut down/and provides more uniform flow under low flow conditions.

E. Solids content too high for the scrubber design: Most scrubbers using open pipes can't reliably tolerate slurries over 15% by weight. Usually the instrumentation connection begin to plug near this concentration with the venturi plugging at 15-20% solids. It is wise to run the unit at 6-8% solids maximum for best operation. Spray nozzle scrubbers sometimes can't tolerate 2% solids in the liquid circuit. If it must run above this number, an alternate liquid feed circuit should be used; or designs used which incorporate larger nozzles.

F. Wet/Dry Problems: As mentioned under problem A, the liquid distribution must be proper. Many times the inlet spool (piece of scrubber inlet extending down into the approach zone is simply not long enough). In figure 1A you'll note it extends well below the weir. Newer designs use a straight weir but maintain this extension.

G. Thermal Shock: Most venturi scrubbers can't tolerate an external load on their inlet flange. More importantly they must not be thermally loaded.

Proper operation of the quencher helps prevent this. A small horizontal water hold-up ring welded to the interior of the quencher can help keep this surface wetted, preventing thermal shock. Always put the quencher water circuit on a reliable liquid circuit. You can see from figure 1 that the "lemon" system uses the venturi recirculating pump as the quencher water pump. What happens if this pump fails?

The manufacturer does not cover the damage under his warranty.

Put the quencher liquid circuit on a reliable clean water line, not a recirculation line.

H. Stress Corrosion Cracking: Much like thermal shock, attack by halogenated compounds can cause stress corrosion cracking. Proper material selection is important. Don't recirculate if halogens are being scrubbed out. The venturi circuit will merely serve to concentrate them; Higher alloys are needed.

At 600° F inlet temperature, even 50 ppm HCl can have devastating effects on stainless steel.

I. Low L/G: The L/G (liquid to Gas ratio) is important not only for particulate removal but also for scrubber operation. Typically only 2 gallons in 10 of scrubbing liquid really does the scrubbing. The rest is used to convey, flush, dilute, humidify and cool.

Extremely low L/G ratios invite problems. When the inlet grain loading is 10 and above, most venturis use L/G ratios of 10-15. When the loading is 5-10 grains, the scrubber operates in the 7-10 L/G range.

Some new upflow scrubbers use only 4-5 gallons per 1000 ACFM for this same flow.

One manufacturer claimed a few years ago that his design used only 1 gallon per 1000 ACFM. Calculating this out, the scrubber sump would be a muddy unpumpable glop of 65% solids. He revised his figures to 4-5 gallons/1000 cfm "for this application". Get specific recommendations from the designer, not from brochures.

Adjustable Venturi Problems:

Adjustable venturi scrubbers include damper blade type (either round such as a butterfly damper or rectangular such as a louver damper), annular (in which a center body, usually conical, moves up and down) or a disc design. The basic function is to vary the area of the venturi in an effort to produce the pressure drop required for a given efficiency.

Dampers which pivot from a shaft usually vary the throat area by a function of the sine of the angle of rotation. Center bodies which advance along the center of the venturi throat may vary as a function of the angle of the center body cone versus the fixed outer housing. Disc scrubber throats vary the area linearly.

The different types available result from different needs. A draft sensitive process using a damper blade scrubber whose area varies as the sine of the angle is a potential problem. Changing the angular position of the damper can have a dramatic effect on process suction. An annular venturi or disc venturi would be less sensitive.

On very low pressure drops however, the annular may not provide adequate mixing and therefore be at a disadvantage. Typically annular venturis have a lower mechanical loss than damper blade designs, a result of better geometry and stream linine.

Adjustable venturi problem solving is best left to the manufacturer. He knows better the thought processes used in its design and may offer constructive solutions.

Wear

Before we go on to the separator, lets take a step backward and look at the entire system for wear locations. Figure 2B shows typical scrubber wear areas.

As mentioned earlier those high velocity points along the path of less resistance are most likely to wear. Notice it varies whether the unit is forced draft or induced draft.

In the induced draft mode, the corner of the venturi elbow (if any), will likely be a wear area. Operating under suction, the air tries to cut this corner, wearing this area considerably on abrasive applications. A wear plate there is a good idea.

Under forced draft, there is less suction in the separator (technically, the air is denser) thus the air tries to impact first at the base of the venturi, then redistribute itself, then proceed to the separator. Forced draft venturis tend to be more easily "fed", meaning they distribute better in the approach section.

The separator wear zone if cyclonic like in our example, wears about the same regardless of fan location. Most tangential entry separators have a draft loss of 2-4" w.c. and thus use restrictions at the point of tangency to provide the higher velocities used to cyclonically separate droplets from gas.

Not only does wear occur at this point but also through about 100° of rotation beyond this point as the air is forced against the wall. Fiberglass scrubbers have been known to completely wear through at this point. This zone is also a potential entrainment zone which will be discussed later. The plan view in Figure 2B shows this area more clearly.

The "lemon" system we are discussing had to have wear plates installed in this zone to reduce the affects of erosion.

Absorber

Moving on to the absorber, we find a different set of physical constraints at work. Now we must have good distribution, must move vertically rather than cyclonically and must maintain good distribution and flow.

Absorber (Cont'd)

Whether packed tower or tray tower, the absorber must be presented with a uniform gas flow. Any obstructions, baffles, headers etc., which disrupt this flow could have an effect on the absorber.

If the flow is too low, channeling can occur in a packed bed and "weeping" can occur in a tray absorber. "Weeping" exists when the liquid above the tray has a higher pressure than the gas beneath that particular part of the tray. Scrubbing liquid will drain through the tray perforations causing a shift in air flow patterns to a less restrictive point.

Channeling can occur both by liquid distribution and gas flow. A liquid flow directed too strongly to the side wall of the unit can cause a deficiency of liquid in the center, encouraging less resistance and greater gas velocity. If you install packing, leveling it out one day, only to find it grossly shiffted the next, you may have channeling. The hearers, liquid flow or distribution may have to be altered. Commonly, greater spray is applied to the center of a packed absorber since the gas does not proceed in plug flow through the tower (though this is assumed for design purposes).

Here is an absorber checklist.

Packed Tower

Problem	Possible Solutions
Poor Gas Distribution	1. Use and injection type support grid.
	2. Allow extra vertical height-Inlet to grid.
	3. Use less than 8'/sec. vertical velocity
Poor Liquid Distribution	1. Install redistributors every 4-6' of packing.
	2. Rearrange headers and liquid entry.
	3. Use a reflux distributor grid.
Packing Sized Improperly	1. Check with packing manufacturer not scrubber designer. Many companies ingnore recommendations.
Too High Velocity	1. Put another tower in parallel with existing unit.
	2. Cut back in flow rate if possible.
Too Low Velocity	1. Restrict bottom part of grid.
	2. Use small packing.
	3. Use redistributors.
	4. Raise water rate.

Tray Absorber

Problems	Possible Solutions
Weeping	1. Select open area proper to eliminate weeping.
	2. Bleed in air if possible
	3. Blank off excess area.
Plugging	1. Use spray wash header. Check operation.
	2. Reduce solids content in scrubbing liquid.
	3. Clean periodically.
	4. Raise flow rate (check factory).
Distribution Poor	1. Check, inspect trays. Lack of uniformity of condition indicates poor distribution. Baffle as required to offset poor gas flow.
	2. Use end weirs on the downcomers to retain extra water on the tray.
	3. Clean weir boxes.
Weir Sizing	1. Size for full flow, maximum condition. If too small, enlarge or install supplemental external weirs.
	2. Keep them clean.
Mechanical	1. Make certain trays are securely in place.
	2. Stiffen warped trays.
	3. Tighten all fittings.
	4. Reweld baffle strips, caps, keeper plates, etc., or replace trays if broken.

Having solved the absorber problem, our hypothetical case now presents us with the droplet removal devices: The vane eliminator, the chevron, and the mesh pad, and our previously introduced cyclonic separator.

Each have two major problems, extrainment and build-up. Build-up is the easier of the two problems. It is controlled by judicious cleaning (or flushing) by sprays or headers as follows:

Vane	1. Center spray (intermittent)
	2. Periphery flush (intermittent)
Chevron	1. Spray from below
Mesh	1. Spray from above
	2. Spray from both above and beneath
Cyclonic	1. Routine continuous flow

Entrainment is another matter. Figure 3 shows a vane eliminator in cross section with some modification to improve droplet separation.

A. Add a cone on the center spool to act as a vortex finder. The swirling air above the vane needs a surface to pivot from. Making a 20° (from the horizontal) cone produces a point on which this vortex may pivot. It can produce sometimes dramatic improvements.
B. Clean or enlarge drain(s).
   Internal drains need periodic cleaning. Otherwise they will back up, overflowing previously removed liquid back into the air stream.
C. Clean or enlarge down pipe. For reasons above.
D. If all else fails, install an external drain.
E. Clean unit on spection. Many 18 gauge vane eliminators can be cleaned with a rubber mallet. Striking it about a foot out from the center hub sometimes vibrates build-up off.
F. Re-weld any loose vanes.
G. Make certain center manhole is sealed.
H. Use flush water at the rate of 2 gallons per minute per foot of periphery.
I. Use the center flush spray (if provided).

A vane eliminator too high up in the vessel will typically not function properly regardless of modification. One low in the vessel can be improved.

Mesh pads are merely filters. Like filters they build up. Spraying from beneath and above periodically can remove some material.. Spraying from beneath only will drive the material further into the mesh dictating removal and cleaning or replacement.

Chevrons are typically spray cleaned from below.

If the vertical velocity is above 600 ft./min., most chevrons will begin to entrain. At about 900 ft./min., mesh pads begin entrainment. Vane eliminators have open area velocities of 1200-1600 ft./min. depending upon application.

Any modular type droplet eliminator (chevron or mesh) should be sealed at the wall to prevent sneak-by.

Cyclonic separators sometimes re-entrain because the scrubbing liquid previously thrown against the vessel wall streams back down on top of the cyclonic inlet. Forming a puddle, it will overflow into the air stream creating a spray. This can be eliminated or reduced by installing a wiper angle as shown in Figure 3 to direct this flow towards the center of the scrubber much like a rain gutter. By reducing the area, (section B-BO of the inlet, higher velocities can be obtained sometimes resulting in improved droplet removal capability.

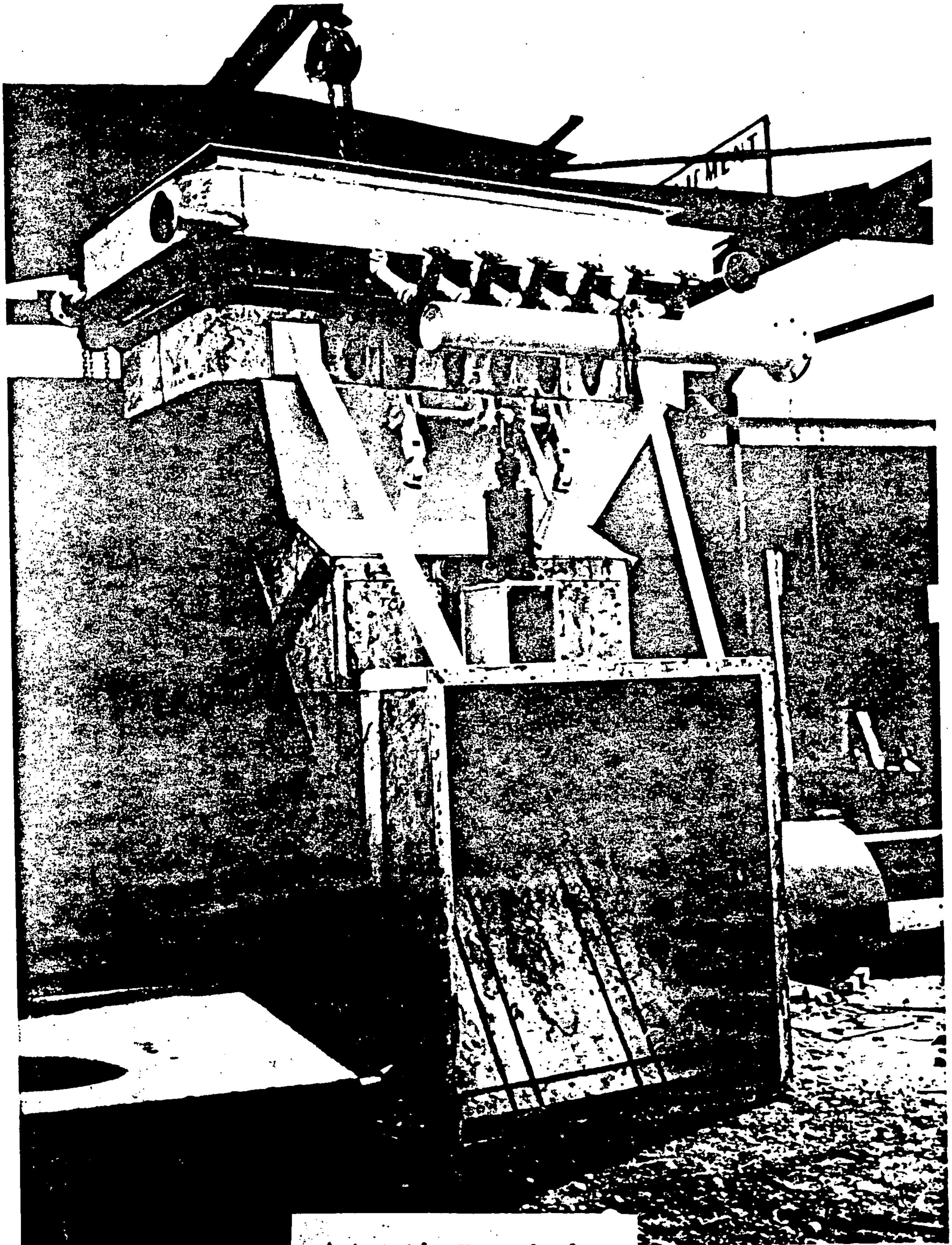
Wow, we made it. The gas can now leave up the stack. The stack had better be of low enough velocity (under 30'/sec) to reduce the chances of re-entrainment though.

What about instrumentation connections? If they don't work, how can you analyze the problem? Figure 4 shows some typical instrumentation connections including the pressure tap angled so as to reduce plugging, the vented level control fitting to reduce turbulence and stabilize readings, and the tank mounted pH or O.R.P. probe (placed so that you can get at it).

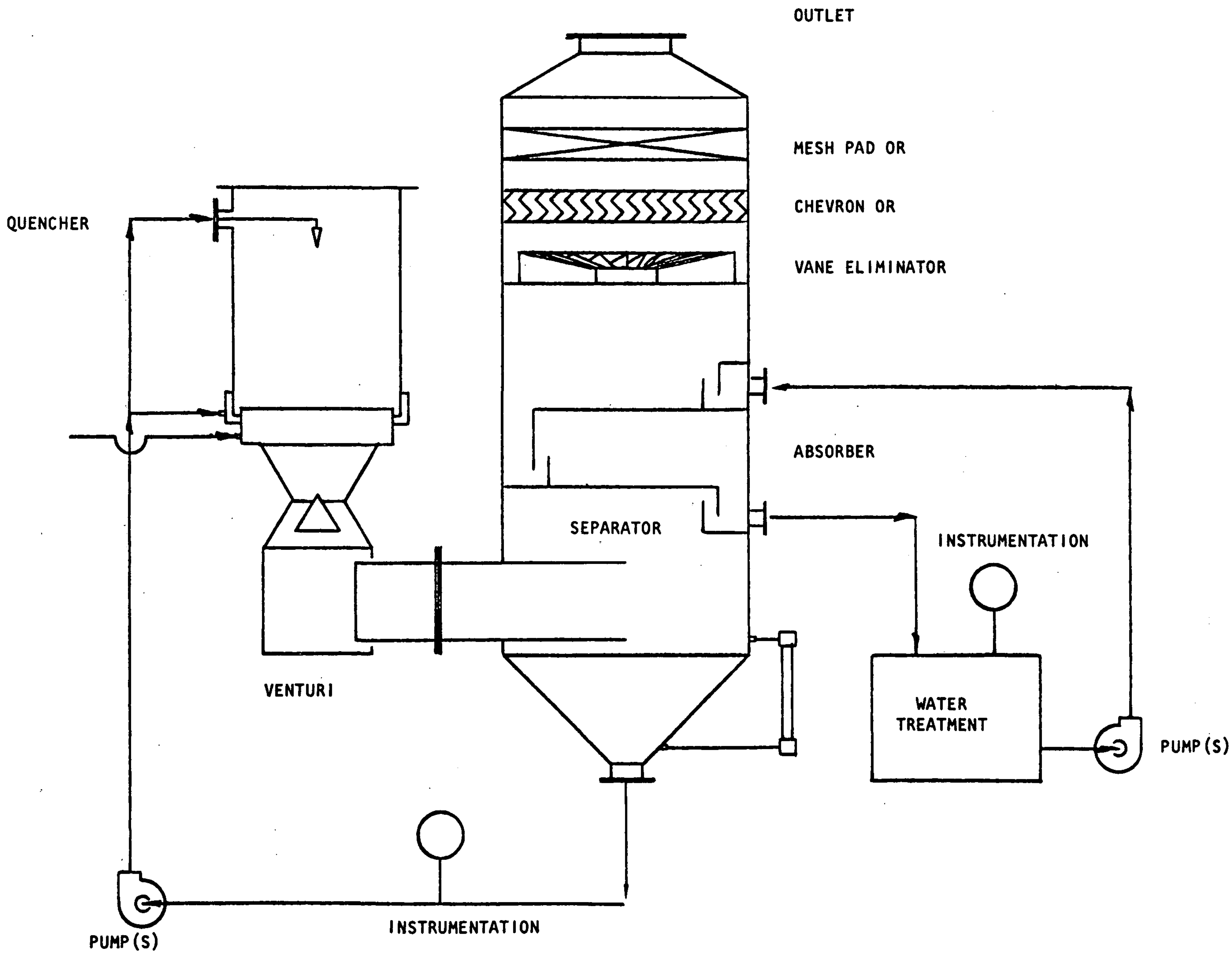
Using these suggestions, your "lemon" should be salvageable. Had this example been a dynamic scrubber or spray tower, general comments and trends would apply equally as well. Time does not permit a similar example.

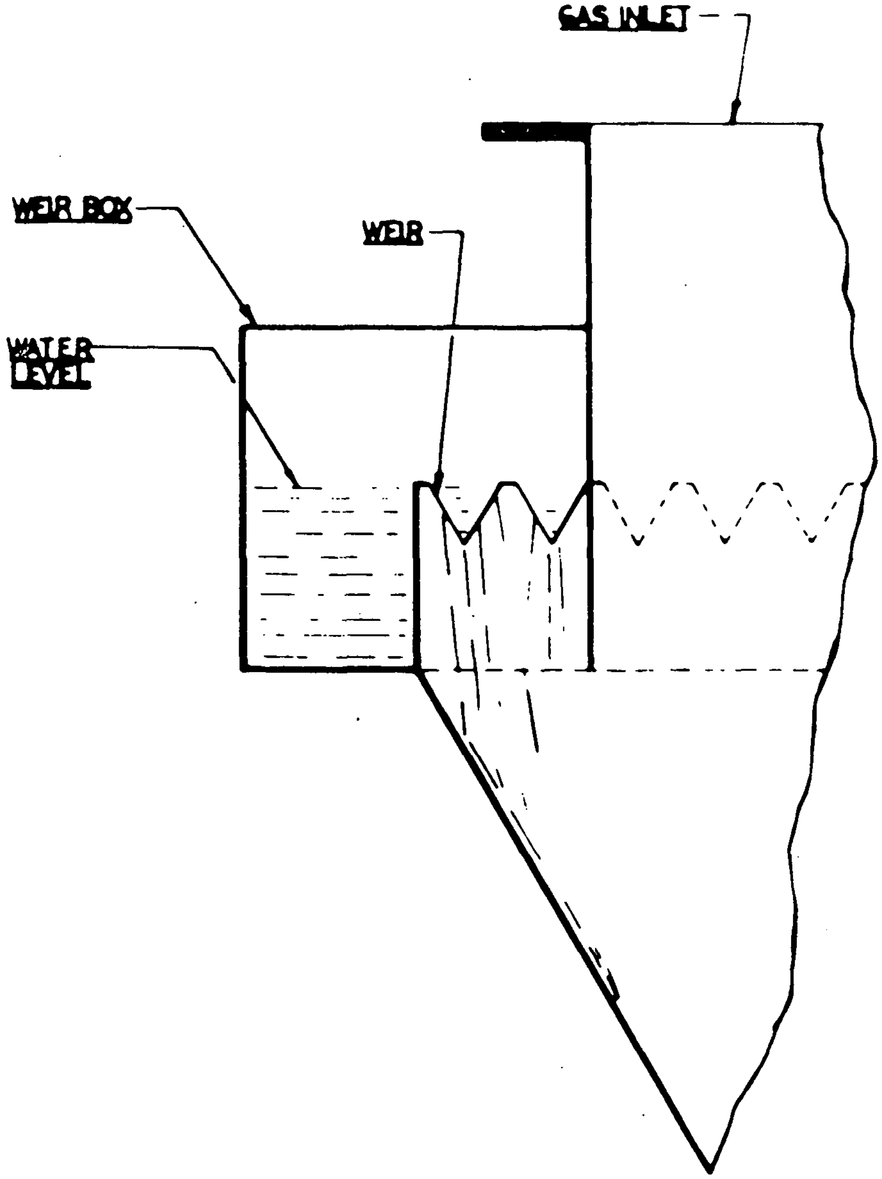
We hope our comments give added insight into solving wet scrubber operational problems. Specific questions, of course, should be discussed with the particular scrubber manufacturer prior to start of work.

Thank you.



Automatic Ventri-Slot

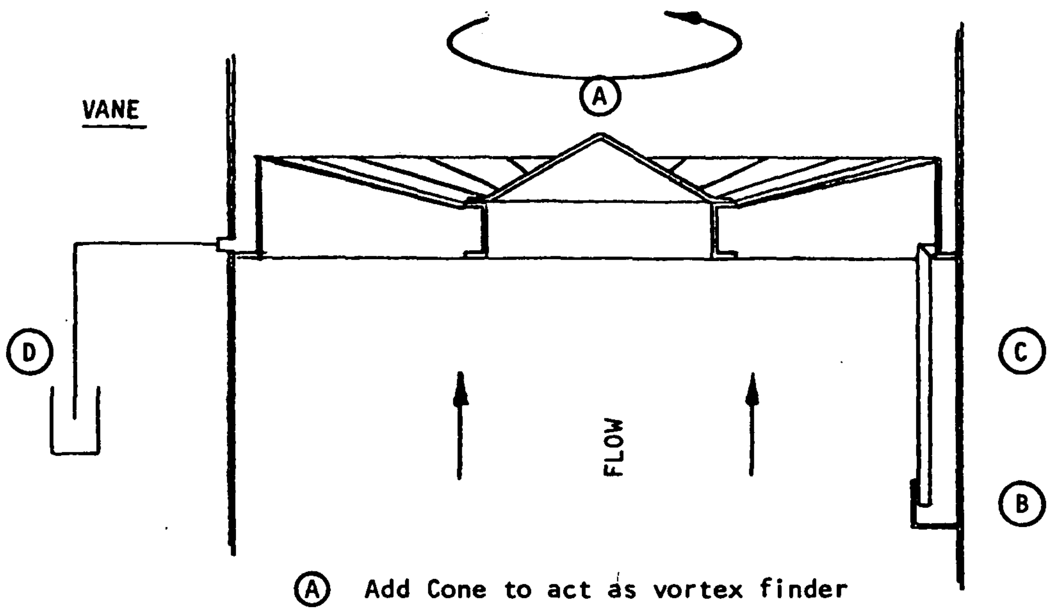

OUTLET
MESH PAD OR
CHEVRON OR
VANE ELIMINATOR
QUENCHER
ABSORBER
SEPARATOR
INSTRUMENTATION
VENTURI
WATER
TREATMENT
PUMP(S)
INSTRUMENTATION
PUMP(S)



PEABODY GAS INLET QUENCH SECTION

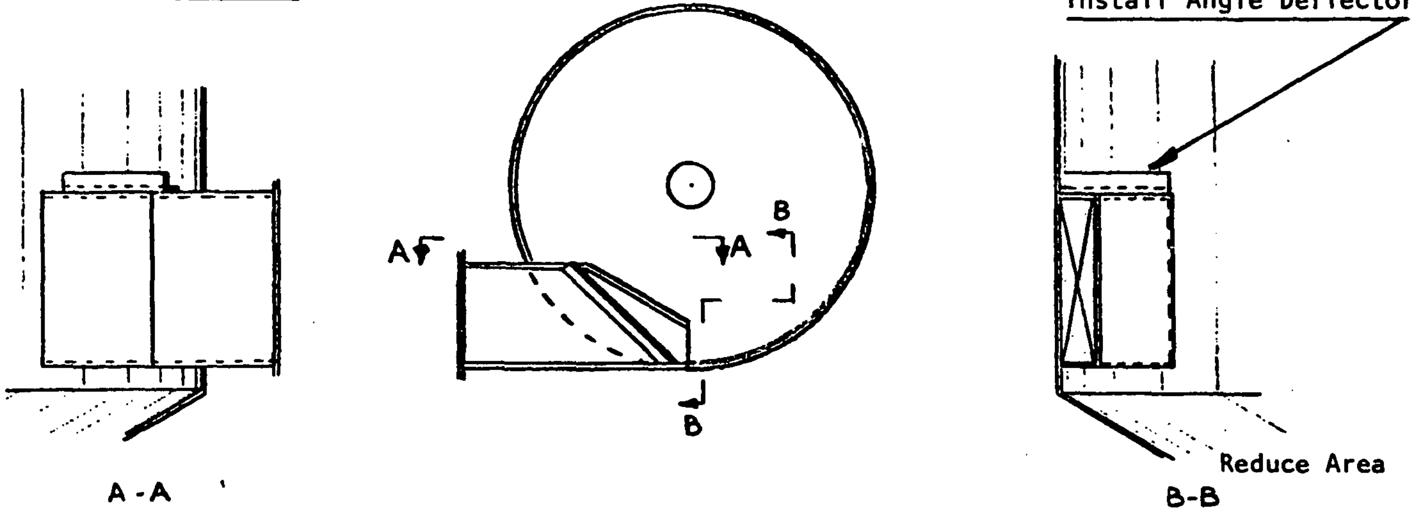
IMPROVING DROPLET ELIMINATOR PERFORMANCE

VANE

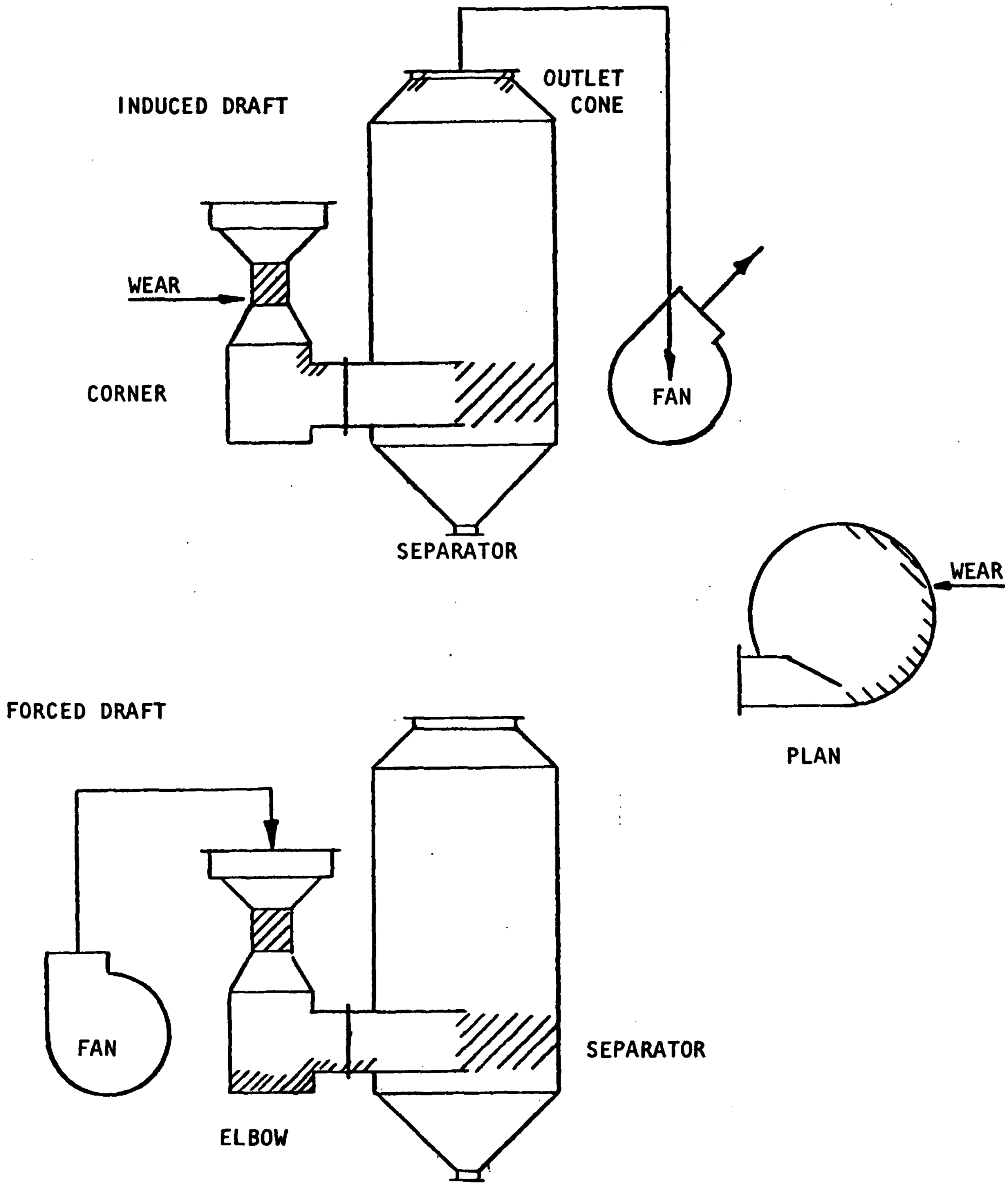


- Ⓐ Add Cone to act as vortex finder
- Ⓑ Clean or Enlarge Drain
- Ⓒ Clean or Enlarge Down Pipe
- Ⓓ Install External Drain

CYCLONIC

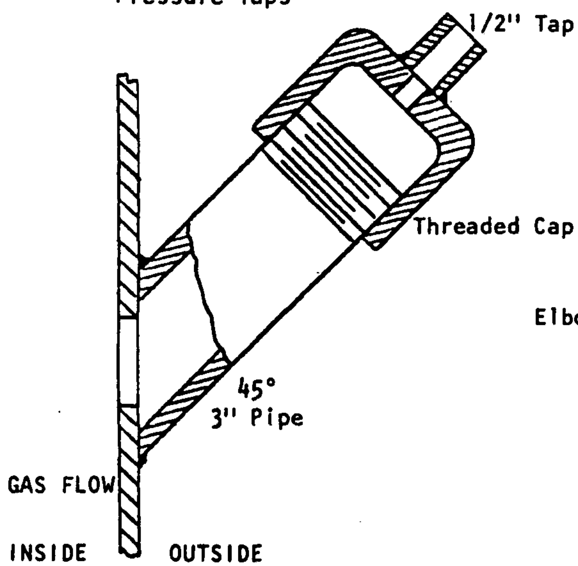


TYPICAL WEAR AREAS



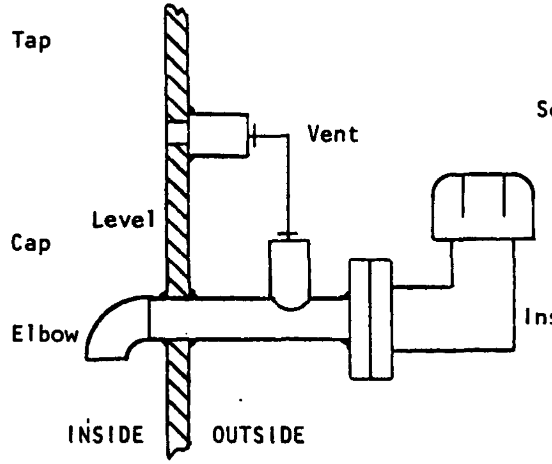
MISCELLANEOUS

Pressure Taps

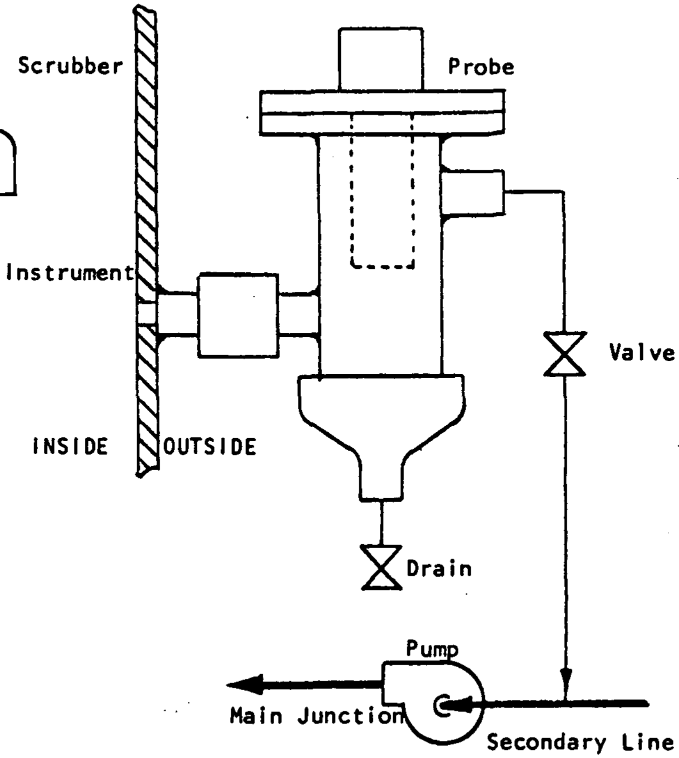


LEVEL CONTROL FITTINGS

TURBULENCE REDUCER



PH/O.R.P. PROBE CONNECTION



These can be drained to remove particulates. Also ultra sonic cleaning can enhance pH probe cleaning.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1979 — 657-011/7008

VII-3

Maintaining Venturi-Tray Scrubbers

William J. Kelly

Maintaining venturi-tray scrubbers

Here are ways to design and maintain these scrubbers so as to prevent most problems. The author provides a detailed list of things to look for and do should problems occur.

William J. Kelly, Swemco Inc.

☐ Venturi-tray-scrubber maintenance starts with equipment design, continues with preventive maintenance, and ends with troubleshooting. This article gives design tips that will make maintenance easier, suggests a preventive-maintenance program, and tells what to do should trouble develop.

Design considerations

The following will determine service life and maintenance requirements of a combination tray-venturi scrubber:

- Corrosion protection.
- Temperature protection.
- Erosion protection.
- Access to equipment.
- Solids accumulation.

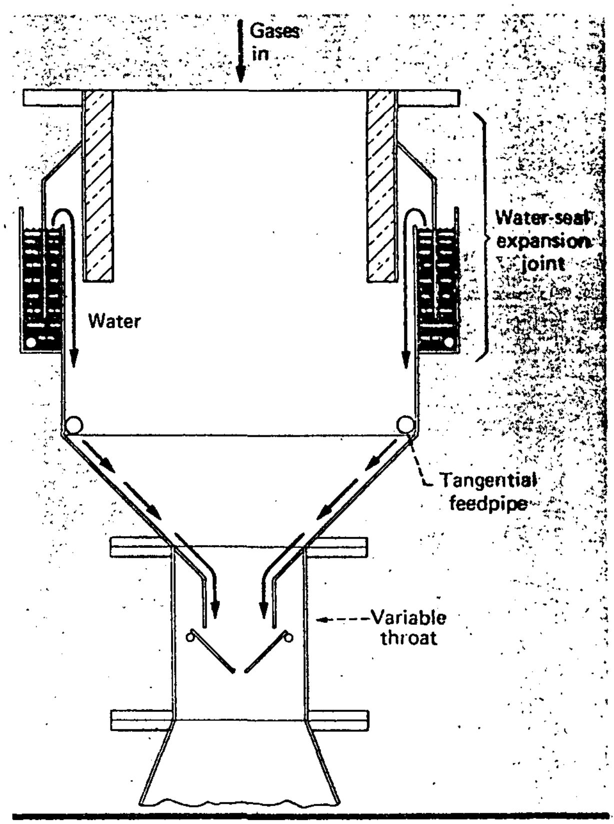
Corrosion protection

Corrosion considerations are complex and should be undertaken according to specific application. Corrosion has been given a great deal of attention in the technical literature. The protective measures discussed here are common-sense guidelines for those involved in purchasing scrubbing equipment. The purchaser should:

- Require mill certification for all alloy materials used in scrubber, fan and duct fabrication.
- Deal only with reputable suppliers and check their past performance.
- Request multi-source recommendations on selection of alloys, resins or refractories from materials manufacturers and users.
- Use test coupons (whenever possible) on existing equipment that is being replaced, to determine corrosion rates.

Temperature protection

When handling high-temperature inlet gas (above 700°F), it is imperative that proper scrubber-liquor distribution be maintained. This will ensure continuous liquor-film protection on surfaces exposed to the high temperature. Fig. 1 shows a typical venturi scrubber with "wetted wall" protection. A water-seal expansion joint compensates for thermal expansion and contraction and prevents stress from developing in the high-temperature zones. This seal also floods the upper venturi section to keep all surfaces wet and at relatively low temperature. The continuous washing also prevents "wet-dry interfaces," where solids build up on the scrubber wall and where corrosion and stress cracking can occur.



Venturi scrubber has wetted walls **Fig. 1**

Tangential feed pipes, although used primarily to inject scrubbing liquor to the throat, also provide a wall-washing action and assure that surfaces are protected from high temperature. Proper distribution of liquor on very-high-temperature applications (above 1,200°F) greatly reduces the possibility of stress cracking, carbide precipitation and sigma-phase contamination of alloy. In addition, the continuous flush prevents local high-acid concentration and corrosion. Another zone where corrosion is related to temperature is the area above the mist eliminator, where dewpoint corrosion is common. Proper material selection in this zone is critical.

Preventive maintenance — **Table I**

Equipment check	Frequency
Make internal inspection to remove construction debris.	Before startup.
Test level, temperature and pressure controls and alarms.	Before startup; 6 to 12-month intervals thereafter.
For automatic throats, use manual override to check free motion and the correct position of end-points. Refer to manufacturers' instructions for lubrication requirements.	Before startup; 6 to 12-month intervals thereafter.
Be sure that trays are bolted tight and level.	Before startup; 6 to 24-month intervals thereafter.
Check direction of sprays, and clearances of pipes and nozzles.	Before startup; 1 to 6-month intervals thereafter.
Make sure vessel is vertical. True vertical installation is important, due to gravity flow.	Before startup.
If water seal is provided, check vertical and horizontal clearances. Ensure correct openings for liquor flow, and proper tolerances for expansion.	Before startup; 3 to 12-month intervals thereafter.
Observe operation and pattern of quench sprays. If any problem is suspected, contact manufacturer.	Before startup; 3 to 6-month intervals thereafter.
Temporarily apply full water flow to the unit and check the liquor drain for fast draindown or pumpdown. If liquor holds up in bottom of unit for several seconds a constriction should be suspected.	Before startup; 12 to 24-month intervals thereafter.
Initiate gas flow and take pressure-drop readings across trays, throat and overall unit. Readings should be made at full gas flow. Refer to operating instructions for design pressure-drops.	Initial startup; 1-week to 1-month intervals thereafter.
When system reaches steady state, check gas and liquor temperatures in and out of the scrubber.	Initial startup; 1-week to 1-month intervals thereafter.
Observe stack appearance.	Initial startup; 1-day to 1-week intervals thereafter.
On units with hot inlet-gas, check outside shell temperature at the gas-inlet zone. A high relative temperature difference indicates local hot spots and possible stress-cracking zones.	Initial startup; 1 to 12-month intervals thereafter.
Analyze recycle liquor for unexpected components. Determine the effect of these constituents since they may greatly foreshorten service life (for example, high-chloride liquor in stainless steel service).	Initial startup; 1-day to 1-week intervals thereafter.
Note venturi-throat response to changes in pressure drop on units with automatically variable throats. (Typically, changes in gas flow occur at relatively slow rates so that hunting and lagging are almost never a problem.)	Initial startup; 1-week to 6-month intervals thereafter.
Check recycle and drain piping and pump for surging and cavitation. Causes may be scrubber induced—liquor foaming, high scrubber vacuum, loss of sump level, etc.	Initial startup; 1 to 6-month intervals thereafter.
After an initial period of operation (1-4 weeks) shut down and make a thorough internal inpection, specifically looking for: (a) Plugging or blocking of trays, nozzles or weirs. (b) High-velocity-zone wear (throat, sprays, turns, etc.) (c) High-temperature spots in gas-inlet zone (d) Signs of corrosion (e) General mechanical condition of internals. Detecting a progressive type of problem at this stage provides the time margin necessary to modify the equipment before serious damage can occur. If indications of a problem are so slight as to be questionable, schedule an additional shutdown at a similar interval for an additional checkout.	1 to 6-month intervals following initial shutdown.

Correcting scrubber problems

Table II

Major causes	Action
Poor cleaning performance	
a. Low scrubbing-liquor flowrate.	a. Check pump output. Look for plugged piping and nozzles, incorrectly opened valves, overthrottled pump-discharge valve.
b. Low pressure-drop across venturi.	b. Check for low scrubbing-liquor flowrate; low gas flowrate; inoperative or uncalibrated variable-throat controller; damaged variable-throat blade/disk.
c. Inlet dust loading or size distribution beyond scrubber design capability.	c. If operating modifications fail to correct the problem, analyze particle size and quantity.
d. Excessive gas flow.	d. Check fan-damper setting, venturi-throat setting, system fan operation vs. fan curve.
e. Partially blocked entrainment separator.	e. Check washdown sprays if installed. Check composition of spray liquor. If scaling occurs, investigate use of low-pH flushing liquor.
High exit-gas temperature	
a. Very low venturi-liquid flowrate.	a. Check pump output; look for plugged piping, nozzles, etc., incorrectly opened valves, overthrottled pump-discharge valves.
b. Low tray-water flowrate.	b. Check pump output, look for plugged piping, nozzles, etc., incorrectly opened valves, overthrottled pump-discharge valves.
c. Tray(s) (partially) plugged with solids.	c. Check condition of tray flushing sprays if installed. If scaling is observed, use a low-pH wash periodically to dissolve scale. Check percent solids in recycle liquor.
d. High cooling-water inlet temperature.	d. Check heat-exchanger operation and adjust cooling-water flowrate and temperature.
e. High scrubber-inlet temperature or excess gas-flow.	e. Check upstream equipment operation.
Exhaust-gas liquor entrainment	
a. Moisture eliminator drain plugged (tangential vane eliminators only).	a. Shut down and snake out the eliminator drain. If problem recurs, add flushing water to continuously irrigate drain pipe.
b. Excessive tray-liquor flow (tower flooding).	b. Reduce flow; calibrate flow-control mechanism if installed.
c. Excessive water frothing (possibly due to foaming agent in liquor).	c. Sparge a liquor sample. If liquor froth does not disappear quickly, foaming may be choking downcomers and drains. Analyze liquor for foaming agents.
d. Plugging of chevron-type eliminator.	d. Check flushing-spray conditions and pattern. Use more flushing periods per hour. Poor gas-cleaning performance will accelerate buildup. Check liquor chemistry for scaling agents.
e. Excessive gas flow.	e. Check fan damper position. Check variable venturi-throat opening.
Fan motor overload	
a. Low scrubber-pressure-drop due to excessive throat opening.	a. Normally, the fan damper will provide enough "choke" to prevent overload, so fan damper must be checked with variable throat opening. Check throat operator and liquor flow.
Plugged spray nozzles	
a. Nozzle openings too small.	a. Modify strainer/nozzle-opening ratio so that nozzle holes are at least twice the diameter of strainer openings.
b. Solids concentration too high in spray liquor.	b. Check separation equipment. Check for excessive dust load in gas stream. Check for purge-line malfunctioning.

Major causes	Action
Plugged spray nozzles (cont'd)	
c. Pipe scale or debris entering liquid stream beyond strainer.	c. Remove spray heads and flush spray piping and nozzles. Replace piping if corrosion is apparent.
Excessive nozzle wear	
a. Solids concentration too high in spray liquor.	a. Check separation equipment. Check for excessive dust load in gas stream and for purge-line malfunctioning.
b. Abrasives in spray liquor.	b. Remove abrasives from liquor stream or install abrasion-resistant linings in wear zones.
c. Low pH in combination with abrasives, causing erosion/corrosion.	c. Check separation equipment. Check for excessive dust load in gas stream and for purge-line malfunctioning. Remove abrasives from liquor stream or install abrasion-resistant linings in wear zones. Add alkali for pH modification.
Plugged trays	
a. Hot gases entering equipment before liquid flow is initiated.	a. This condition causes "bakeout" of solids. Shut down. Try "washing" trays in place by recycling strong detergent. Otherwise, remove trays and scrape clean.
b. Inefficient venturi scrubbing, allowing high solids levels in gas stream to contact trays.	b. Check throat pressure-drop and venturi liquor rate.
c. High solids in tray liquor, formation of insoluble salts in scrubber.	c. Check solids-separation equipment. Analyze liquor and determine and eliminate cause of high solids.
d. No water flow or very low water flow to trays.	d. Check pump output; look for plugged piping, nozzles, incorrectly opened valves, overthrottled pump discharge valves.
Excessive throat wear	
a. High solids recirculation.	a. Check solids-separation equipment. Check for excessive dust load in gas stream and for purge-line malfunctioning.
b. Corrosion/erosion	b. Check separation equipment. Check for excessive dust load in gas stream and for purge-line malfunctioning. Add alkali for pH modification. Install abrasion-resistant liners in high-wear zones if liquor modifications are not practical.
c. Excessive gas velocity.	c. Check throat pressure-drop and reduce to design point.
Erratic automatic-throat operation	
a. Prime-mover malfunction.	a. Remove from service, repair or replace. Most throats can be held in a fixed position close to design pressure-drop by mechanical means during this procedure.
b. Sensor signal incorrect.	b. Check sensor taps on vessel for solids buildup. Check transmission tubing for liquid buildup or air leaks. Clean or repair sensor.
c. Transmitted signal incorrect.	c. Clean or repair sensor. Check instrument air-supply pressure and filters. Check tubing for leaks. Check positioner filter and connections. (Clean instrument air is critical here.) Thoroughly clean positioner internals and check freeness of operation.
d. Damaged damper disk-mechanism.	d. First make external inspection of drive train. If damaged area is not observed, shut unit down and make internal inspection using a throat-actuator manual override. Check for packing damage and excessively tight packing gland.

Erosion protection

In the high-velocity venturi throats, at tangential liquor and gas zones, and near spray areas, consideration must be given the possibility of erosion, as well as the combined effect of corrosion-erosion. This becomes of primary importance when gas-stream solids are abrasive and the liquor being recycled is acid. For these operating conditions, design options such as use of silicon carbide and alumina wear-surfaces must be considered. Fig. 2 shows Hastelloy alloy C high-velocity spray nozzles that were used for handling dilute sulfuric acid and abrasive solids. Service life of these nozzles was approximately two weeks. The abrasive solids in the liquor continuously eroded the corrosion-resistant skin of the alloy so that corrosion and erosion worked together to cause a catastrophic failure. Nozzles of silicon carbide have replaced alloy nozzles for this kind of service and, in most instances, have provided years of troublefree service.

Access to equipment

If critical areas are inaccessible, developing problems may go undetected during normal inspections. Access doors, sight ports, or both, should be provided to allow inspection of wear and corrosion zones, as well as areas where there is solids buildup potential. When downtime must be kept at a minimum, fast-opening doors with reliable latches should be considered.

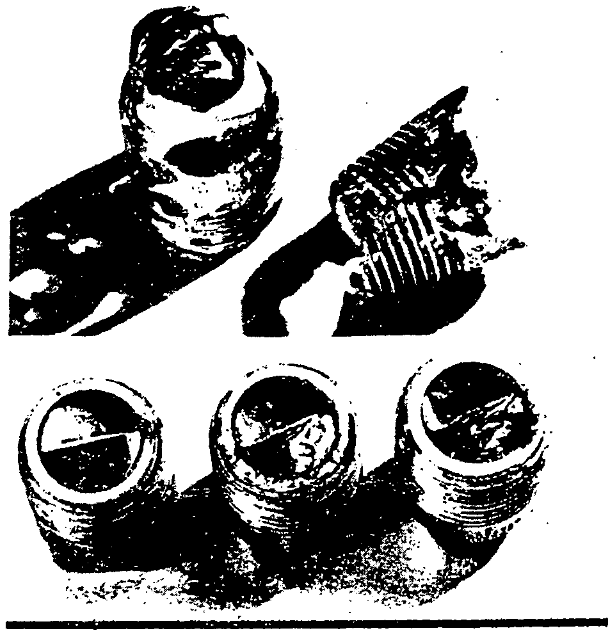
For many applications, it is reasonable to make spray headers removable during operation, thus allowing for a quick check of these critical components. Shutoff valves and elbow connections directly upstream of each header will simplify removal.

Solids accumulation

Another consideration in scrubber design is the prevention of plugging and blockage of small-clearance openings such as spray heads, liquor pipes and tray perforations. Interference with normal gas and liquor flow patterns can result in high-temperature and corrosion damage to local areas of the scrubber and, in some cases, to downstream equipment. Spray nozzle openings on slurry service should be above ½-in. dia. In some cases where the solids concentrations are high or the solids are coarse and sticky, minimum openings must be increased to 1-in. dia. or larger. Low-pressure, open-pipe feeds are often preferred over sprays for scrubber-liquor injection where high solids concentrations or high temperature is anticipated.

Tray plugging occurs when solids in the incoming gas and recycle liquor build up around and eventually bridge the tray perforations. The basic causes of plugging are improper design of tray-flushing sprays, plugged flushing nozzles, low tray-liquor flow, sticky solids in the gas stream, and chemical scaling (usually in the form of calcium salts).

Selection of a mist eliminator is usually a compromise between maximum performance and minimum maintenance. Generally, the smaller the open area that the eliminator presents to the gas stream, the higher the mist-removal efficiency and the greater the possibility of plugging. Mesh-type mist-eliminators must be avoided on applications where there is anything more than a trace of solids in the gas or liquor. Parallel-blade chevron designs



Eroded high-velocity spray nozzles — Fig. 2

are often indicated where sticky materials or high dust-loads are involved. Chevron units require flush sprays above or below the blades (or both) on many applications, and flushing liquor should be clean.

Open-vane separators are a good choice for many scrubber units up to a maximum diameter of 14 ft. Open cyclonic separators will not plug up, since they have no internals, but their efficiencies are below those of impingement-type entrainment separators.

Preventive maintenance

When a scrubber is properly designed for its specific application, and unexpected conditions do not turn up in actual operation, it should provide many years of troublefree service. Table I gives a typical preventive-maintenance schedule for a combination venturi-tray scrubber. The appropriate intervals between inspections differ substantially from job to job, and the intervals indicated are approximate minimums and maximums. It is suggested that preventive-maintenance checks start with the minimum intervals and be gradually increased toward the maximum ones. Following a guide of this type will further assure a troublefree and extended service life.

The author

William J. Kelly is project manager for Swemco Inc., 470 Park Ave. South, New York, NY 10016, telephone (212) 725-5450. He previously worked as product manager of cooling towers for Blazer Corp., and as a scrubber sales engineer for Peabody Engineering. After receiving a B.S.M.E. degree from New York State University, he spent several years as U.S. Merchant Marine officer, and as a Navy nuclear test engineer.