SCRUBBER DESIGNS FOR HARD CHROME PLATING

by

Frank B. Power
Application Engineer

and

William M. Schott
Sales and Marketing Manager

Kimre Incorporated,
Perrine, Florida, U.S.A.

Presented to the
AMERICAN ELECTROPLATERS
and
SURFACE FINISHERS SOCIETY

at the

Eleventh AESF/EPA Environmental Control Conference
for the
Metal Finishing Industry

Orlando, Florida, U.S.A.
January 29, 1992

Notes on "Scrubber Design for Hard Chrome Plating"

The source of this document is www.mareislandmurder.com. This site describes how the U.S. Navy deliberately and secretly poisoned many thousands of workers at Mare Island Naval Shipyard and doubtless at many other places throughout the world, with large amounts of highly toxic Chromic Acid released to the air. This study, "Scrubber Design for Hard Chrome Plating" was provided to the Mare Island Engineers Union (IFPTE Local 25) as part of a package of documents concerning the operation of the Mare Island Shipyard metal plating shop.

The Scrubbers designated by Mare Island Management and the Bay Area Air Quality Management District to have been installed on the Mare Island Shipyard metal plating shop are Harrington plastic vertical flow packed bed scrubbers. In order to find out more about these particular scrubbers I called Harrington in 1996 and talked to a design engineer about the scrubbers used on the Mare Island Shipyard Plating Shop.

A number of extremely serious problems with the Chrome Plating scrubbers installed on the Mare Island Plating Shop were identified during this conversation.

1. The single pump provided to provide water flow to the scrubbers was seriously undersized. Mare Island had provided one pump for all the scrubbers for all the plating processes on the plating shop roof. The Harrington representative recommended, at a minimum there should be one pump per scrubber. The water flow, when it was provided to the scrubbers, which was almost never, was completely insufficient due to inadequate pumping capacity.

2. The wrong design of scrubber was used for chrome plating. The installed scrubbers, if provided with an adequate water flow, which they mostly were not, would be, at best, 9.0% (nine percent) efficient at removing Chromic Acid from exhausted plating process air. There were two reasons specified for this:
    a. The scrubbers installed on the plating shop roof were vertical scrubbers instead of horizontal scrubbers. A vertical scrubber is not a chrome plating scrubber.
    b. The scrubbers used dumped packing instead of mesh pads to capture the chromic acid mist.

I believe this conversation transcript illuminates the content of the study "Scrubber Design for Hard Chrome Plating" and so it is being included with this study.

You are invited to visit www.mareislandmurder.com to see for yourself that the U.S. Navy is an employer who knows how to slaughter its employees.

UNION (34)

HARRINGTON

Industrial Plastics Inc.

July 29, 1996

Mr. Henry W. Scherer, President
International Federation of Professional and Technical Engineers
Local 25
PO Box 2253
Vallejo, CA 94592-0253

Dear Henry,

Thank you for providing me with our transcript and for the compliments you gave me. As you requested, I am returning the transcript you provided with a few minor changes.

If possible, I would very much like a copy of the revised transcript.

Once again, thank you.

Sincerely,

Sean Whitaker

Environmental Engineering Group
14480 YORBA AVENUE • CHINO, CALIFORNIA 91710 • (909) 597-8641 • *FAX (909) 597-9940*

Sean Whitaker

Transcript of three telephone conversations between Henry W. Scherer of IFPTE Local 25 and Mr. Shaun Whittaker, Technical Representative for Harrington Plastics, Inc., manufacturers of air pollution abatement devices, "scrubbers" used in the Mare Island Naval Shipyard metal plating shop ventilation system.

In the following, "S" refers to Scherer, and "W" refers to Whittaker. whitaker

The following conversation was initiated by Henry W. Scherer, President IFPTE Local 25 to obtain information pertinent to operation and maintenance of the metal plating shop scrubbers as specified by the manufacturer.

S: May I speak to the technical representative please.

W: Good afternoon this is Shaun.

S: Shaun, I'm calling from Mare Island. Some of your scrubbers were used in the Mare Island plating shop before it was decommissioned and I am doing a study of their operation and maintenance. I would appreciate it if you could answer some questions for me concerning these things. It appears as if the shop operated the scrubbers incorrectly and did not run water through them all of the time, but thought of them as self cleaning filters and so when the filters would become clogged, would run water to clean the filters and then would shut off the water.

W: Okay.

that

S: The situation is this is an improper way to operate these pieces of equipment, is that correct?

W: Yes.

S: What would the long term results of this sort of operation be, have you ever run across this sort of situation before?

W: The scrubber has packing in it, not filter pads.

S: Yes. I understand the scrubbers contain packing not filters. Packing is small rings, balls or other solid shapes whose purpose is to provide surface area.

W: The long term problem of this type of operation...first of all the pumps are supposed to run all of the time to remove whatever is there that is to be removed from the air stream. That's the first problem. Other than that, if the purpose of the scrubber was to remove any type of salt, such as sodium cyanide, the problem is that the salt would build up in the scrubber packing and it would begin to crystallize. This will happen with any salt such as sodium cyanide or any other "sodium" ~~salt~~. type chemical.

S: Okay.

W: The material contained in the air flow would collect on the packing and would not be washed off. It would begin to build up.

S: Would the build up of solids eventually clog up the packing so that no air could pass through it?

W: It would not likely reach a point of complete shut off, but the air flow would decrease progressively until the amount of air flow would be so small that the system would appear not to be working.

W: We had an experience with a company who did something similar. They did not want to undergo the water expense and did not add anything but makeup water, the minerals from the water built up on the packing; eventually the unit went dry. The salt built up and up and they had to go in with jackhammers to get the packing out. it was nothing more than one giant crystal ball.

S: I can understand that. Let's suppose we had a scrubber taking in air from a process giving off sodium cyanide mist. Even though there was crystallization of this in the packing, would there be a significant release of the material?

W: It depends. The packing is what does the removal of the mist. If you are starting with clean packing, as an example, if the mist particles are five microns or larger in diameter they will be entrained on the packing. Particles smaller than five microns in diameter will go through the packing regardless of whether or not the water is on. However, if the scrubber water supply is shut off, the evaporation of the water from the droplets on the packing will cause the salt to be retained on the packing as a film of salt. Once a film of salt has built up on the packing it becomes less efficient and more material passes through the scrubber. The point is that the water spray in the scrubber is to rinse the packing clean. It is the packing that does the filtering, and if it is not rinsed, the stuff it is filtering will build up on it rapidly.

S: So, shortly after the water is shut off, the packing will become coated with a film of solid sodium cyanide, and once this happens, the scrubber is essentially not filtering anything anymore?

W: Correct.

S: I want to bring up the use of these scrubber units for chrome plating. One night there was a massive spill of chromic acid out of the top of the chrome scrubbers. Can you give me any insight into how such a thing might occur?

W: A massive spill out of the top of the scrubbers?

S: Yes, the material came out as a dense mist which actually wet the side of adjacent buildings. Do you know of any mechanism by which this could happen?

W: I take it this is a vertical scrubber?

S: Yes, the plans show the orientation is vertical. The discharge was out the top of the unit.

W: Was there a fan on the top?

S: Yes.

W: Suddenly water gushed out the top?

S: Yes, but it was chromic acid, not water.

W: Did the problem fix itself?

S: I don't know. I don't think so. People on the scene didn't act as if they knew what was happening or as if they knew what to do. I know there was a lot of material that was sprayed out. It appeared to be concentrated chromic acid.

W: Well, first of all that scrubber is not a chromic acid scrubber. It won't remove chromic acid. The droplet size generated by chrome plating is much smaller than five microns in diameter. A vertical scrubber is not a chrome scrubber.

S: Yes.

Delete

W: ~~First of all,~~ that was a poor application of a scrubber.

S: I can see that.

W: I can see why the top of that roof would wind up with chromic acid all over it. If somebody had done that during the day you probably would have seen a nice chromic acid plume. I would guess that once they saw the chromic acid coming out of the scrubber they would stop~~ped~~ the process generating the chromic acid mist or shut off the air line leading to the scrubber. The scrubber won't scrub chromic acid. If they got big drops of water, I would say the mist eliminator in the scrubber broke.

S: That is what I thought too. Would the chromic acid have eaten out the mist separators?

W: No. They are made of polypropylene, and this is not attacked by chromic acid.

S: So it looks like the mist eliminators just broke.

W: Yes, this does happen occasionally, but, ~~The~~ scrubbers used for your chrome operation were not appropriate. The mist droplet size generated by chromic acid is on the order of one to three microns in diameter.

W: The packed bed scrubber is only efficient with droplets of five microns and larger, so most of the chromic acid mist just passed through the scrubber.

W: We do make a scrubber specifically for chromic acid. It is horizontal and uses mesh pads rather than packing to condense the chromic acid mist. It is horizontal so that each element of mesh padding can drain. If the scrubber was horizontal, the chromic acid would just drain downward into the next mesh pad and would impede removal of the droplets. The problem is the small size of the chromic acid mist. It is too small in diameter to be removed by a conventional scrubber, and just passes through. We call the scrubbers we make for chromic acid chromium removers. They are given the designation the HCR series.

S: Yes, we had a professional company come in and do a very calibrated test which measured the amount of chromic acid entering and then removing the chrome acid scrubbers. The efficiency was determined to be about nine percent.

W: Yes, this is about what you could expect from the use of the vertical scrubber with normal packing to scrub a chromic acid system.

S: What about stack height off the top of a scrubber?

W: We do not engineer stacks. If a plan calls for a ten foot discharge stack, this is what we build for the customer.

S: You are just concerned with what goes on inside the scrubber box?

W: Yes, this is what we design and engineer.

S: Is it possible that if the chromic acid scrubbers were operated like the cyanide scrubbers, and the water was turned on only when the operators thought the filter pads were clogged, a build up of chromic acid crystals would build up to the point where the packing was so clogged that water would not flow through it, would build up and fill the top part of the scrubber and then exit as mist when it hit the fan blades?

W: Yes, however, if there was a build up of crystals on the mist separator plates they would no longer remove the mist and it would pass through the scrubber. Just like the cyanide scrubbers, once the packing is coated, it will not absorb.

--- SECOND CONVERSATION---

S: To move onto another topic. What is the response of the scrubber to a decrease in water flow below the recommended minimum flow? Does filtration efficiency drop off suddenly at a certain point, or is the decrease in filtration efficiency proportional and gradual?

W: It depends upon the chemical of concern.

S: Say it is sodium cyanide.

W: Well, first of all absorption of cyanide requires caustic injection. This means simply, that a base such as sodium hydroxide must be added to the scrubber water to make it basic. It cannot be scrubbed with just water. You must have pH control. Without it the scrubber will not work.

S: If you didn't have pH control there was no scrubbing?

W: Not if you are trying to scrub cyanide.

S: I'm confused.

W: Well, there are two forms of cyanide to worry about. There is sodium cyanide. This is a solid chemical. It is dissolved into water to make various plating solutions. If sodium cyanide comes into contact with acid, hydrogen cyanide gas will be generated. This is extremely toxic. It is death gas. Hydrogen cyanide is a gas and will not be removed from the scrubber unless the water is pH controlled to be made basic. You get hydrogen cyanide generated when a scrubber is drawing a suction off of an acid tank and a cyanide tank. They will react in the air stream and will form hydrogen cyanide before the scrubber. The hydrogen cyanide will not be removed if water alone is in the scrubber. The mist droplets which reach the scrubber, and still contain some dissolved sodium cyanide, will be removed if their size is greater than or equal to five microns in diameter.

S: I see. Is hydrogen cyanide always present.

W: Where there is sodium cyanide and acid there will always be some hydrogen cyanide. It must be accounted for in the design of the particular scrubber system. pH control is necessary to remove the hydrogen cyanide gas. Water will not remove it. ← period added

S: So, this is a very important variable which must be taken into account. One must have a good ideal of the amount of cyanide and acid which will be in the air lines to the scrubber. One must also maintain the water at a basic pH to remove the hydrogen cyanide.

- idea

S: Is it possible without pH control to have so much acid entering the scrubber that most of the sodium cyanide is converted to hydrogen cyanide before it reaches the scrubber?

W: This can happen under the right conditions. It all depends upon what is in the tanks that are connected to a particular scrubber and other conditions. It is important to realize that gas acids such as hydrogen chloride are absorbed into the water mist. Once they are absorbed they will react with the sodium cyanide in the mist droplets to form the gas hydrogen cyanide. Hydrogen cyanide moves out of the water droplets and into the air. The hydrogen cyanide will stay in the air stream unless it is absorbed into water which has basic pH. The Hydrogen cyanide moves right through the scrubber and is not absorbed if the water is not pH controlled to be basic. Having a pH controller takes care of all variables. A pH controller makes sure the water in the scrubber is always basic.

S: What about the sodium cyanide. If the water is turned off will it still be absorbed in the scrubber.

W: You miss the point. The droplets of mist are not absorbed in the scrubber. They impact on the packing surfaces, agglomerate together into larger drops and then are washed off the packing by the water flow from the pump. Mist droplets larger than or equal to five microns in diameter will impact on the packing with a 99.9 percent efficiency and be removed. If the water is turned off they will still impact on the packing surface, but they will not be washed off and will evaporate. The evaporated solid chemicals will coat the packing.

S: So, once the water is turned off the packing begins to crystallize and rock up.

W: Yes. They were right in that turning off the water would not affect the ability of the scrubber to remove the sodium cyanide or chromic acid droplets initially. However, once this is done the packing would begin to crystallize, and once this has proceeded some way, the scrubber would no longer absorb many particles. These would pass through the scrubber unhindered. The size of particle absorbed would go up considerably. The removal process would be much less efficient.

S: By this you mean it would take a larger size particle to be removed by the scrubber?

W: Yes. I cannot say how much, but the particles would have to be much larger than five microns to be captured and removed from the air stream.

S: So, once the packing got coated it wouldn't pick up the Sodium cyanide any more.

W: It would drastically loose efficiency.

S: There were many complaints of the air lines to the cyanide and other process tanks loosing suction. This would be caused by the restriction resulting from the build up of cyanide salt on the packing.

W: Yes.

---THIRD CONVERSATION---

S: I would like to discuss water flow through the scrubbers. Is it intended by the manufacturer that each scrubber should have its own circulation pump?

W: Not exactly. You need enough pumping capacity to provide the proper flowrate and the proper pressure to overcome piping flow restrictions.

S: Suppose there were multiple scrubbers hooked together, with each scrubber being fed from the same pump?

W: There is no problem with this conceptually. Generally, It would be very difficult to get one pump to provide enough flow and enough pressure. What was the required flow rate for your scrubbers? I think you would have a hard time finding a pump that would provide the required flow at the required pressure.

S: 136 gallons per minute.

W: How big a pump and how many scrubbers?

S: Ten horsepower and four scrubbers.

W: A ten horsepower pump would not provide the required flow at the required pressure. You see the sprayers in the scrubber require 60 feet of head. A ten horsepower pump might provide the amount of flow if all it had to do was pump water without any flow restriction. It all has to do with the piping system. Friction in the piping will cause pressure loss. Height differences between the outlet of the pump and the scrubber will cause pressure loss. The pump must expend energy to overcome flow and height difference losses, and this lowers the pump capacity. Any particular pump will be capable of pumping a lot of water with no restriction, but less with more restriction. I do not see how a ten horsepower pump could provide enough power to serve four scrubbers simultaneously. This is not how we do it normally.

S: What is the normal recommendation of the manufacturer?

W: We recommend that each scrubber be served by two pumps. One to provide flow and the other to provide backup in the event of a failure of the normal pump. In this way you are always assured of protection. Even if you would have a remote tank we would recommend one pump per scrubber with one backup pump per scrubber.

S: I see.

W: We think it is not a good idea to use one pump for multiple scrubbers since if your single pump fails you loose all of your scrubbers. This is not a good idea. Most scrubbers we sell today have what we call a one plus one configuration. This is where you have two identical pumps wired so that if one fails the other starts up immediately. This is industry standard now.

S: I can see that this is the way to obtain reliability.

W: How old were your scrubbers? What time period are we talking about?

S: Somewhere between 1984 and 1987.

W: We would have recommended the one plus one configuration then.

S: It seems to me what we had was a local contractor who was working to a contract amount which confined the expense and who did all of the engineering specifications, but no one talked to you.

W: It would appear that way.

S: I haven't been able to find any records that anyone talked to you then. For all I know I am the first. I am just trying to find out how things went wrong.

W: Back in the early eighties the situation was simply that no matter what you wanted to filter from the air, be it volatile organic solvents, cyanide or chrome, all you had to do is put a scrubber on it and it would be okay. This was generally accepted until 1985 or 1986 when people started to ask themselves just how good are these things actually working. Then by 1989 there were much stricter rules in force.

S: Sometime in 1987 or 1988 Mare Island had a company come in and do a formal controlled study of the chrome scrubbers. This was due to the force of impending legislation and regulation. Everyone was amazed to find the removal efficiency of the chrome scrubbers was about nine percent.

S: So, at the very least we should have had eight pumps?

W: That is the recommended configuration.

S: There were reported problems of the scrubbers backing up and water discharging into the ventilation ducts. Can you see how this could occur?

W: There are a variety of ways it could occur. If you have a pump box next to the scrubber sump, a condition can occur where the level in the scrubber will rise due to air pressure in the scrubber box.

S: The Mare Island installation did not have pumps at the scrubber.

W: Really? We intend the scrubber sump to serve as the sump for each pump. We assume, unless it is specified otherwise, that the pump will draw a suction on the scrubber sump. What did Mare Island do?

S: All four scrubbers drained through connecting gravity drain piping to a common tank. A single pump drawing a suction on this tank provided flow to all four scrubbers. Do you suppose restrictions in the drain line would cause a back up in the scrubber? Could this be something as simple as a clogged drain line?

W: This is a strange system configuration. Normally, we assume the scrubber sump which is built into the scrubber body will be used. The Mare Island set up is what we call a remote sump. We assume that the pump will draw its suction directly on the scrubber sump. So the scrubbers did not have individual pumps on themselves?

S: No. They had a single ten horsepower pump. All the drains were connected. All four cyanide scrubbers drained to one tank, and both chrome scrubbers drained to another.

W: How was level controlled in these scrubbers?

S: There was no level control. The problem was overflowing, so it appears there was no level control.

W: With a remote sump configuration the normal system is to have a six inch diameter drain in the scrubber sump so that all the water drains quickly back to the remote sump. You know, with the remote sump configuration, all you really have is a box of packing ~~rocks~~. That's all a scrubber really is.

S: I don't think we used a six inch drain. I think we used a one to two inch drain. Maybe even three inches. I don't have the plans with me and I am not sure, but I do know they were not larger than three inches in diameter.

W: That would definitely be too small to drain 136 gallons per minute. You need a six inch drain for a remote sump type setup. There is no way a one or two inch drain line will drain 136 gallons per minute. This could definitely be a problem. However, we custom build all scrubbers and draw the plans. These are submitted to the customer for approval. Once the plans come back stamped approved, we build and ship the scrubbers.

S: My reading of the plans is that they were provided to you by a local contractor who specified all dimensions.

W: In that case we would build per plan. If the plan indicated to us that there would be a problem, we would contact the contractor and make sure this is what is really wanted.

S: These plans do not make any mention of the set up for draining or that they are to be ganged together with one pump. They merely specify the scrubber dimensions and hole sizes.

W: In that case we build to plan. We draw the scrubber plans and submit them to the customer for approval. If the plans come back stamped approved, we build to those plans. If we are not told that a remote sump is intended, we cannot design for it and assume the normal configuration will be used.

S: So, with four scrubbers being served by a single ten horsepower pump, they were likely starved of water. It doesn't seem to me that you could tell what the flow rate was to any particular scrubber without having an extremely detailed piping diagram.

W: That is correct. You would need to do some very detailed piping flow calculations. It could be the result would be anything. You could have one scrubber getting full flow and the others getting nothing, each getting the same amount, but less than required. Anything is possible with that sort of set up.

delete this Line

S: One and two inch drain lines won't do the job?

W: That is correct.

S: So, the overflow problem could be a clogged drain or too small a drain?

W: Yes. When the pump is connected directly to the scrubber sump, and there is a high suction vacuum, there is another cause, but this is not applicable to the remote sump type setup at Mare Island.

S: I see. I want to discuss the matter of providing a filtered push ventilation system.

W: What do you mean by this?

S: The Mare Island environment was very industrial. There were many large facilities doing metal fabrication, grinding and other dust producing work. This dust was everywhere.

S: I have read some texts that say dust can be a real problem with scrubbers, and that in such a case it is necessary to provide a ventilation system that provides filtered air into the shop to make up for the air removed by the suction system leading to the scrubbers.

W: Yes. Dust can cause loading and clogging of the packing. Its like mud, and can stick and clog the packing. If you have a high dust level, like 10 grams per second, you can run into very severe clogging problems. The scrubbers are very efficient filters. Filtration depends upon particle size. A scrubber will clean all particles out of the air which are five microns or larger in size with 99.9 percent efficiency. This includes dust.

S: I want to thank you for allowing me to use up a lot of your valuable time. I also want you to know I am going to prepare a transcript of this conversation. I want to send you a copy. What is the correct name and address?

14480

W: I want a copy. Please send it to Sean Whitaker, Harrington Plastics, 1480 Yorba Ave., Chino. CA 91710

S: I will send you a copy. I think you solved most of my questions. I want to conclude by observing that there were a lot of problems with the plating shop ventilation system which went on for a long time. It seems to me that many of these problems could have been solved by calling you. However, after having spent the money and done the work, it is clear the advice would have required them to scrap a lot of what had been done.

W: Yes.

S: Thank you.

W: Anytime.

SCRUBBER DESIGNS FOR HARD CHROME PLATING

Frank B. Power
William M. Schott
Kimre, Inc.
Perrine, Florida

I. ABSTRACT

Emission control in the chrome plating industry has seen an evolution in regulation. This has resulted in an evolution in the gas-cleaning or scrubbing technologies employed. Packed bed scrubbers and chevron eliminators offer reasonable efficiencies down to 8-15 micron droplets. Knitted-mesh mist eliminators were able to improve efficiencies even further.

With the adoption of more stringent emission limits by California and other regional air resource boards, a uniquely interlaced monofilament structure has been proven to meet those strict limits in a cost-effective manner. Systems designed using this interlaced monofilament structure achieve efficiencies of 99+% on droplets of one micron and larger. This paper discusses the changes in scrubbing technology in the plating industry and describes various design ideas and technologies behind systems utilizing this interlaced monofilament structure.

II. INTRODUCTION

There are many types of scrubber or gas-cleaning equipment. Generic types, along with their mechanisms of collection, are considered. Fiber-type scrubbers and an advanced design using uniquely interlaced monofilaments with a specific geometric orientation are considered in more detail. This will illustrate the design methods for successful scrubber operations.

The emissions standards might be set, the operating limits might be set as far as water balance or space; however, the DESIGN parameters are really not set. The actual size distribution of droplets to be collected is not known, nor is a reasonable method to generate the size distribution known. This makes the comparison of alternatives extremely difficult.

Scrubber selection is evaluated in terms of capital cost, operating cost, and Risk. Risk arises from variability in operating conditions, uncertainty in particle size distribution and in the uncertain progress in regulation. We prefer robust design for easily adjustable performance and reduced maintenance. Upfront design can minimize capital and operating cost. It also makes it more likely that the unknowns mentioned above can be successfully dealt with. The technology described here has an enormous range of features (Figure 1).[1]

One researcher has remarked that separation costs go up by a factor of 10 when the size of the droplets to be eliminated decreases by a factor 10.[2] All the more reason for good, flexible design.

III. PROCESS DESCRIPTION

In hard and decorative plating, the object to be plated is placed in a bath with a chromic acid solution. The object is then connected at the negative electrode of an electrolytic cell. When a voltage is placed across the cell, chromium is deposited on the object.

However, as a side reaction, water in the plating solution decomposes to oxygen and hydrogen. As those gases rise to the surface, the gas bubbles burst creating chromic acid mist droplets.

These droplets are collected in hoods and exhausted to control devices like scrubbers. The exhaust airflow is then emitted into the atmosphere.[3]

IV. SCRUBBERS: WHAT ARE THEY?

Traditionally scrubbers are one or more pieces of equipment that provide:

1. Contact of a gas and an aqueous solution to absorb gases (vapor), and/or assist the collection of particulates (mist or dust).

2. Separation of the aqueous and collected particle from the treated gas.

Examples of such traditional scrubbers are:

Venturi scrubbers
Cross-flow scrubbers
Vertical Countercurrent packed towers
Cyclonic separators
Spray towers

as shown in Figures 2 and 3.

The obvious and distinguishing features are "CONTACT" and "SEPARATION" of liquid. The term "SCRUBBER" is applied more widely today and it actually seems quite difficult to generate <u>the</u> definition for scrubbers.

V. HOW DO SCRUBBERS WORK?

The many different methodologies of equipment and the methods of scrubbing in the classical sense have only two significant effects:

1. Absorption, and
2. Collection of liquids and solids

For some scrubbers enthalpy control is of paramount importance but it is not usually significant as applied to plating. It is not considered further here. In addition to this, of course, other functions, not "scrubbing" functions, impact on the scrubbing requirements, and may be incorporated in the same vessel.

A. ABSORPTION

Absorption involves the contact of a gas with an aqueous solution in order to promote mass transfer of a soluble gas component into the liquid stream. In the case of chrome scrubbing, the chromic acid is present in mist droplets, not as a gas. Absorption, therefore is not significant and is not considered further. It is, however, extremely important in other acid scrubbing applications like hydrochloric acid (HCl).

B. REMOVAL OF SOLID PARTICULATES AND LIQUID MIST

The term "particulate" is used for solid particulate, liquid mist of all sizes, suspensions of solids in liquid mist, and all else which is not absorption. This is a broader definition than EPA Method 5. For a scrubber to function, the particulate must be collected, and combined into an aqueous phase, and the aqueous phase must be separated from the gas. Collection mechanisms are discussed at length in the literature.[4] Calvert is especially thorough on the factors involved in collection. In design, one has to consider separation and re-entrainment.

General mechanisms for collection are:

1. Inertial impaction which applies to larger droplets or particulates. Impaction occurs when the droplet's momentum carries it into the fiber instead of following the gas stream around the fiber.

2. Brownian movement or diffusion applies to submicron particulates. The random movement of the particulates as they collide with the gas molecules forces impingement on the fibers. However, the fibers used are extremely fine (approx. 1.3 micron). Removal by Brownian diffusion is typically done by fine fiber elements known as "candles".

3. Interception applies to smaller droplets which are carried around fibers with the gas stream. However the inertia created by this path carries the droplet into downstream fibers. Its effect is most noticeable in the droplet size range below where inertial impaction occurs and above where diffusional impaction occurs.

The uniquely interlaced monofilament structure relies on interception and impaction mechanisms (See Figure 4). Moreover for systems to achieve the new strict standards, interception is believed to be significant. When interception and impaction are used, collection is a function of:

GEOMETRY	MATERIAL PROPERTIES
Fiber diameter	Liquid density
Fiber orientation	Liquid viscosity
Particle diameter	Gas density
Bed thickness	Gas viscosity
FLOW	
Gas Velocity	

Smaller fiber diameter, larger particles and higher velocities favor better collection. Unfortunately, the same factors favor high pluggage, high pressure drop, poor separation and increased chemical attack. These are important factors in chrome scrubber designs.

VI. "NEW TECHNOLOGY"

The technology described here has been called "newly emerging" in an EPA study for NESHAP.[5] With over 10,000 installations of the structure worldwide ranging from less than 1 CFH (0.5 l/h) to about 35,000,000 cfm (17000m^3/sec) and an additional disposable use of more than 10,000 units per month, neither the structure nor the technology can be considered new.
What is this structure?

The basic media structure is made in very long pieces six feet wide and is composed of round monofilaments interlaced in a patented structure (See Figure 5). The ladder-like arrangement specifically orients the filaments to lie essentially perpendicular to the flow of the gas. Virtually any removal efficiency can be achieved by controlling:

- Fiber diameter (from .002 to.0625 inches or 50 micron to 1.6mm diameter), as shown in Figure 6.
- Solid fraction (from .03 to .06)
- Material of construction in polypropylene, PVDF (Kynar™), ETFE (Tefzel™), FEP (Teflon™), PFA (Teflon™),
- Liquid rates, and
- Gas velocity

VII. <u>CHROME SCRUBBER DESIGNS</u> using the uniquely interlaced monofilament structure.

Each style of coarseness of this structure has its own performance characteristics - removal efficiency, liquid handling capacity, pluggage resistance, pressure drop, etc. Therefore, pad designs can run from simple elements comprised of one style, to more complex pads comprised of several styles--composite pads (Figure 7).

The NESHAP report mentioned above looked at technologies used in chrome scrubbing. It summarized that "control techniques incorporating the use of a composite mesh pad appear to be the most promising of all the control options.".[5]

A composite pad utilizes the best qualities of each style to provide a more versatile arrangement than the individual styles alone could provide. Composite pads are important in chrome scrubbing because high removal efficiency, high liquid handling and reduced maintenance are critical. Troubleshooting performance problems is also made easier. Styles may simply by added or removed from composite pads to improve efficiency, pluggage resistance, pressure drop, or liquid handling capacity. This can be done very cost-effectively.

Irrigation of the media with recirculated water is recommended for optimum performance of the scrubber. Indirectly, irrigation affects the efficiency of collection. While the mechanisms of collection are unchanged with or without water, the viscous chromic acid droplets tend to cling to the media. Over time, the chrome becomes more concentrated and more viscous. This in turn increases the pressure drop, the potential for chemical attack on the fibers of the media, and the possibility of re-entrainment of the droplets due to pluggage or blinding of the fibers. Therefore, while the chrome scrubber can run "dry", irrigation of the media provides longer operating cycles before maintenance is required.

In the earliest stages of chrome abatement (pre 1987) while chrome was under consideration for regulation under NESHAP, plating shops were generally interested in controlling chrome to the point where deposition on the stack and nearby buildings and automobiles was eliminated. They wanted this type of control without the need for maintenance of the scrubber unit. In these installations only coarse fiber stiles were used. The coarse styles have the efficiency to eliminate the drops that cause spotting of cars (approximately 10 microns and up), while offering the liquid handling capacity and pluggage resistance required for services where the minimum of maintenance is employed. We have received reports that units of this design have operated satisfactorily for periods up to a year before maintenance/cleaning was required.

Unfortunately, when units with this design were tested by the EPA for chromium emissions the performance (98% removal, .078 mg/ampere-hr) was not satisfactory for meeting the limits adopted by CARB in 1988 for medium and large hard chrome plating shops. It was clear that the size distribution of the chromic acid mist contained a significant percentage below the 8-10 micron size range. Therefore finer fiber styles would be required to meet the standards.

Composite pad mist eliminator systems then began to be employed utilizing medium to coarse fiber diameters. These designs are able to achieve removal efficiencies of 99+% for droplets 3-5 microns and up while maintaining a very reasonable amount of liquid handling capacity and pluggage resistance. Whereas, such composite structures may be able to meet emission limits for medium-sized plating shops (this design has not been tested), it is our opinion that such a design will not meet the standards for large hard chrome plating shops (99.8% or .006 mg/ampere-hr).

Without a reasonable size distribution available and with a need to meet the standards set forth by CARB, scrubber manufactures and end-users began to specify removal efficiencies of 99% at 1 micron and 99+% at 2 micron droplets in order to be certain to meet the limits. On top of this level of performance, the mist eliminator systems must be designed for lowest maintenance cost.

Removal efficiencies in the 1-3 micron size range necessitate using the finest fiber sizes (.002 to .008 inches, 50 to 200 micron diameters), while the lower maintenance aspect requires coarse fiber sizes.

The basic methodology to designing a system to meet the above criteria is to collect the mist and particulates in a stage-wise approach. The design would begin with coarse fiber styles on the upstream side and gradually work down to finer styles toward the downstream. The coarse styles remove the majority of the droplets while protecting the finer styles from pluggage. The finer styles then only handle the smaller droplets (<3 microns) at a much lighter liquid loading.

It is possible to design a single stage mist eliminator using the uniquely interlaced monofilament structure that will achieve the CARB emission limits. However, the pad would be very deep and it would be difficult to keep the inner layers of material clean or unblinded. Therefore, due to the potential maintenance difficulties a multiple stage mist elimination system is preferred. (See Figure 8)

Bypassing is probably the single-most cause for a mist eliminator's inefficiency problems. Bypassing refers to any portion of an airflow that is able to circumvent or short-circuit a mist eliminator. The airflow which bypasses a mist eliminator carries with it a certain percentage of mist or particulates. Obviously, these particulates go uncontrolled by the pad. Bypassing occurs because of fit problems between the mist eliminator and the housing or because of a design flaw in the scrubber. In either case, a single-stage mist eliminator system is more susceptible to bypass problems and has a greater potential to fail than a multiple stage system. With the exception of a serious design flaw in the vessel, the probability for gas bypassing all stages of a multiple pad arrangement is small.

Each stage of a multiple stage system has a specific design purpose.

The first stage of a multiple stage system would consist almost entirely of coarse fiber styles. This pad would eliminate essentially all of the droplets above 3-5 microns. As in the description of a composite pad above, this stage would also offer protection of finer stages downstream.

The second stage is primarily comprised of finer fiber styles. It is designed to operate as a coalescing element. In this case, the smaller chromic acid droplets (1-3 microns) are collected and agglomerated into larger, easily collectible droplets. The coalescer pad operates in a "flooded" state. This means the majority of the drops collected in this pad will be re-entrained. But the droplets will be quite large (>40 microns) and, therefore, easily eliminated.

The third and final stage of the system is a simple re-entrainment separator pad comprised of medium to coarse fiber diameters. This pad merely collects any of the droplets that may re-entrain from the coalescer pad upstream.

For chrome scrubber designs, a horizontal flow with the mist eliminator pads installed vertically is preferred. Horizontal flow allows better drainage of the collected chrome. Also the pads can be designed for easy access on line for maintenance--in many cases without shutting the unit down.

Vertical flow scrubbers are also acceptable. The basic design principles and collection mechanisms are the same as in horizontal flow units. However, the vessel design is a little more complicated with respect to drainage and maintenance. (See Figure 9)

VI. SUMMARY

The tough emission standards set down by the CARB can be met. This has been demonstrated by various technologies including units utilizing the uniquely interlaced monofilament structure. The successful application of this technology is due to the systematic interaction and cooperation between the manufacturer of this structure, a few very skilled scrubber manufacturers, and the end-users. Because of this progression of the technology, scrubber systems can vary from site to site based upon the resources available from the end-user and still be able to meet the strict standards.

Because of this versatility, chrome scrubber designs using the uniquely interlaced monofilament structure provide the most cost effective solutions to the industry's needs.

REFERENCES

1. Pedersen, George C., "Electroplating: Evolution of Scrubber Technology"; presented at Eleventh AESF/EPA Environmental Control Conference, Miami, Florida, February 1990.

2. Burkholz, Armin, "Droplet Separation", VCH Publishers, New York, NY, 1989.

3. Murcheson, Gary et at, "Proposed Airborne Toxic Control Measure for Emissions of Hexavalent Chromium from Chrome Plating and Chromic Acid Anodizing Operations", Prepared by State of California Air Resources Boards, January, 1988.

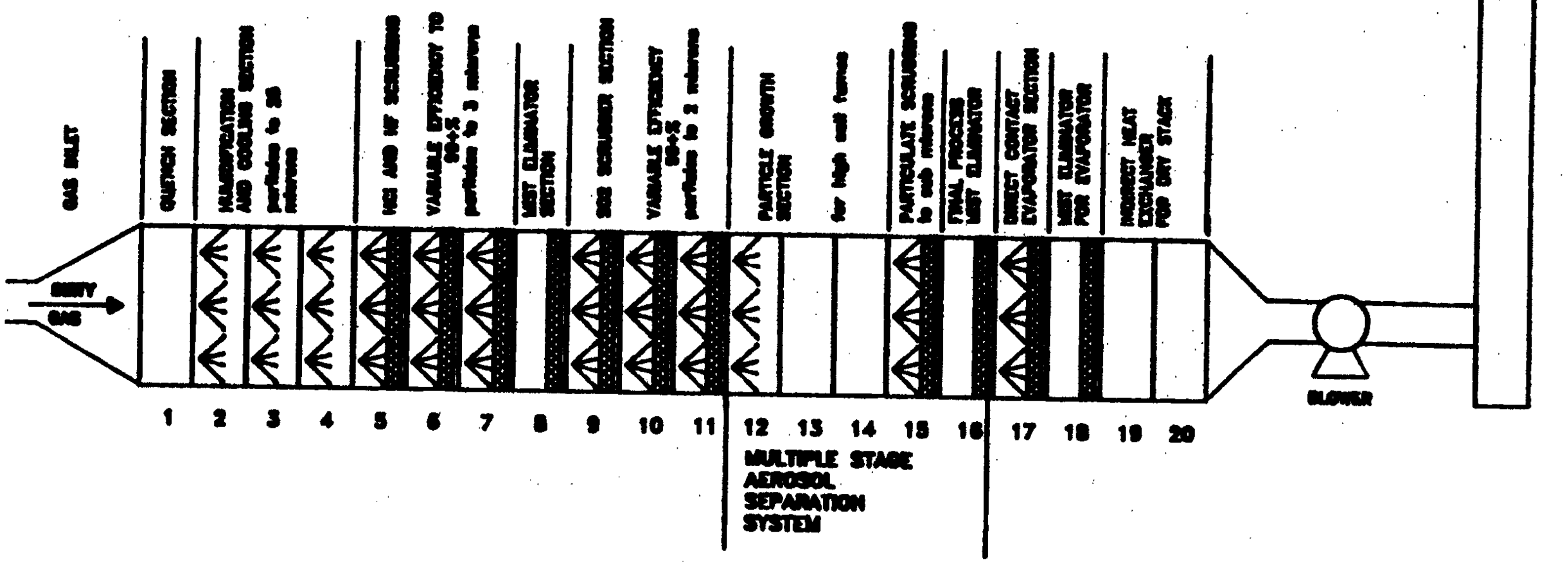
4. Calvert, Seymour et al, "Wet Scrubber System Study, Volume 1, Scrubber Handbook", APT, Inc., Prepared for Environmental Protection Agency, July 1972.

5. "Chromium Electroplating Chromic Acid Anodizing - NESHAP", briefing for National Air Pollution Control Techniques Advisory Committee, January 1991.

FIGURE 1

STATE-OF-THE-ART CONCEPT
OF
FLUE GAS CLEANING PROCESS
TO PROVIDE
CLEAN AND DRY STACK GAS

COMMENTS: – ONLY GAS LINE SHOWN
– MODULAR DESIGN ALLOWS ADJUSTMENT FOR DIFFERENT WASTE STREAMS
– WORST CONCEIVABLE CASE SHOWN. NO KNOWN WASTE COMBUSTION STREAM WOULD REQUIRE THIS EXTREME.



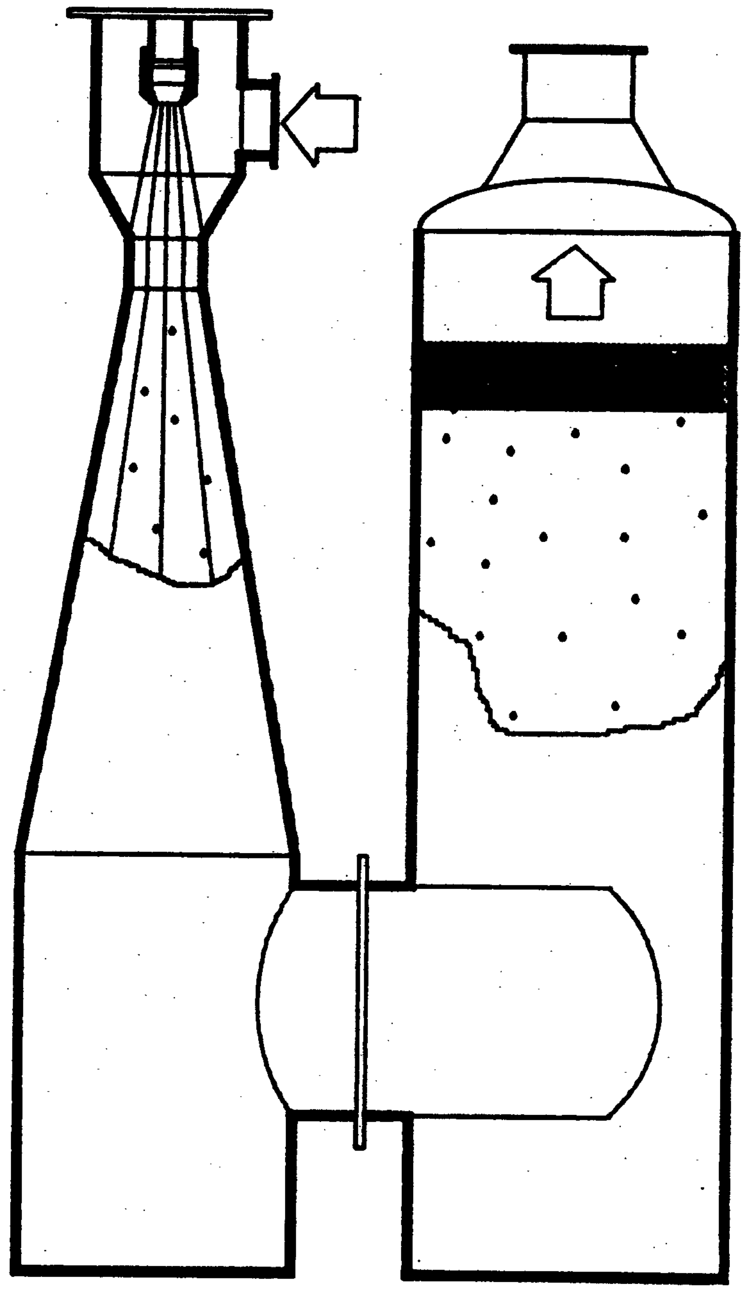


FIGURE 2
VENTURI SCRUBBER

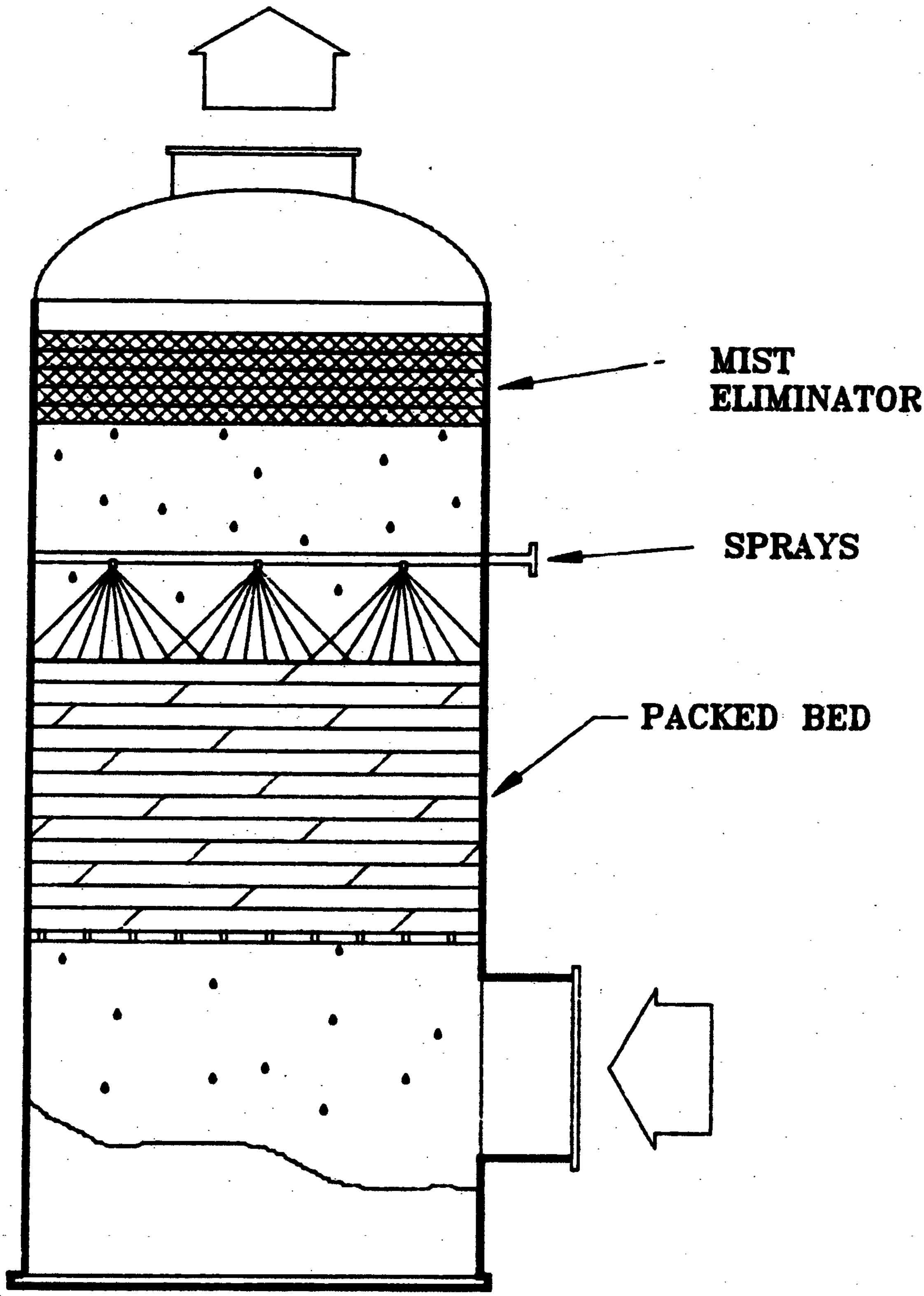
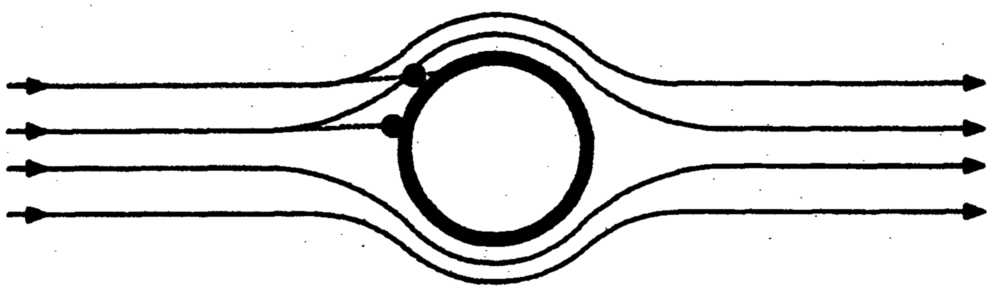
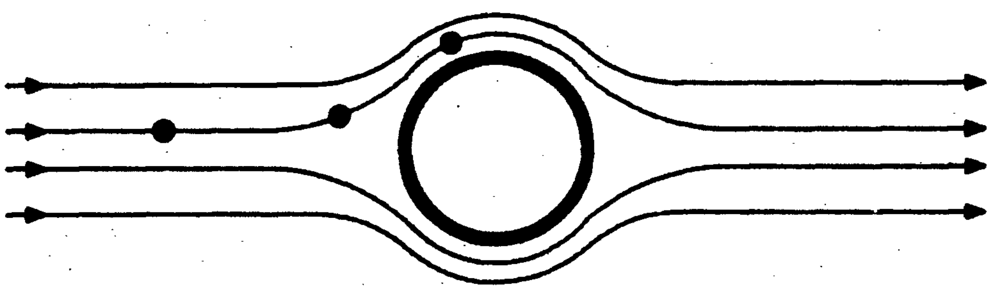


FIGURE 3
PACKED TOWER

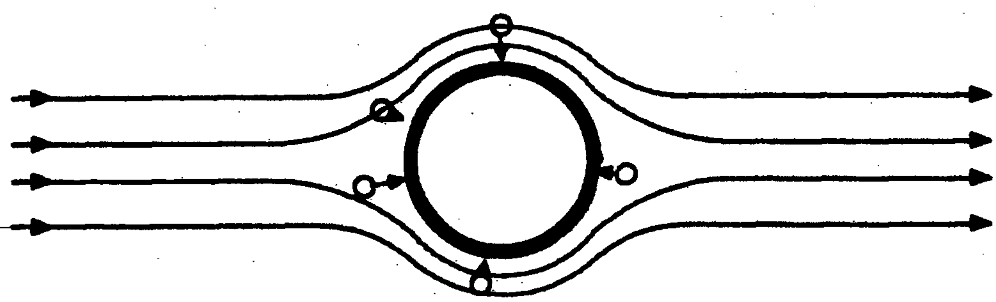
FIGURE 4:
MECHANISMS OF COLLECTION



INERTIAL IMPACTION

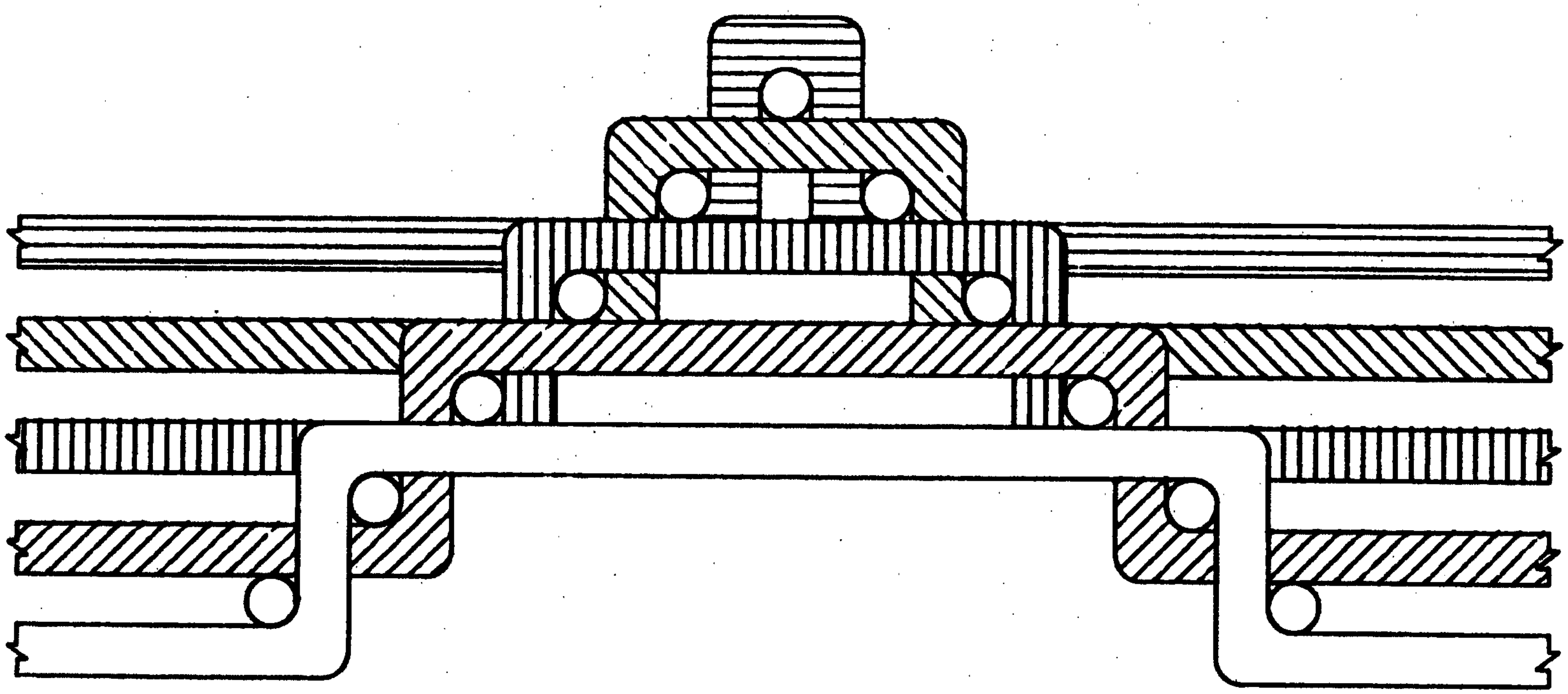


INTERCEPTION



BROWNIAN DIFFUSION

FIGURE 5: MONOFILAMENT STRUCTURE



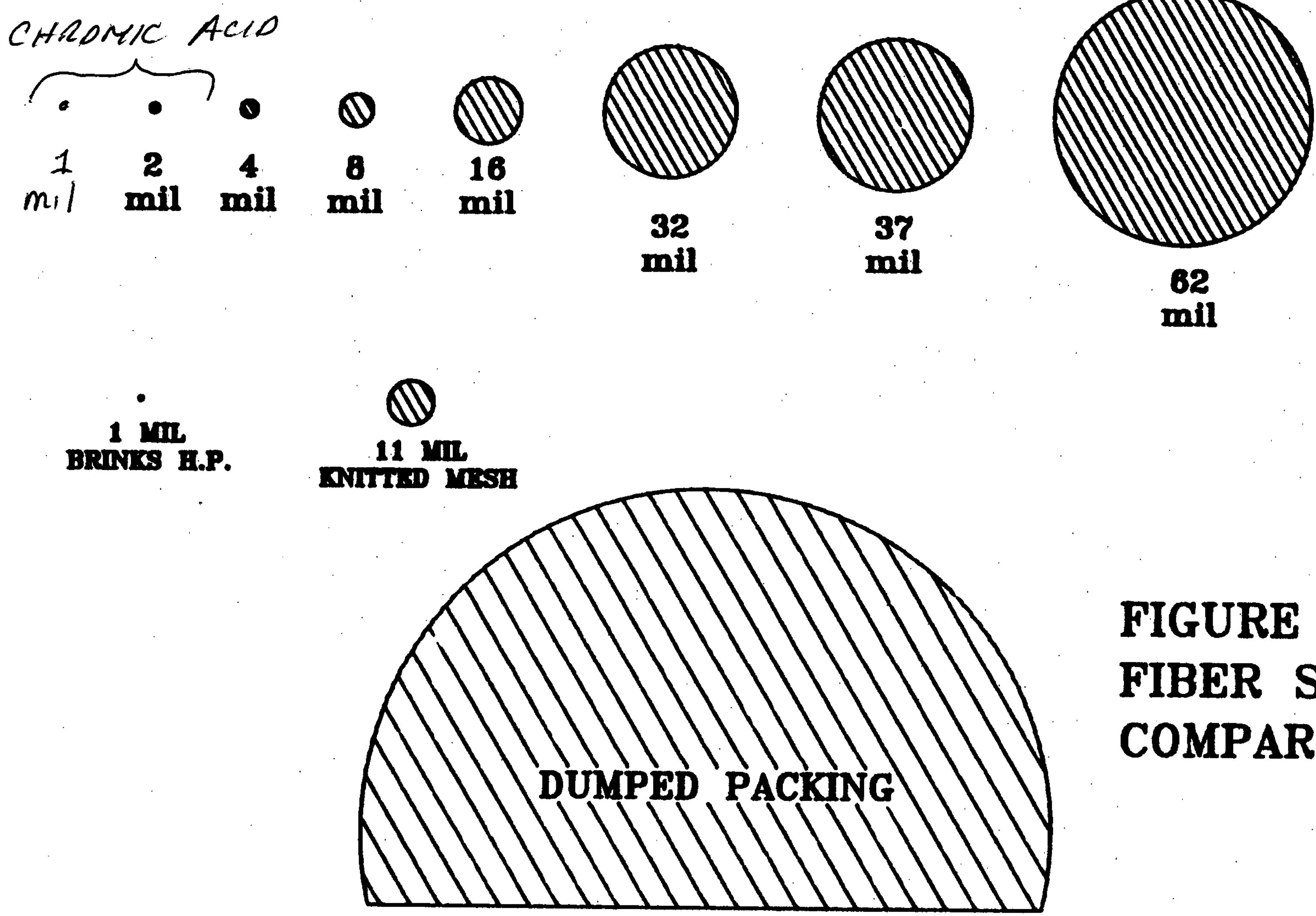
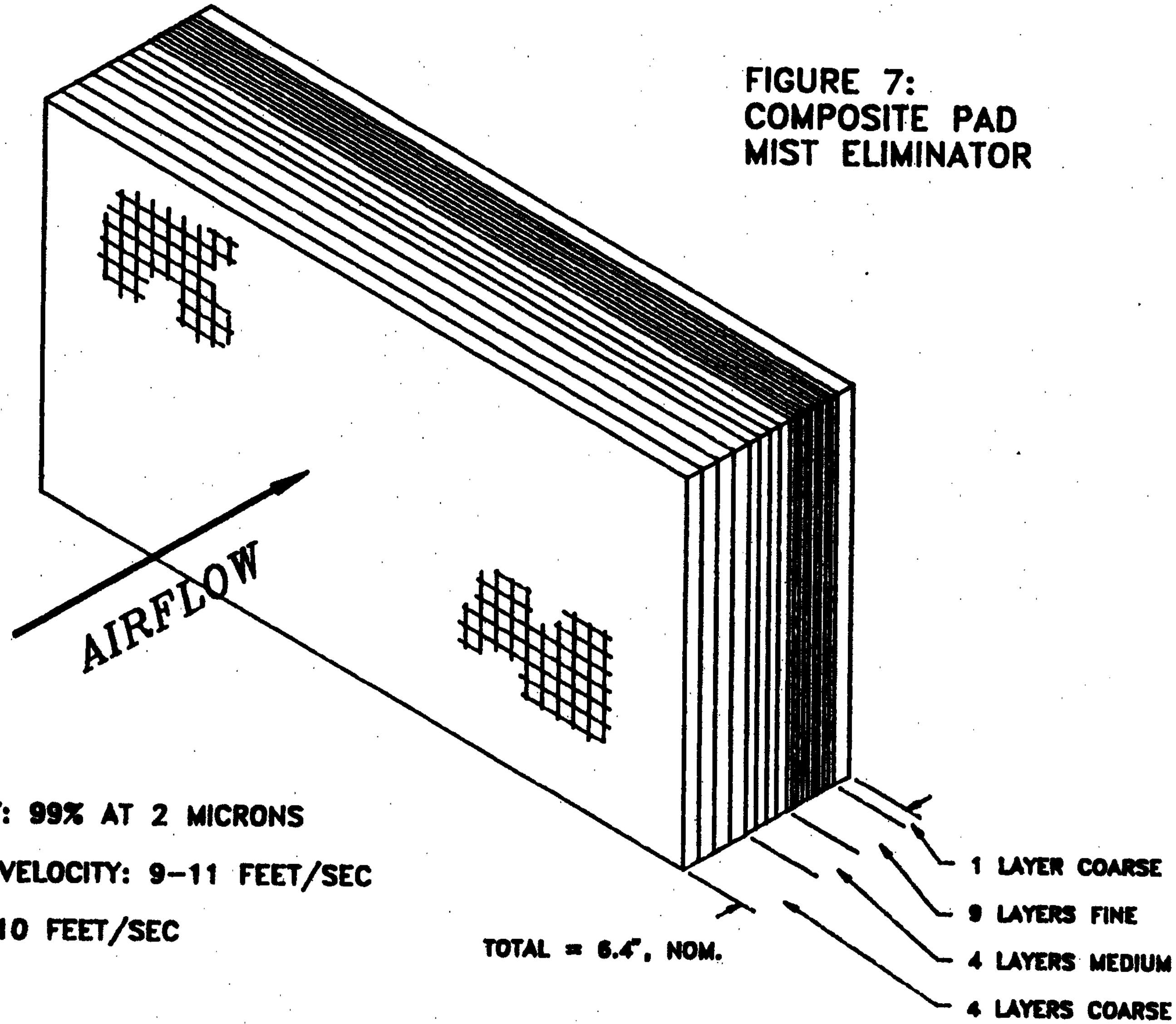


FIGURE 6: FIBER SIZE COMPARISON

FIGURE 7:
COMPOSITE PAD
MIST ELIMINATOR

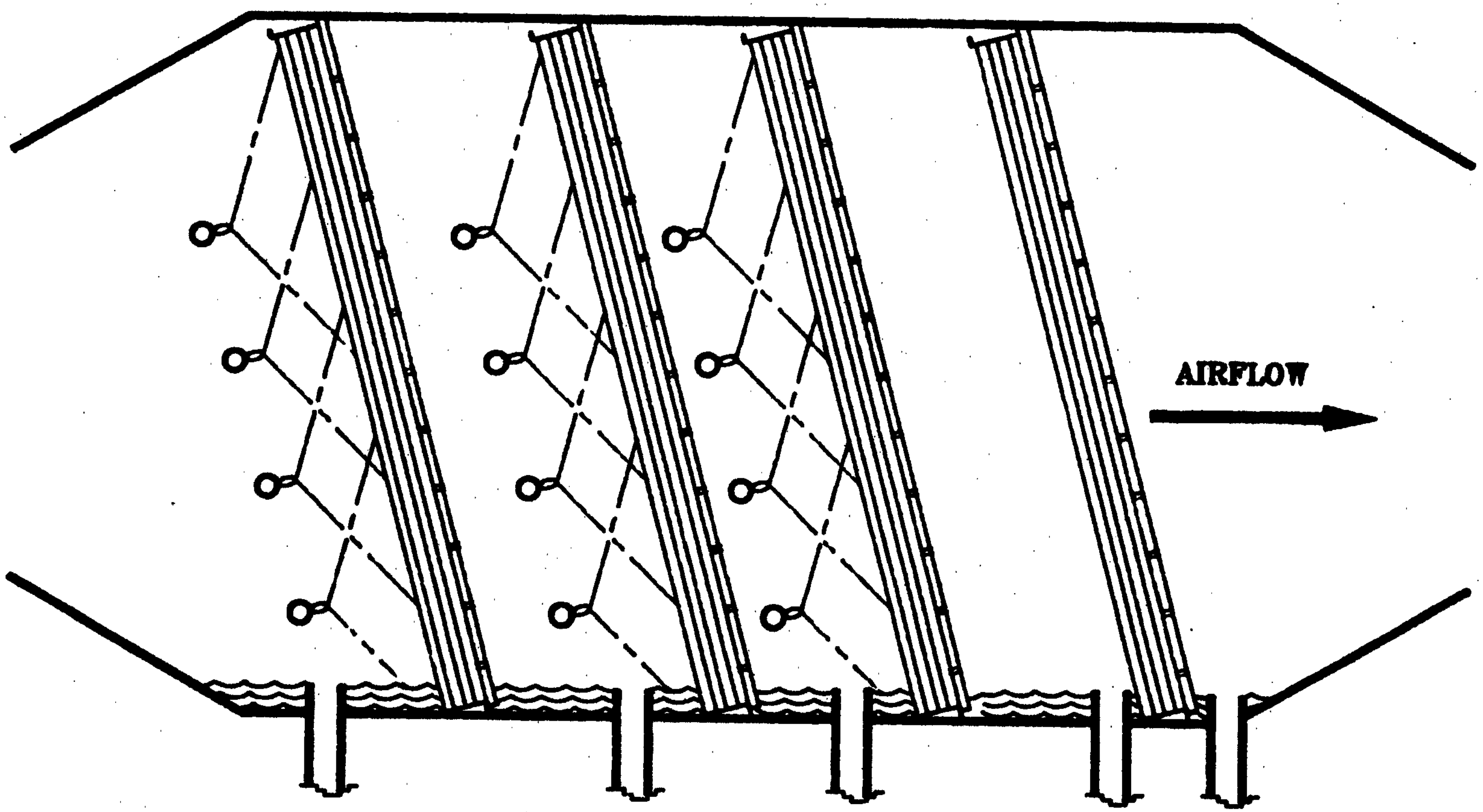


REMOVAL EFFICIENCY: 99% AT 2 MICRONS

RECOMMENDED GAS VELOCITY: 9–11 FEET/SEC

ΔP = 3.25" WC @ 10 FEET/SEC

FIGURE 8: CROSS-FLOW SCRUBBER



DIMENSIONS UP TO 15' HIGH X 25' WIDE

FIGURE 9: VERTICAL FLOW SCRUBBER