

NEW TECHNOLOGY FOR IMPROVED FOUNDRY ENVIRONMENTS

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ABSTRACT

This paper presents the results of recent research at the University of Arizona on methods for control of dust, fume, vapor and smoke. The dust reduction systems are based on the discovery that industrial dusts are naturally charged as they disperse into the air. These dusts can be induced to agglomerate and fall out by exposure to small quantities of oppositely charged water fog.

Control of smoke, vapors, fume, etc., has been done with a variety of new and improved electrostatic techniques. Particular attention has been aimed at welding smoke and the control of diesel exhaust particulates. Other applications have involved the development of an "electrostatic fence" designed to "push" smoke and dust toward a hood or other collector. Electrostatic systems can also be used for demisting and the control of sulfur dioxide. Laboratory and industrial studies of the above technologies will be discussed in the paper.

INTRODUCTION

Improvement of foundry working conditions has been an important goal of health professions for many years and a great deal has been done to reduce the hazards of the foundry environment. Nevertheless, we must recognize that high temperatures, toxic gases, metallic fume and respiratory dusts are still sources of injury to foundry workers. The problem is complicated by the obvious need to maintain economical operations while improving the foundry environment; a closed foundry does little for the ex-worker's health or the nation's gross national product.

In the discussion below we will consider the work done at the University of Arizona in the development of new devices to improve working conditions in the foundry. Where possible data and/or photographs of equipment in action will be presented. However, there are a number of operating systems where the plant owners have insisted that no mention of their installation be made.

Charged Fog for Dust and Smoke Control

Dust and smoke are serious foundry problems particularly in grinding, arc washing, silica unloading, sand handling and shakeout areas. In most cases the hoods or other dust control systems are located above the worker's head, virtually insuring that the dust will go past the worker before it gets to the collection system. This situation and our knowledge that dust respirators are relatively ineffective suggests that efforts be made to suppress the dust at the point of generation.

The University has been working on the application of charged fog for this purpose for some years with support from the Environmental Protection Agency and the American Foundrymen's Society. This work has demonstrated that most, if not all, respirable dusts are electrostatically charged as they are dispersed into the air and that the dusts can be induced to agglomerate and fall out by exposure to appropriately charged water fog* (1). The use of charged fog provides several advantages. The fog and the dust particles are attracted to one another leading to rapid wetting and agglomeration. The electrostatic charging process encourages rapid breakup of large water drops into smaller droplets. This makes for more efficient use of water and reduces the quantity of liquid needed for dust suppression. It might be noted that minimal water use is important for two reasons: first, it reduces the problems with mud formation and the hazard of rusting metal components; second, it reduces the total consumption of water which is becoming ever more important in the water short Southwest.

APPLICATIONS TO DUST CONTROL

Hand Grinders and Sanders

Hand grinders and sanders are an example of devices where dust must be controlled on the device itself if operator dust exposure is to be reduced. A system for this purpose is shown schematically in Figure 1. The unit has been installed on an operational hand grinder by the ARO Company of Bryan, Ohio and is shown in operation in Figure 2. Some of the results with this system in the grinding and sanding modes are shown in Figures 3 and 4. There was a significant reduction in respirable dust and operator comments indicated that it is possible to grind more rapidly without the danger of "grinding burn". Prototype models of this unit are under test at several industrial organizations. In one automobile company it proved possible to grind lead solder (used as a body filter) without dust masks because the lead dust was reduced below the OSHA limit. This had never been possible with conventional dust control systems. It should be noted that the quantity of water used is quite small (0.8 gal./hr) so that there is no problem with mud or a wet floor. The wetted dust is deposited in the grinding area where it remains in large clumps and can be swept up for removal.

*The charged fog guns are manufactured and sold by the Ritten Corporation, 40 Rittenhouse Place, Ardmore, Pennsylvania 19003, (215) 896-0900.

Swing Grinders

Swing grinders are another example of a foundry system that is not amenable to conventional control by hoods because of the vertical suspension and the need for constant movement over the work. There have been some systems for providing water to the work by high pressure diffusion into the sides of the grinding wheel itself but the devices are quite expensive (some \$20,000 per installation) and the high pressure pumps require extensive maintenance.

In Figure 5 we show a system that can be attached to a conventional grinding wheel to provide a flow of finely divided water droplets to the wheel-work interface. The addition of the Coanda effect lip shown in Figure 5 is an important part of the system since it insures that the water droplets will cling to the wheel in spite of the high centrifugal forces developed by the rotating wheel.

This system has been tested on a limited scale in the laboratory where there was every evidence of a significant reduction in fine "float dust". The operator noted that it was possible to grind at a much faster rate because of the cooling effect of the water flow.

Control of Dust During Transfer Operations

Sand and material transfer operations are frequent sources of dust that may be difficult to control with hoods. In Figure 6 we show an application to a dust dumping system from a fly ash hopper. The irritating dust normally blows directly into the plant through the door shown in Figure 6 (upper photograph). With the fog generator (Fogger II) "on" (lower photograph) the dust is completely suppressed.

Another problem in sand operation is "boil up" during dumping; this was simulated with the apparatus shown schematically in Figure 7. An experiment to show how the system worked in practice resulted in the photographs of Figures 8 and 9. In Figure 8 the fog generator (Fogger I) was "off", in Figure 9 the fogger was "on" and the dust suppression was quite significant.

Other applications of the fogging system have been made on foundry shakeout. The results with foggers mounted over the shakeout area were very satisfactory but company policy forbade the taking of photographs. An application to a sander is shown in Figure 10; in one case (left photo) the system was "off" and there was significant dust blown about the room. In the right hand photograph the fogger was "on" and dust suppression was quite effective.

Bag splitting and dumping of silica powder is a frequent source of employee exposure. In Figure 11 we show data taken at a West Coast foundry bag splitting room. This data was taken by company personnel and the reduction of dust exposure on the workman is of particular significance. We should note here that silica dust is known to be negatively charged (1) and the fog used in the experiment was positively charged so that rapid wetting and agglomeration would be expected to occur.

Another silica experiment involved a sand car unloading system. The set-up is shown schematically in Figure 12; the results, using positive fog, are shown in Figure 13. There was a significant reduction in respirable dust and an even larger reduction of silica. Once again this effect could have been anticipated from the knowledge that silica dust has a high negative charge.

Control of Carbonaceous Fume and Particulates

Fumes of this type are among the most persistent and dangerous in the foundry. In some cases the fumes are due to burn-off of coke used as a binder in mold formation. Other fumes are generated by the combustion of residual oil on metal scrap. Electrical techniques for the control of oil smoke will be discussed below. Here we shall note that charged fog is quite effective for the control of coke fume and particulates. Typical results are shown in Figures 14 and 15. In Figure 14 we show the effect of charged fog on particulates where a significant reduction in dust level was observed with (+) charged fog. The data of Figure 15 was taken to observe the effect of charged fog on benzene solubles. The analysis involved a low cost gas chromatograph that did not provide details about the absorbed materials but it was clear that the benzene solubles were significantly reduced by (+) charged fog.

Electrostatic control techniques for control of tarlike particulates have been another area of interest and here we might note that the usual tube and wire electrostatic precipitator (ESP) is quite effective. The major problem in the use of ESP systems has been the removal of the deposited material since it cannot be shaken off. We have been looking at the design of a tube and wire ESP with an inner rotating liner; as the tars are deposited on the liner it rotates beneath a scraper that picks up the tars and carries them, via an internal worm, to a storage container. The first application of this area of technology has been in the control of diesel engine particles. In Figure 16 we show some recent results with a small diesel engine exhausting into a tube and wire ESP. Not only was there a huge reduction in the fine particulate level, we also noted significant agglomeration as demonstrated by the upward trend of the "voltage on" curve for larger particulates. We feel that this is very encouraging since there should be no problem catching these larger particulates with a cyclone system.

This summarizes the work on dust control to date. We have continued with the development of larger fog guns designed to "throw" the fog some distance against the wind. Other systems for use in high temperatures or corrosive environments have been developed and are in application (2). The University and Aerovironment Incorporated of Pasadena, California are engaged in an Environmental Protection Agency support effort to adapt a spinning cup fog generator for use on a front loader and factory sweeper. At the moment the spinning cup fog thrower is undergoing Phase 1 testing at an off-campus site.

The spinning cup system has several advantages; there are no nozzles to clog even if dirty or contaminated water is used, the system is much simpler than conventional nozzles technology, and the spinning cup can vaporize

water at any flow rate limited only by the power of the driving motor. A drawing of the current spinning fog thrower is shown in Figure 17 and a photograph of the system in action is shown in Figure 18.

Control of Welding Smoke and Fume

Arc washing makes use of typical welding components using extra heavy currents to "wash" an arc over the surface and vaporize metal tags, risers, etc. The smoke and metal fume present a control problem because the operator moves around the work and the presence of cranes in the area makes it difficult to mount effective hoods. We have been looking into several techniques for the control of welding fume and smoke; the first was the application of charged fog. In this experiment we felt that it was necessary to not only show that the fog would reduce the pollution but that it did not interfere with the operator or the quality of the weld.

The experimental setup is shown in Figure 19. The welder was a Miller Electric Company, Model 35S, continuous wire unit. The operator was asked to work on cold rolled plate in a normal manner. He was questioned after the experiment about the quality of the weld and the effect, if any, of the charged fog on the working environment.

Typical results with the system are shown in Figure 20. There was a significant reduction in the solid particulates and the operator indicated that the charged fog did not affect his work or the quality of the weld. Turning back to Figure 20, we might note that the reduction in particulates was encouraging, but there was little effect on the visible smoke and fume. This was expected as fume particulates are typically some 0.3 micrometers in diameter and are not easily caught by the much larger (20 micrometer) water droplets.

Other Smoke and Fume Control Systems

For general fume and smoke collection we have developed a new series of electrostatic "pushing" and "catching" apparatus that we refer to as an electrostatic fence. A schematic drawing of a system of this type is shown in Figure 21. For operation the needles are run at a high voltage to generate electrons which in turn produce oxygen negative ions. These ions pass through the grounded screen and charge dust particles; the dust particles are then "pushed" away by the electrostatic field of needles. A system of this type can be used to push dust or smoke toward a reversed system that is operated as a collector. A photograph of a system of this type operating on lead fume is shown in Figure 22. Lead fume is normally very difficult to collect with conventional electrostatic or baghouse systems. It is clear that the electrostatic fence can collect this material quite effectively.

Another application of electrostatic technology involves the use of large scale electrostatic screens to "push" smoke or fume from the point of generation to a collection system. An example of where this might be needed is shown in Figure 23 where the smoke from a copper converter goes up to the smelter roof rather than being caught in the hood positioned behind the

converter. We would envision an electrostatic pusher system of the type shown in Figure 24 for this application. The screen would normally be rolled up like a window shade and would be released and turned on when needed. A small scale unit of this type is shown in action in Figure 25. In this case an aerosol of ammonium chloride was blown toward the system. In the upper figure the system is "off" and the dust, 3.3 m/sec (650 ft/min) goes right through. In the lower photograph the system is "on" at some 12,000 volts and the dust is blown backwards. We have developed the necessary technology to make flexible units of this type in almost any size; further application depends upon a commitment by the industry.

Hoods are popular systems for collecting dust, fume and smoke but in many cases they cannot be applied properly because of crane movements in the area. What is needed is a hood that can be collapsed (like a hoop skirt) or hoisted out of the way when the crane comes by. Another problem with hoods in foundries is the weight and bulk of the motor-fan systems needed to draw air into the hoods. It would be most advantageous to have a collapsible hood that can be "driven" by some method other than the usual mechanical fans.

In Figure 26 we show a demonstration model of an electrostatic hood. The system consists of a grounded outer shell and an inner high voltage element. In the photograph on the left the unit is "off" and the smoke passes through the side of the hood. In the photograph on the right the unit is "on" and the smoke is forced out the top. A hood of this type could easily be made of chain mail mesh and metal rings (like a hoop skirt) with an elephant trunk attached to the top to carry off the collected dust, smoke, etc. As the crane moves past, the hood would be collapsed or drawn up out of the way. Once again the design and application of large scale systems of this type is dependent on the response of the industry.

Still another example of an electrostatic system in action is shown in Figure 27. Here the objective was the condensation of vapors. Vapors can be induced to condense and coagulate in a strong electrostatic field gradient and we suggest that this technique can be used to remove a variety of oil smokes and water droplets from a gas stream. In Figure 27 the vapor (from heated mineral oil) is coming from the left; in the upper photograph the field is off and the smoke simply moves out of the system. In the lower photograph the field is on at -12 kV and the vapor is condensed and deposited inside the collector. We have obtained similar results with a variety of other vapors.

Electrostatic Demisting Technology

Many foundry pollutants are composed of steam or water vapor mixed with various gases or particulates. These mists are difficult to remove from air by conventional impaction demisters especially when fan power to accelerate the gas to high velocity is limited. We have been investigating the application of electrostatic techniques for demisting with the system shown schematically in Figure 28. In a system of this type the mist droplets are forced to pass through a strong electrostatic field. The high dipole moment of the water droplets results in their being drawn to

the needles where coalescence takes place. The coalesced droplets are then forced to the wall by the electrostatic field. The system is shown "off" and "on" in Figure 29 with the mist coming from the right. It is clear that with the field "on" the moisture is totally coalesced. Similar results have been obtained with ammonium chloride particles. It is important to note that this electrostatic coalescing system operates with very low power levels and increases in efficiency as the flow velocity decreases. This is in contrast to the operation of a typical impaction demister where efficiency decreases as the flow velocity drops.

CHARGED FOG TECHNIQUES FOR CONTROL OF SULFUR DIOXIDE

Control of SO_2 has proved to be one of the most difficult and expensive problems for smelters, foundries and power plants. Present EPA technology calls for the injection of calcium carbonate water mixtures to form calcium sulfate slurries that must ultimately be disposed of by burial. The slurry technique has other problems beyond the mere cost of the materials, in that the injection results in a significant reduction in gas temperature as the water evaporates and the dry CaCO_3 is heated. This in turn can lead to a reduction in stack draft and plume rise which may be the cause of further EPA citations or loss in plant efficiency.

We have been investigating the use of charged water fog for the simultaneous reduction of SO_2 and fly ash in a simulated stack environment. We suggest that the SO_2 will be absorbed by the water droplets and that the water droplets will induce the fly ash to agglomerate thereby removing both the fly ash and the SO_2 from the environment. If the quantity of water is small the loss of sensible heat from the flue gases will be quite low and the agglomerated fly ash particles will be dry so that disposal can take place without any hazard to groundwater supplies.

In this connection it is important to note that the reaction of SO_2 and water is not limited by the usual solubility relationships; experiments at Georgia Tech have indicated that when charged water droplets are present the absorption of SO_2 is significantly enhanced (3). There is still some question as to the mechanism involved here but the authors of Reference 3 suggest that when a droplet is electrostatically charged the surface is altered and the number of absorption sites is greatly increased. Further research is needed to verify this concept.

The application of this technology might have important consequences for the foundry, power and smelter industries and for this reason we have performed experiments in the Anaconda supported stack simulation facility shown in Figure 30. Typical results with charged fog and copper smelter fly ash are shown in Figure 31 where we have plotted the reduction in SO_2 and fly ash as a function of operating temperature. It is clear that there is a significant reduction in both pollutants until the temperature exceeds 250°C . At high temperatures there is a loss of water, by evaporation, before the droplets can contact the SO_2 and there may well be some release of SO_2 from the fly ash particles since they were supplied by a copper smelter.

It would seem that this technique offers the opportunity to reduce both SO₂ and fly ash without the costly technology associated with the CaCO₃ system.

DEVELOPMENT OF LOW COST DUST TESTING APPARATUS FOR FOUNDRY APPLICATIONS

One of the problems in industrial dust control is the lack of small, low cost, instrumentation that can be given to environmental health personnel for in-plant testing. In most cases where filter cassettes are used it is necessary to send them to the laboratory for dessication and weighing before the data can be generated. This makes it difficult to test new dust control systems where on-line information would allow for on-the-spot adjustments.

At the University we have been developing a hand held optical system designed to accept the filter cassettes normally used for dust testing. Typical operation involves putting a clean cassette into the optical reader and setting the battery driven lamp so that the scale reads 100%. A dust sample is taken and the used cassette is placed in the reader to determine how much dust is normally present. Then the dust control system is activated and another cassette is exposed and inserted into the reader; the difference between the second and third readings is a direct measure of the reduction in dust level. The cassettes can still be sent to the laboratory for the usual drying and weighing procedures to serve as a check on the optical system; we have found that the correlation between the two techniques is very good. If necessary a calibration curve can be provided to convert the optical dust density readings into typical mg/m³ dust densities. In Figure 32 we show typical test results where a number of dusts were tested for their optical absorption. The general response was quite linear suggesting that the optical dust tester might find a wide use in industry. The system is being tested in selected industries at the present time. We anticipate a retail sale price of under \$200. This cost will include a simple hand operated pump to draw dust laden air through the cassette. Alternatively the usual battery driven pump, supplied for personnel sampling, could be used.

SUMMARY

We suggest that modern technology can be used to significantly reduce the personnel hazard in the foundry industry. In some cases, e.g., charged fog, the technology has already been demonstrated and is in daily use. Other techniques have not emerged from the laboratory environment and need further development. The transfer of these new systems from the university to industry will require not only the financial support of the foundry industry but patience and cooperation as the new devices go through the usual "teething problems".

REFERENCES

1. Hoenig, S. A., "Use of Electrostatically Charged Fog for Control of Fugitive Dust Emissions", EPA-600-7-77-131, November 1977. Available from NTIS, Springfield, Virginia 22161.

2. Hoenig, S. A., "Fugitive and Fine Particle Control Using Electrostatically Charged Fog", EPA-600-7-79-078, March 1979. Available from NTIS, Springfield, Virginia 22161.
3. Matteson, M. J., Gardenia, P. J., "Mass Transfer of Sulfur Dioxide to Growing Droplets", Env. Sci. and Tech., 8, No. 1, pp. 50-55, 1974.

QUESTIONS, ANSWERS AND COMMENTARY

Question (S. Kiefel, Sawbrook Steel Castings):

I understand your process makes very small particles large enough so they would be collected in a dust collector?

Answer (S. Hoenig):

Particles agglomerate.

You see, normally, dust particles won't stick to each other. They have like charges so they repel and they're dry. So they don't stick.

What we do is we wet the particles. Then we make contact. They stick and you get large agglomerates.

Question (S. Kiefel):

I understand you've tried this method on welding. Have you tried it on the arc air process.

Answer (S. Hoenig):

We've never been able to. There isn't one in Tucson.

Response (S. Kiefel):

Would you like to send one to my foundry?

Response (S. Hoenig):

Yes. Leave me your card and I'll happily have the company that manufactures them get in touch with you.

Question (F. Boelter, OSHA):

In the grinder example that you presented initially, was that 1.25 l/hr (0.33 gal./hr) in any way treated, either electrostatically or with any other method?

Answer (S. Hoenig):

No. In that experiment there was no electrostatic effect.

Question (F. Boelter):

In some foundries that I've visited, that are presently using the fogging devices in the pit areas to control the respirable dust. I've discussed with them the idea of using that particular grinder. However, they voiced tremendous concern about rusting problems that might occur.

Answer (S. Hoenig):

I think the answer is that they have to get used to the idea that a lot of water is not being used.

We went through this with a cement company and finally I said "why don't you put a bag of cement out and we'll fog in the area. If the cement turns to concrete, I'll buy it from you". That demonstration finally convinced them.

The method doesn't use a lot of water. If it rains there is more humidity in the plant coming in with the incoming air than will ever be gotten from the fog guns or the grinder.

Comment (F. Boelter):

I think Stan Kiefel's suggestion is a good idea because the arc air process involves compressed air, which many times has some water in it, to begin with. Perhaps it could be treated in some fashion.

Question (G. Mosher, American Foundrymens Society):

In your work with your fogger and the coke oven emissions do you analyze your samples for polynuclear aromatics? And, if so, were they reduced?

Answer (S. Hoenig):

The only instrument we had available to us was a small gas chromatograph, which just handled the benzene. We've just never had access to a better gas chromatograph for that experiment.

Question (H. Scarton, Rensselaer Polytechnic Institute):

Can you comment on the cutting efficiency of the grinding?

Answer (S. Hoenig):

One thing that was commented on at the automobile company, and has also been commented at local foundries, is that they couldn't burn the work. No matter how hard they leaned on that grinder, they couldn't burn the work. When grinding is done dry, burning is quite easy.

Question (H. Scarton):

Often times arc air metal gouging is done on hot castings for metallurgical reasons. Might the fog tend to cool the casting or does it represent an insufficient quantity of moisture to cool the casting?

Answer (S. Hoenig):

We were concerned about that on welding. Our observations were that the fog evaporated completely before it ever got to the work.

I think that's one thing we have to restrain people on. They want to turn the fog gun up all the way and that's just the wrong way to go at it. It is better to start with only as much as necessary.

Question (G. Cusamano, Aer-X-Dust Corporation):

Are the commercially available fog guns switchable as far as polarity goes? If they are used in a situation where there is a mixture of liquid hydrocarbons and particulate all the way down to a very fine particle size range, and if it is not certain which polarity will produce the best results, it would be helpful to switch back and forth.

Answer (S. Hoenig):

The foggers that are commercially available are switchable. On the large spinning fog thrower we just have a fixed power supply, but that could be switched too.

Comment (C. Anderson, DOFASCO, Canada):

At this time of year we're worried about freezing.

Response (S. Hoenig):

At Steep Rock, near Sudbury, they wanted to run with ethylene glycol. We convinced them that was a bad idea; ethylene glycol is quite toxic in vapor form. Instead they're running with glycerine. Their comment was: it really sticks. It's a little expensive, but glycerine is the only chemical that I can think of that is good antifreeze and is approved for all rectal, dermal, and internal applications. There aren't many chemicals you can say that about these days.

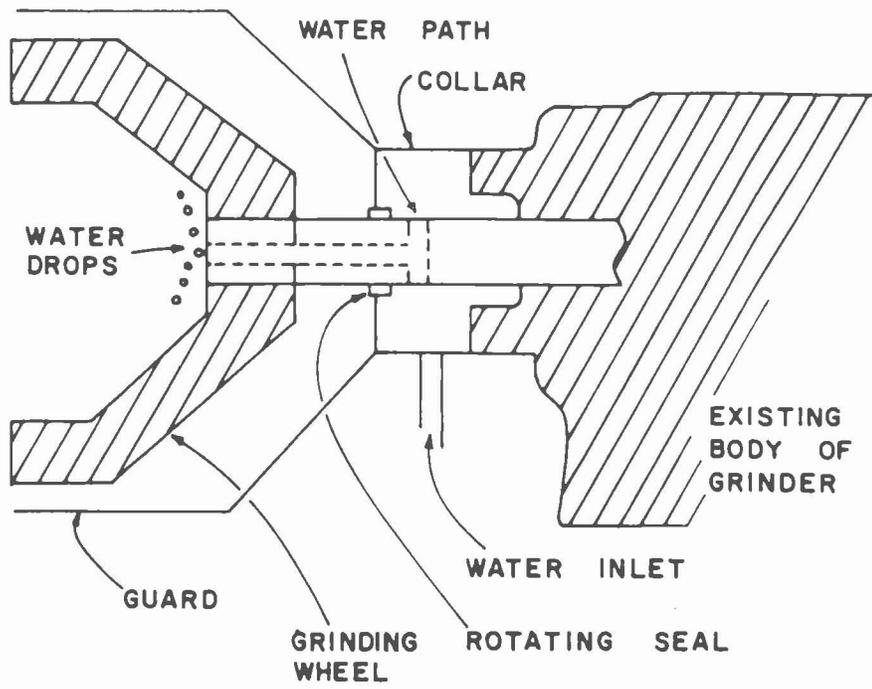


Figure 1. Modification of typical hand cup grinder to provide for dust control by water addition.



Figure 2. Dust controlled cup grinder in operation.

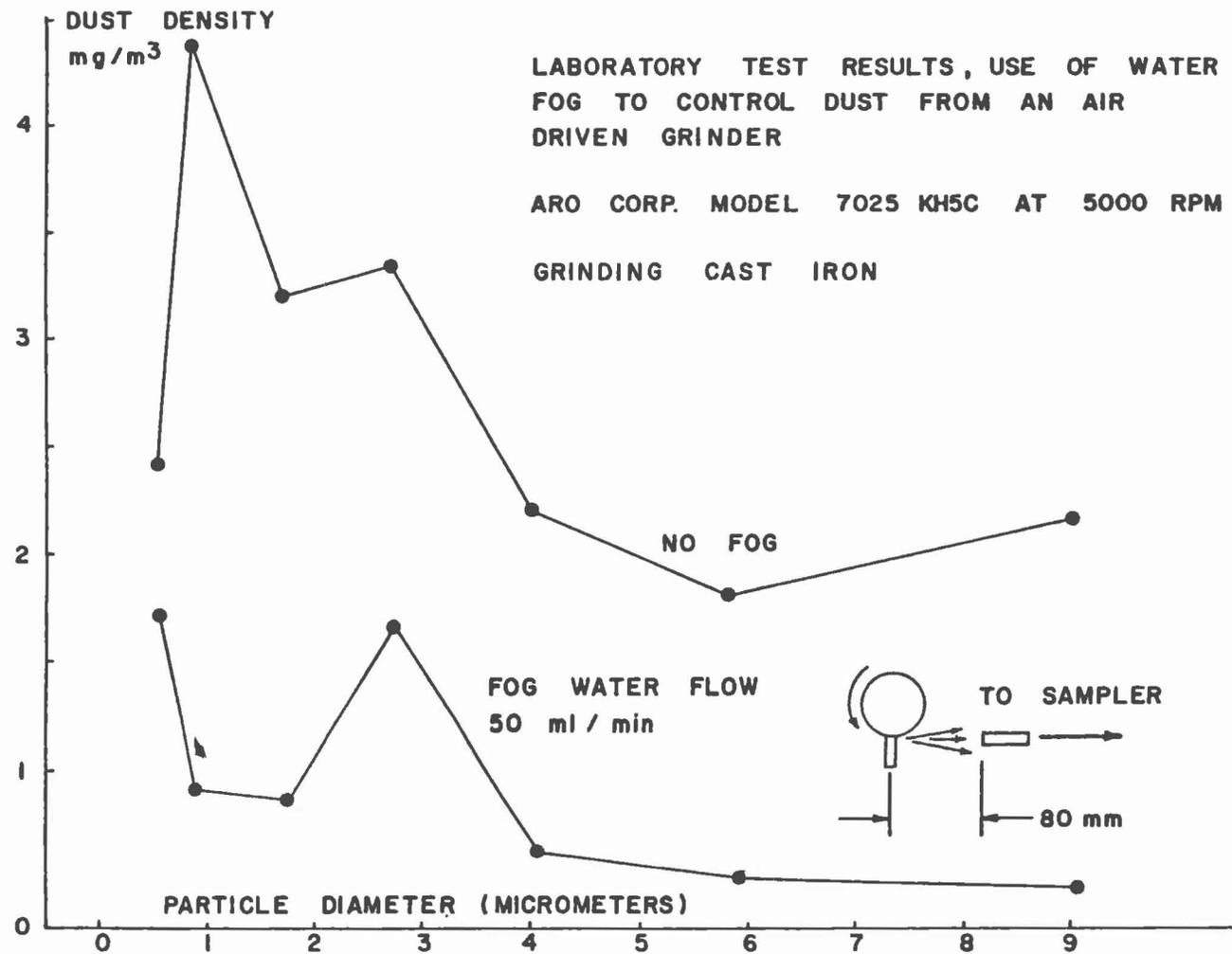


Figure 3. Reduction of dust from air driven hand grinder by water fog.

CONTROL OF SANDING DUST BY MEANS OF WATER FOG
ARO CORP. UNIT WITH SANDING DISC ON CAST IRON
WATER FLOW 35 ml / min

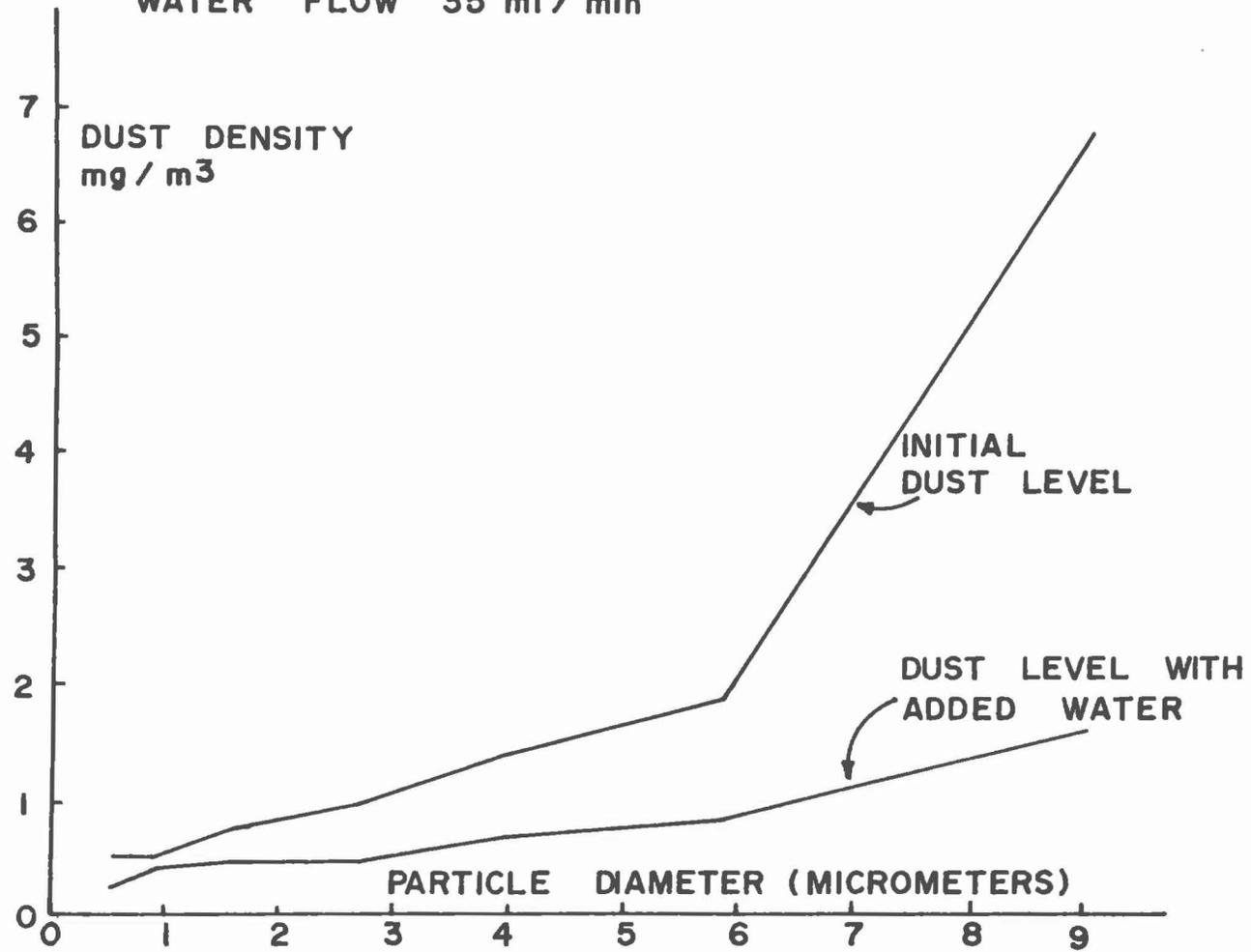


Figure 4. Reduction of dust from air driven hand sander by water fog.

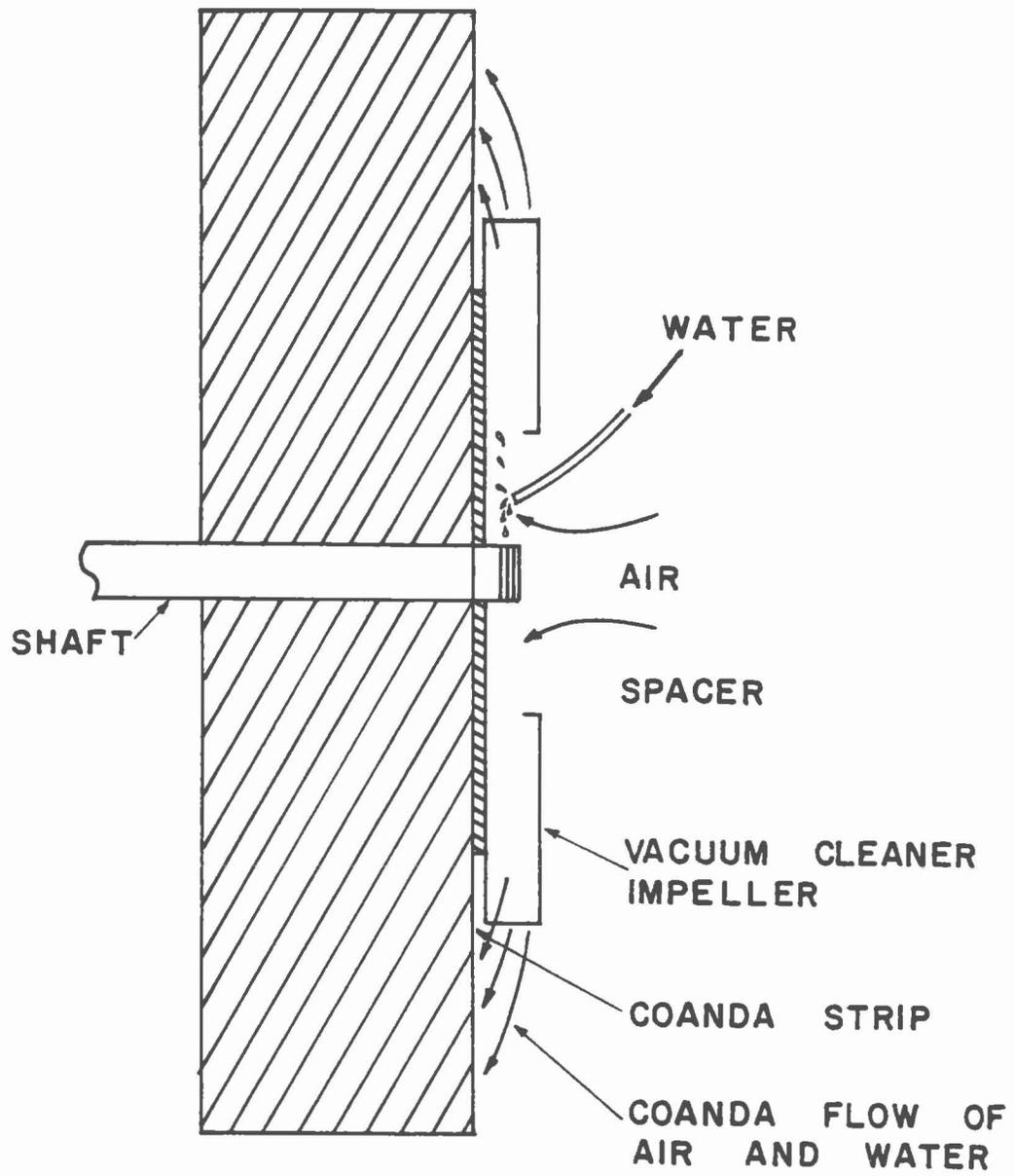


Figure 5. Schematic drawing of dust control system for large grinding wheel.

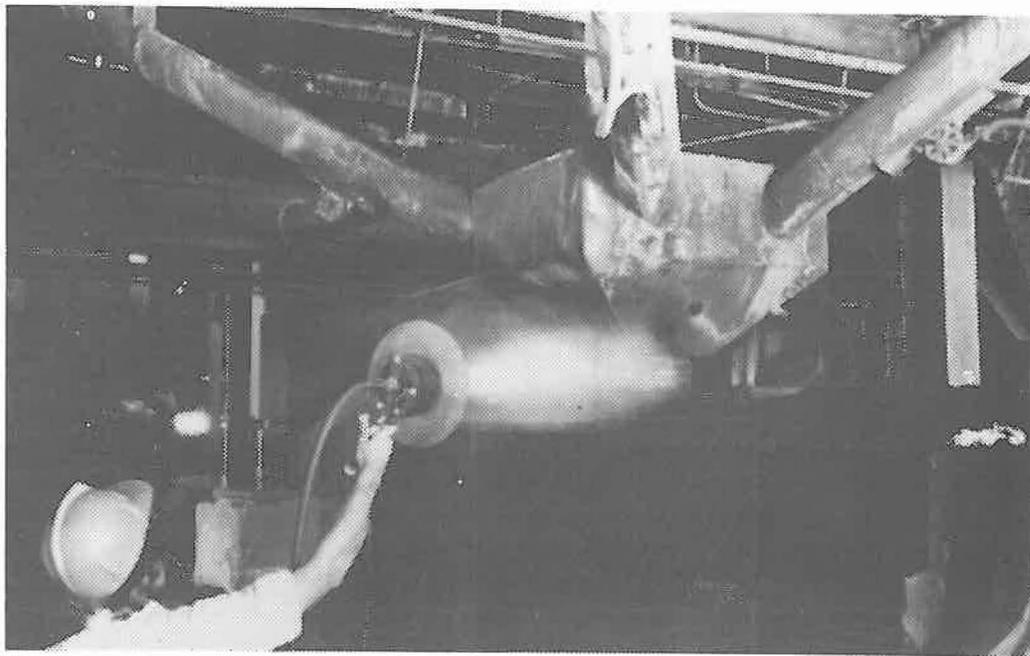
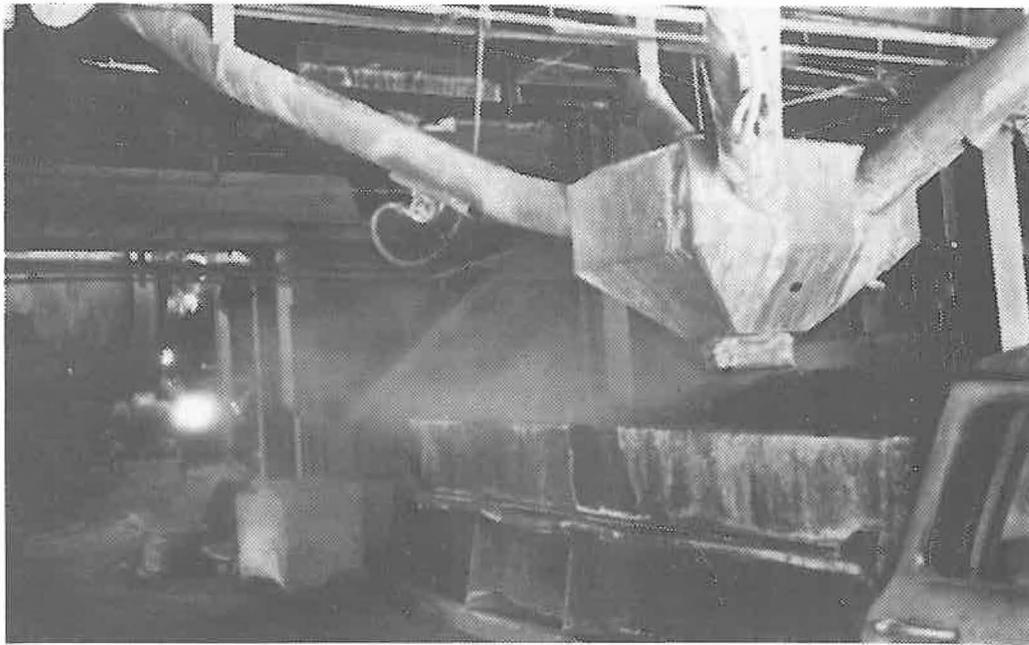


Figure 6. Control of hopper dumping with charged fog.

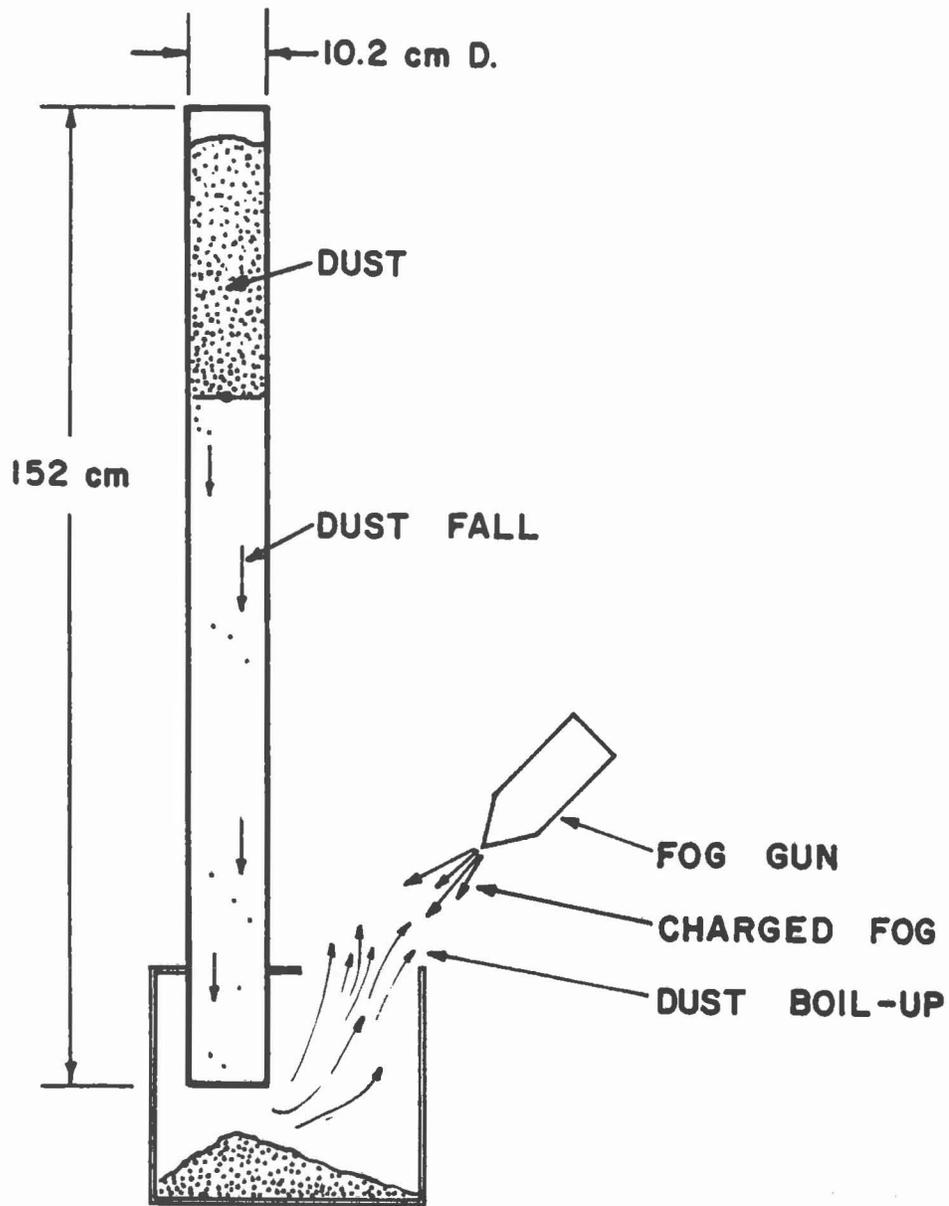


Figure 7. Application of charged fog to the control of dust boil-up.

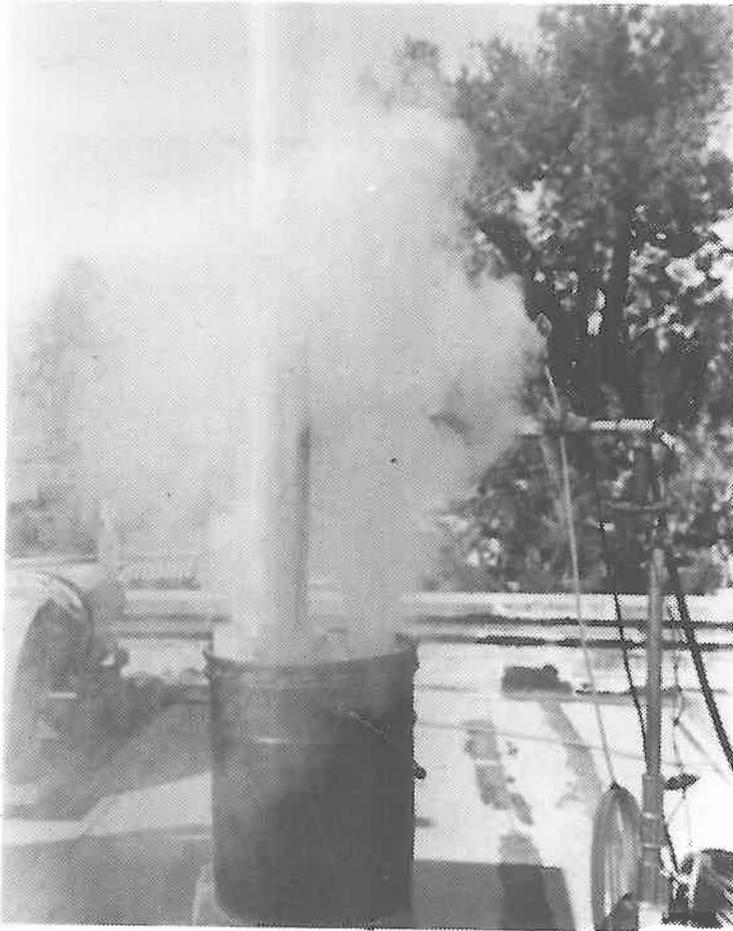


Figure 8. Dust boil-up during the free fall of dust into an open container (uncontrolled).

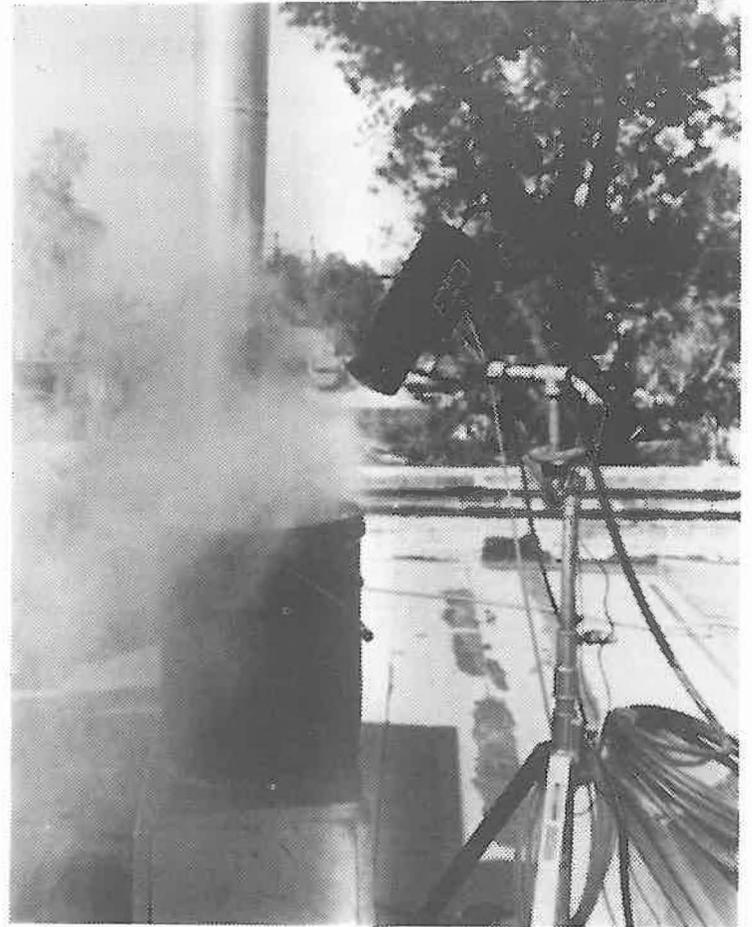


Figure 9. Significant amount of suppression of dust boil-up when the fogger is turned on during the free fall of dust into an open container.

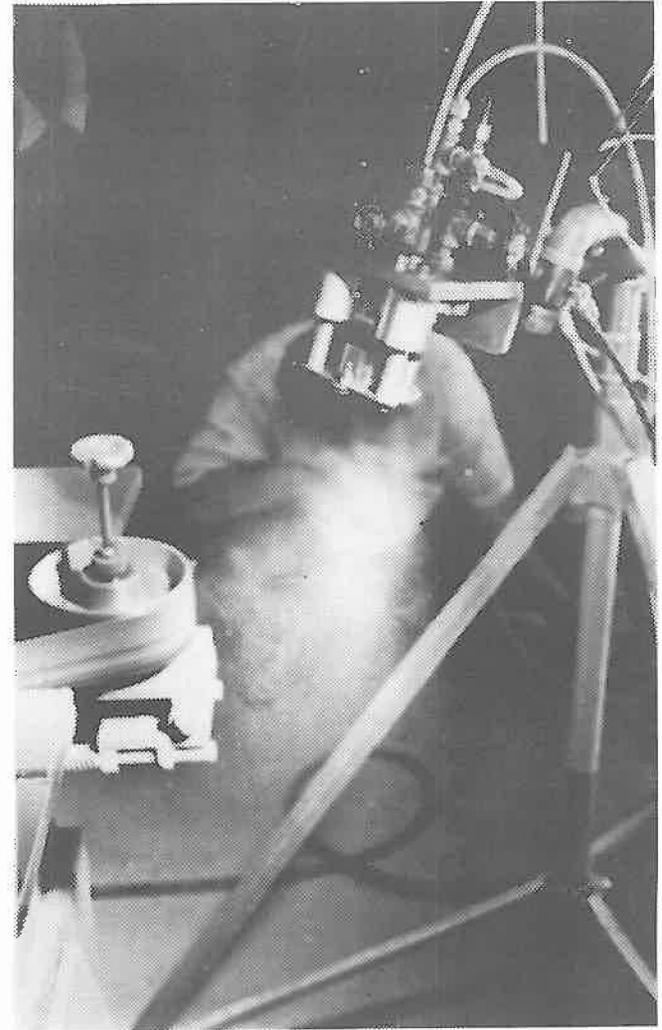
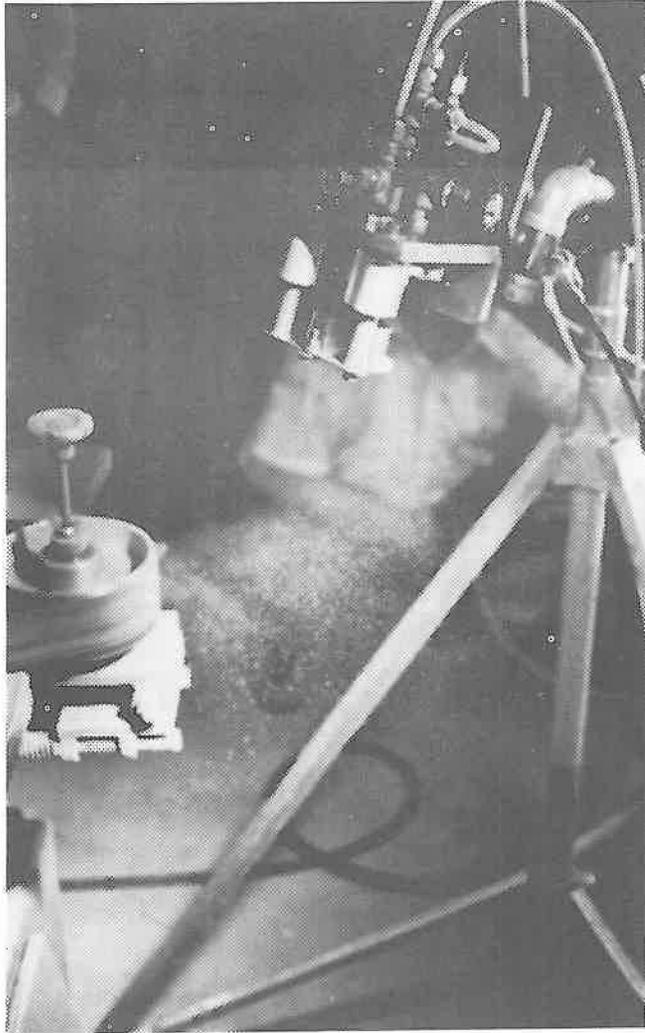


Figure 10. Photographs with (right) and without (left) fog being applied to a sander.

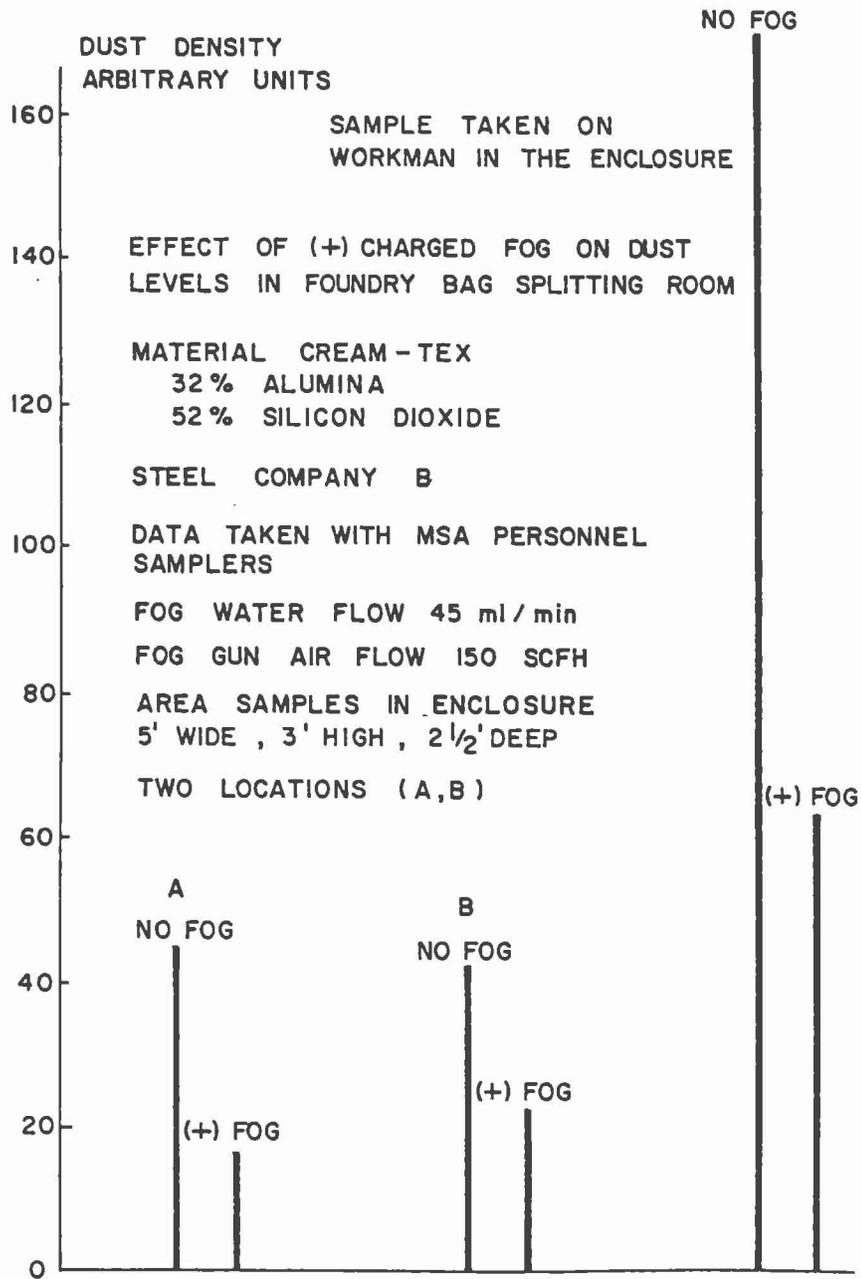


Figure 11. Bag splitting room dust density with and without charged fog.

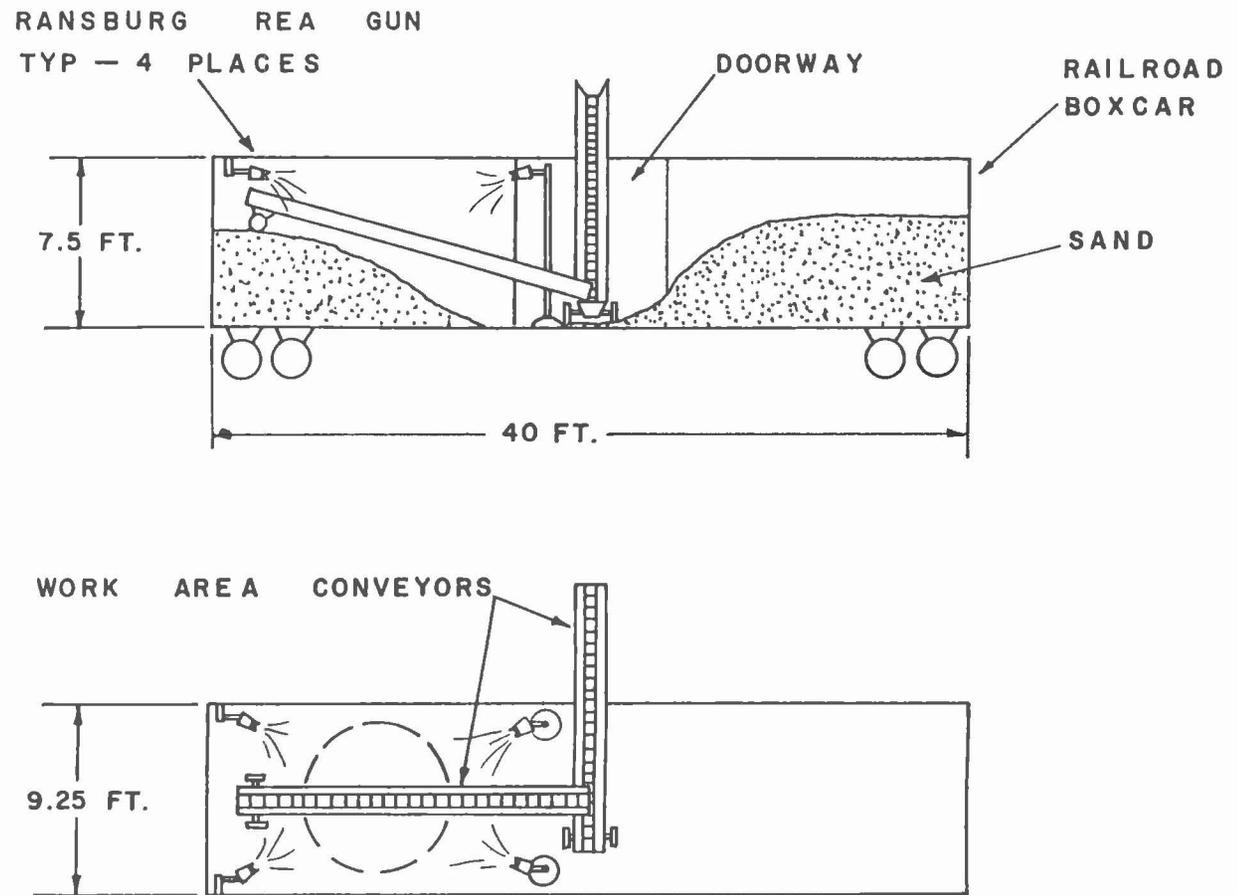


Figure 12. Placement of fogging nozzles in railroad sand car unloading operation. Upper sketch is elevation view; lower sketch is plan view.

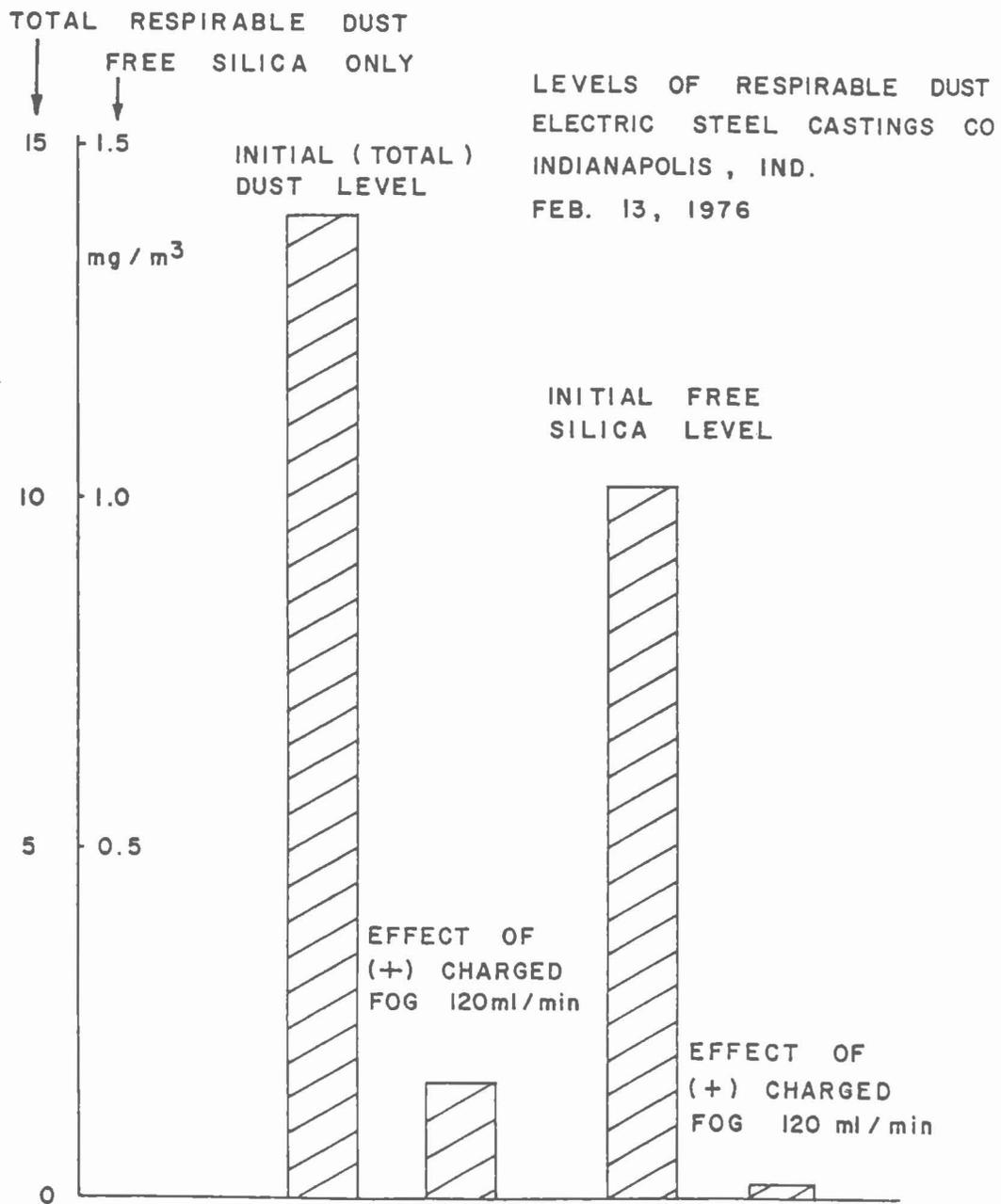


Figure 13. Reduction of dust during a railroad sand car unloading operation.

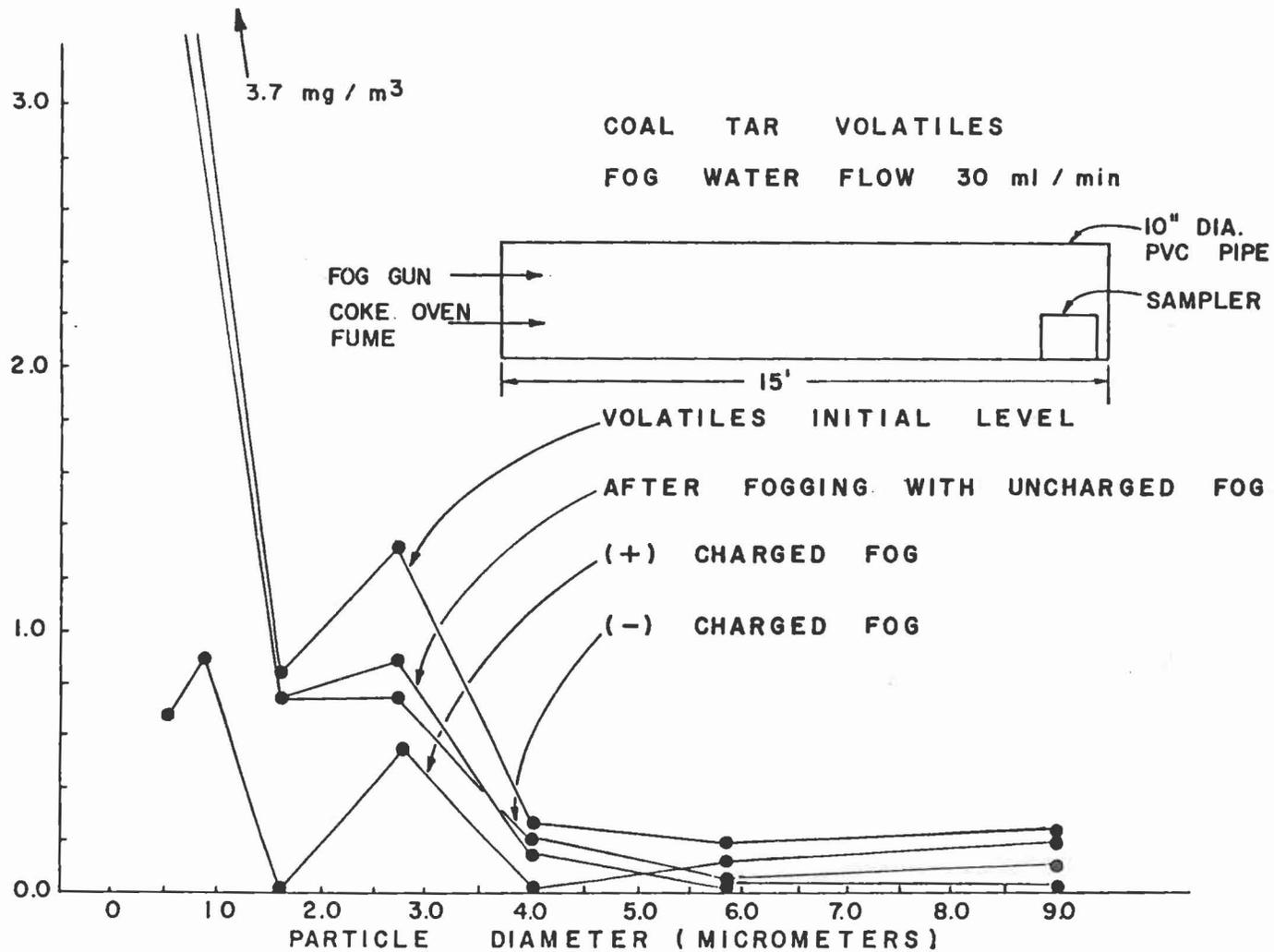


Figure 14. Coal tar volatile concentration versus particle size with and without fogging.

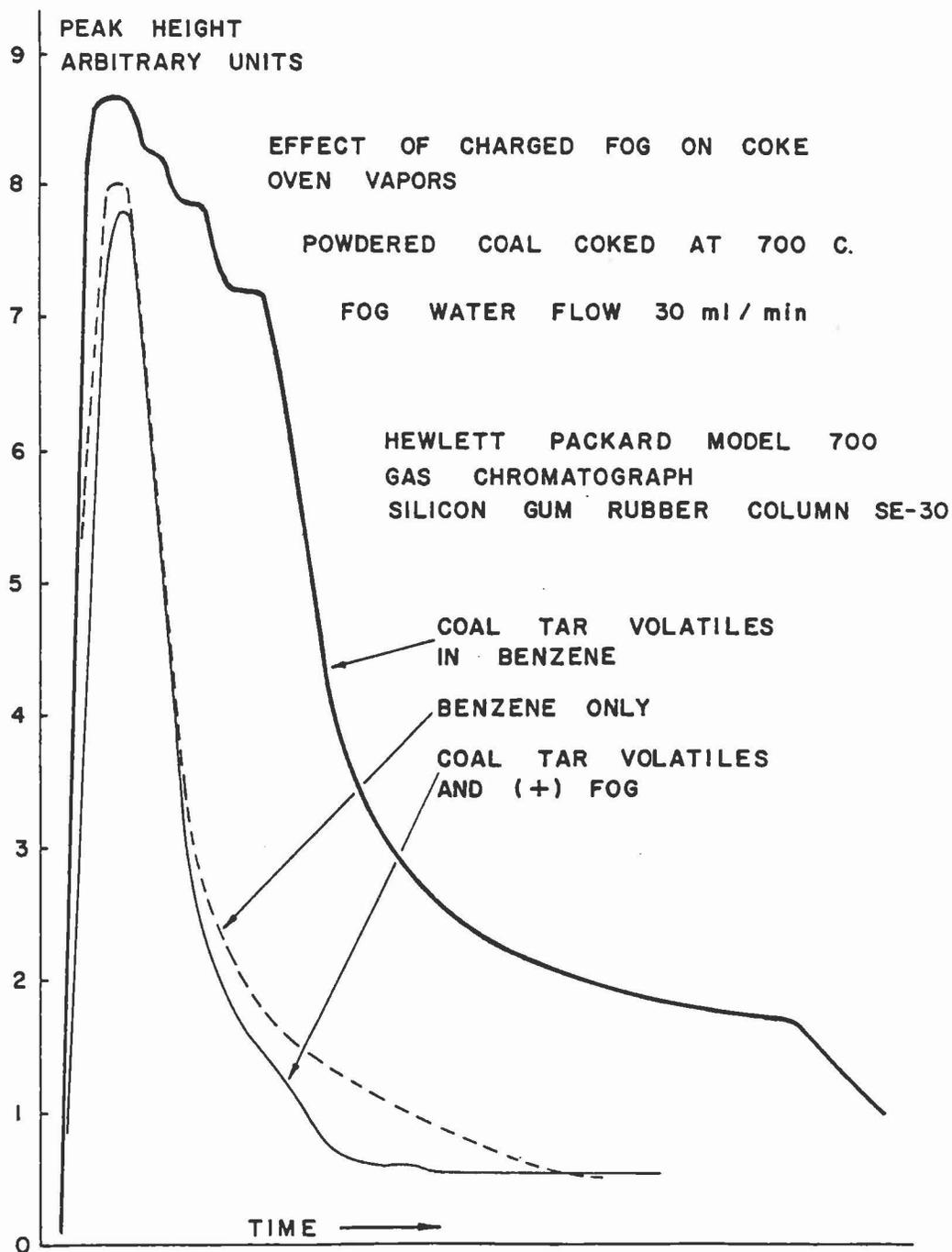


Figure 15. Effect of charged fog on coke oven emissions.

LABORATORY EXPERIMENTS CONTROL OF DIESEL EXHAUST PARTICULATES BY MEANS OF ELECTROSTATIC TECHNIQUES , AIRFLOW VELOCITY 200 FPM (60.8 m/min), CORONA VOLTAGE - 20,000 V.

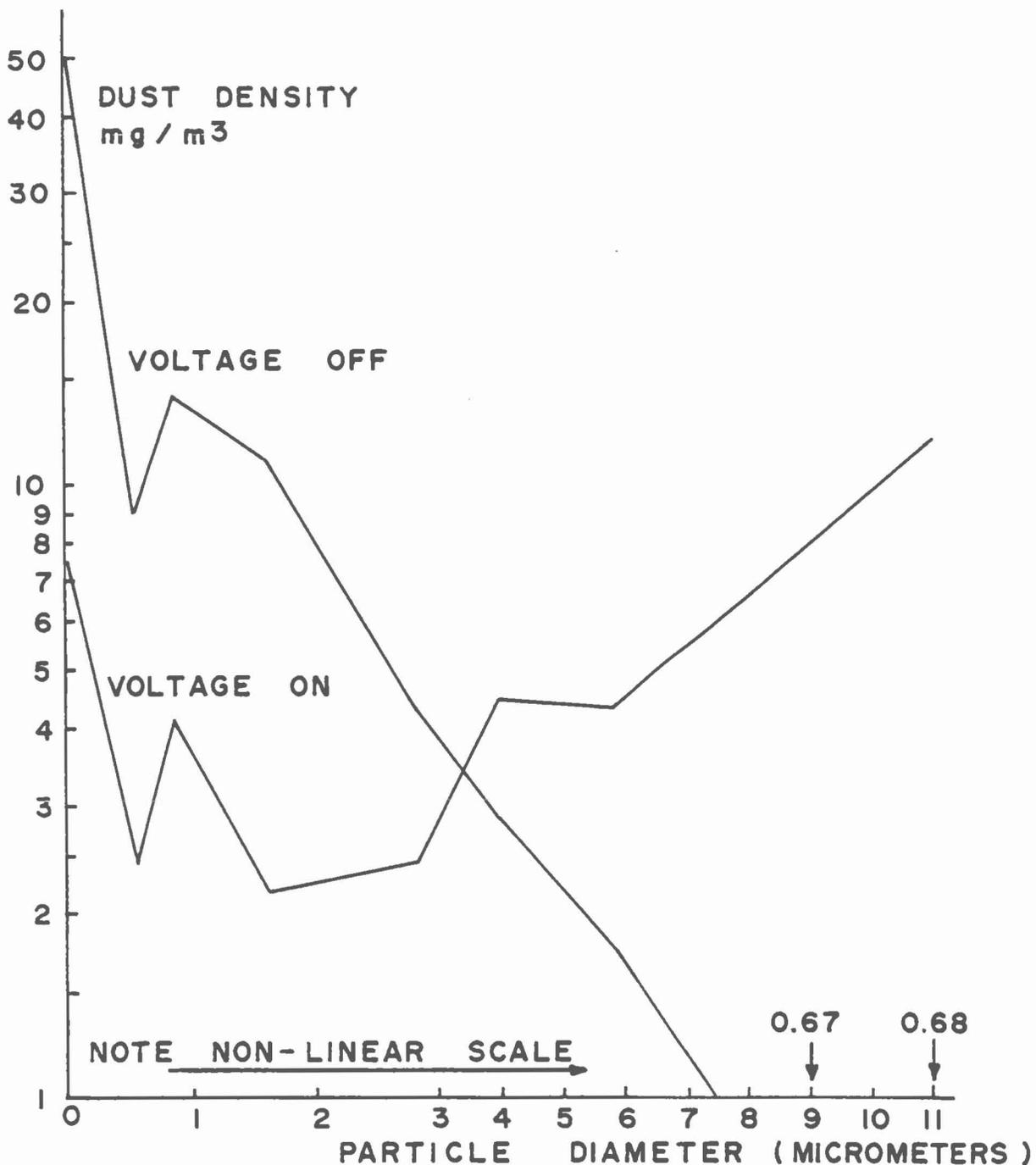
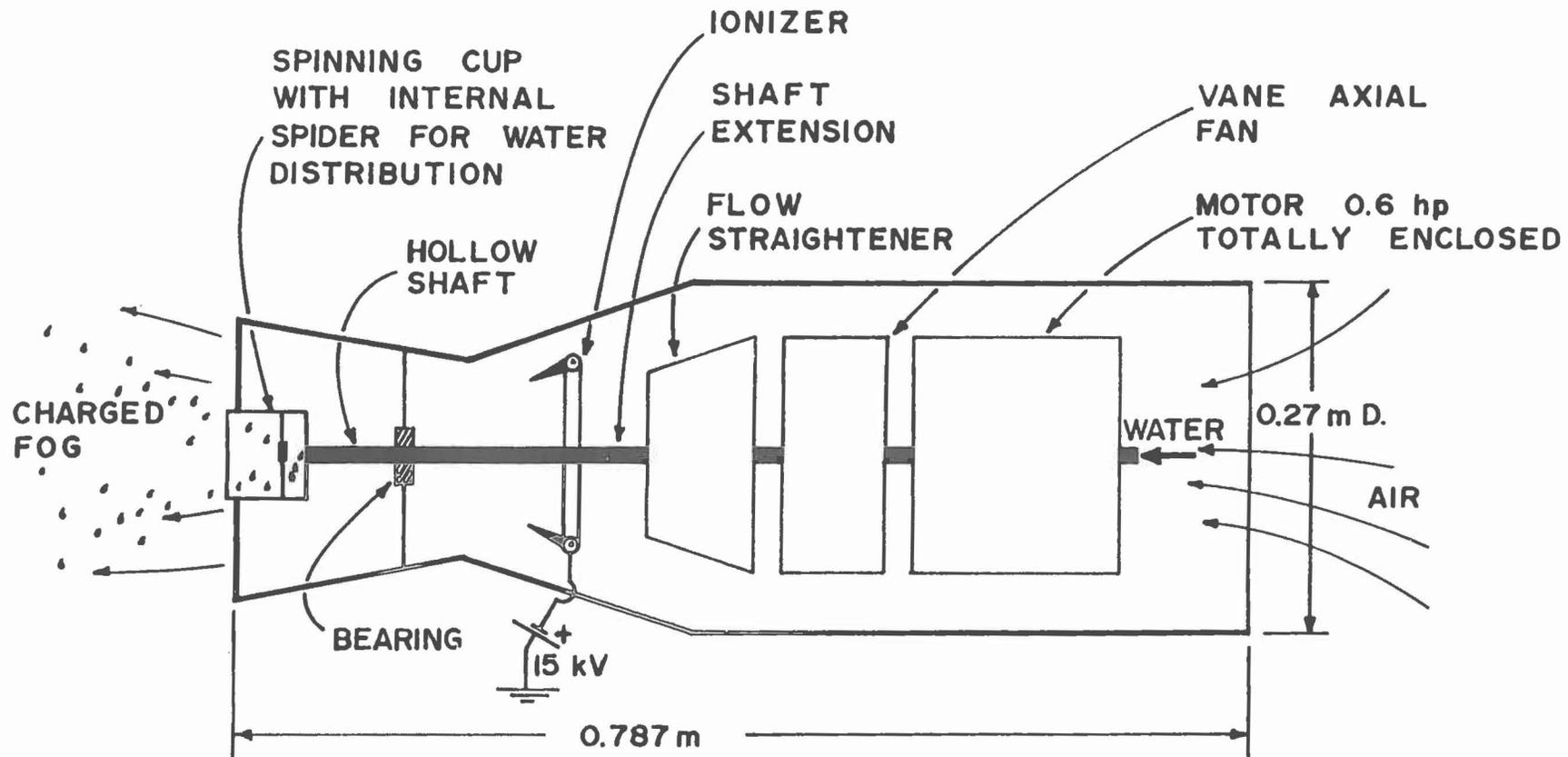


Figure 16. Control of diesel particulate through electrostatic techniques.

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COPPUS ENGINEERING CO. WORCESTER, MA.
MODEL 175 B 2549 m³ / hr

SCHMATIC DRAWING SPINNING CUP FOG THROWER
SCALE 1/4

Figure 17. New spinning cup fog generator.



Figure 18. Electrostatic fog being produced by new spinning c-p fog generator.

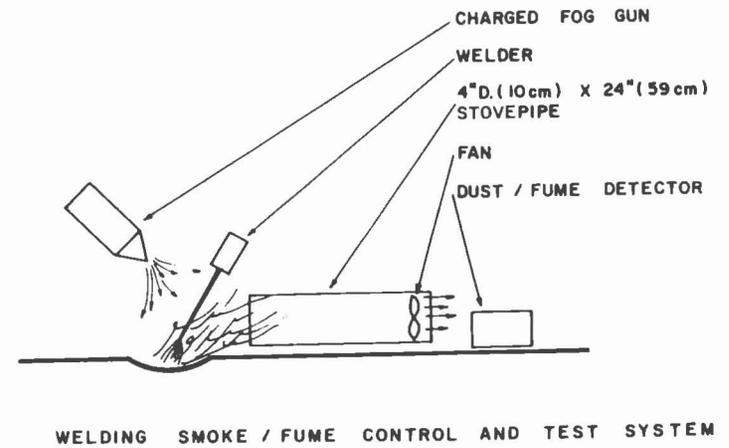


Figure 19. Schematic of experimental test apparatus for control of welding smoke and fume.

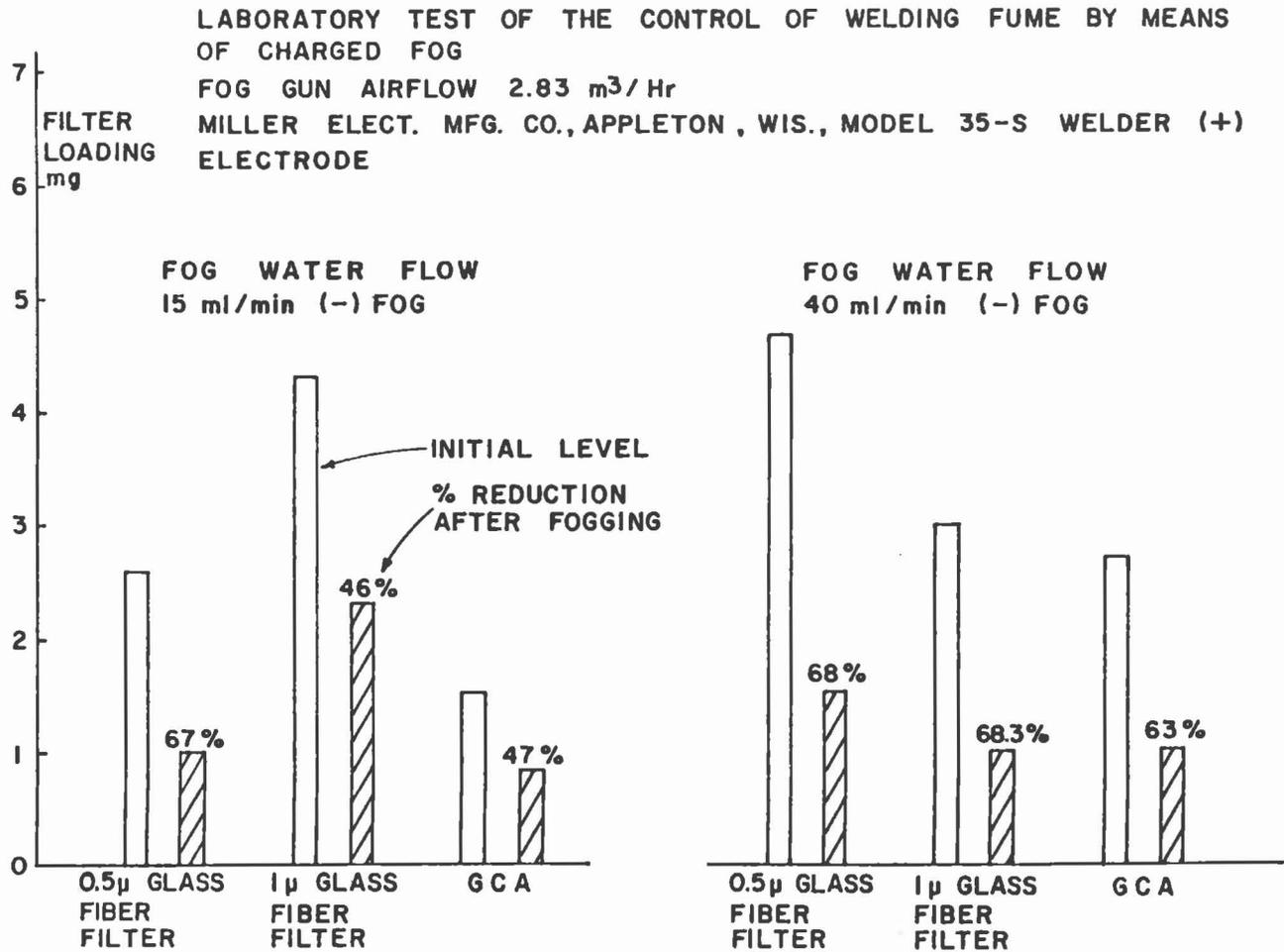


Figure 20. Reduction of welding fume with charged fog.

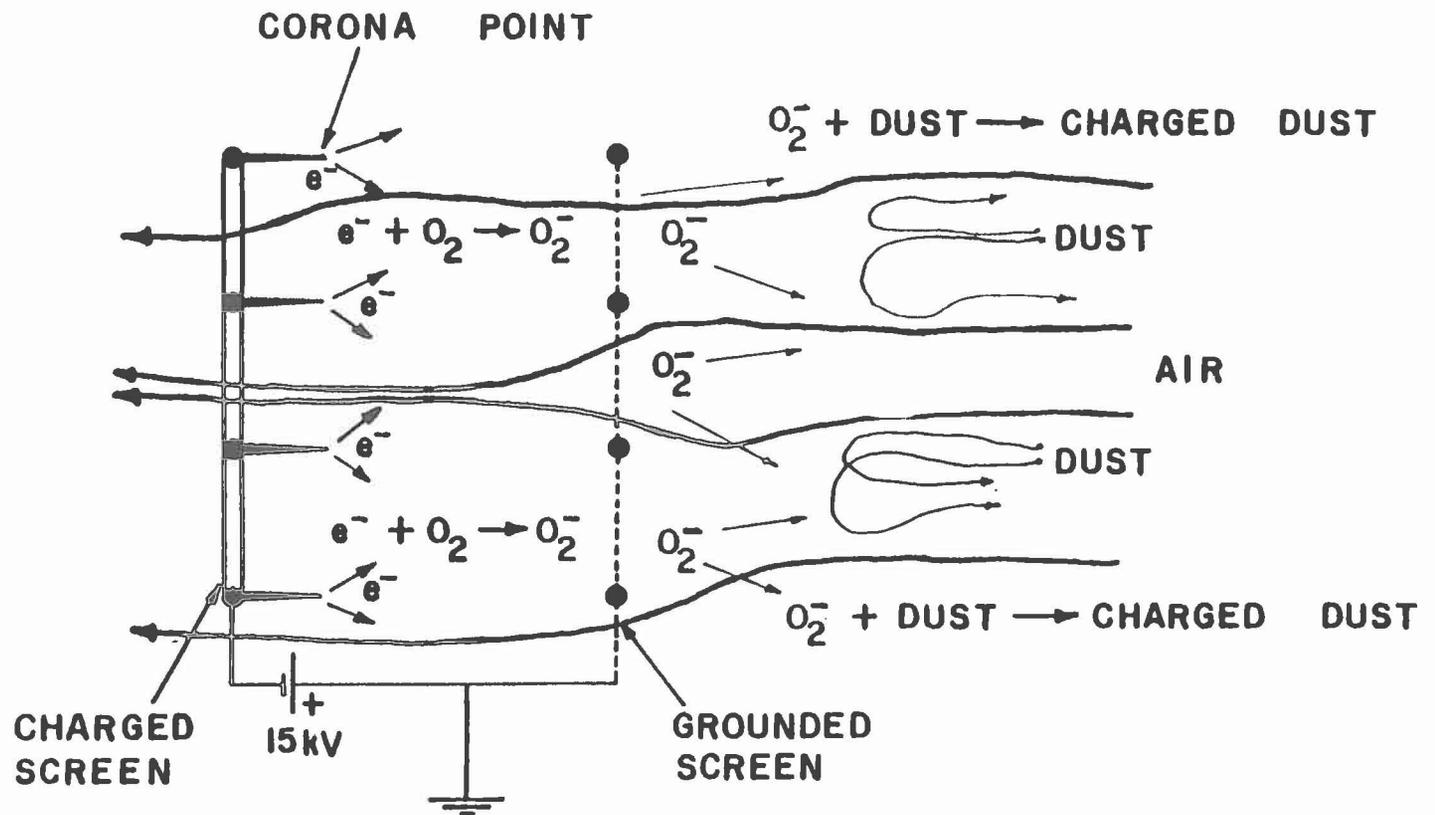


Figure 21. Schematic diagram of electrostatic fence to reject dust and admit air.

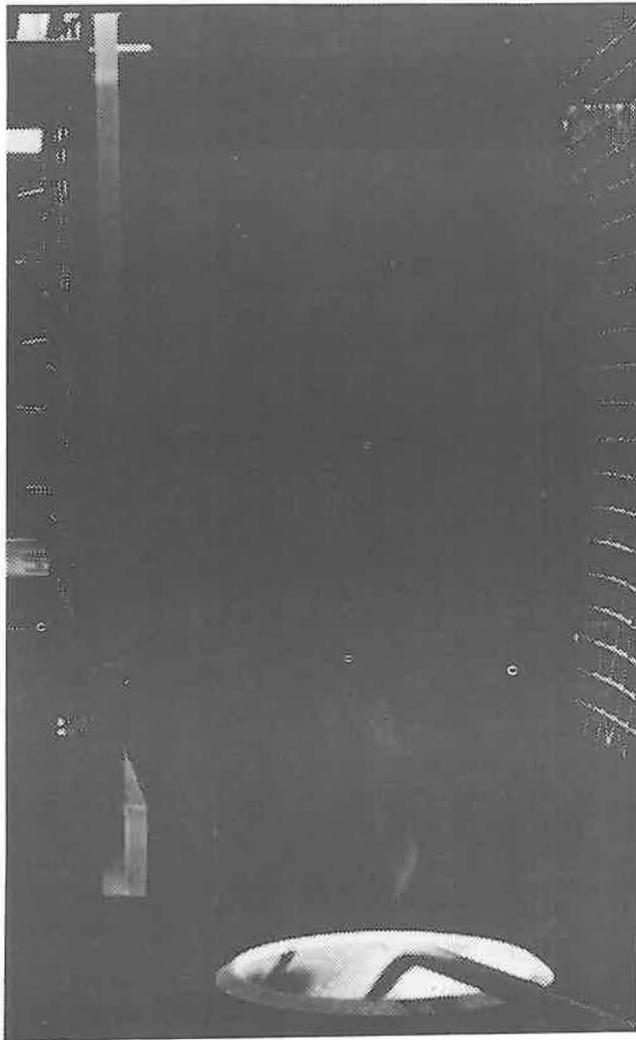


Figure 22. Pushing and collection of lead fume by the electrostatic fence.



Figure 23. Smoke generation of copper smelter converter.

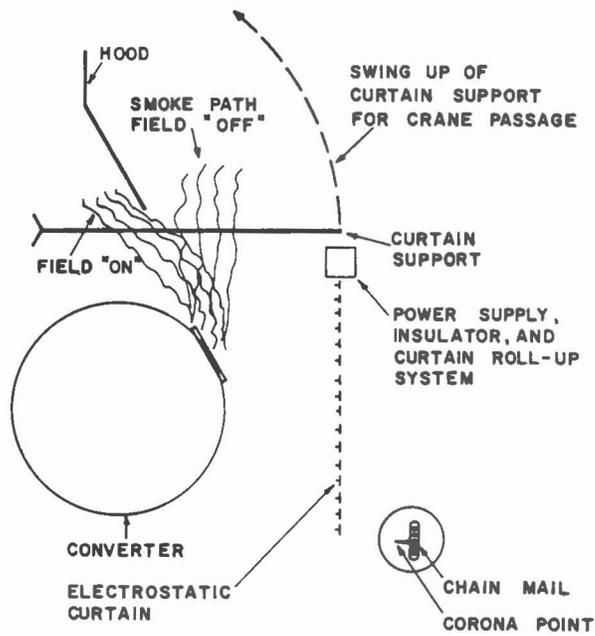


Figure 24. Electrostatic curtain system for copper smelter converter.

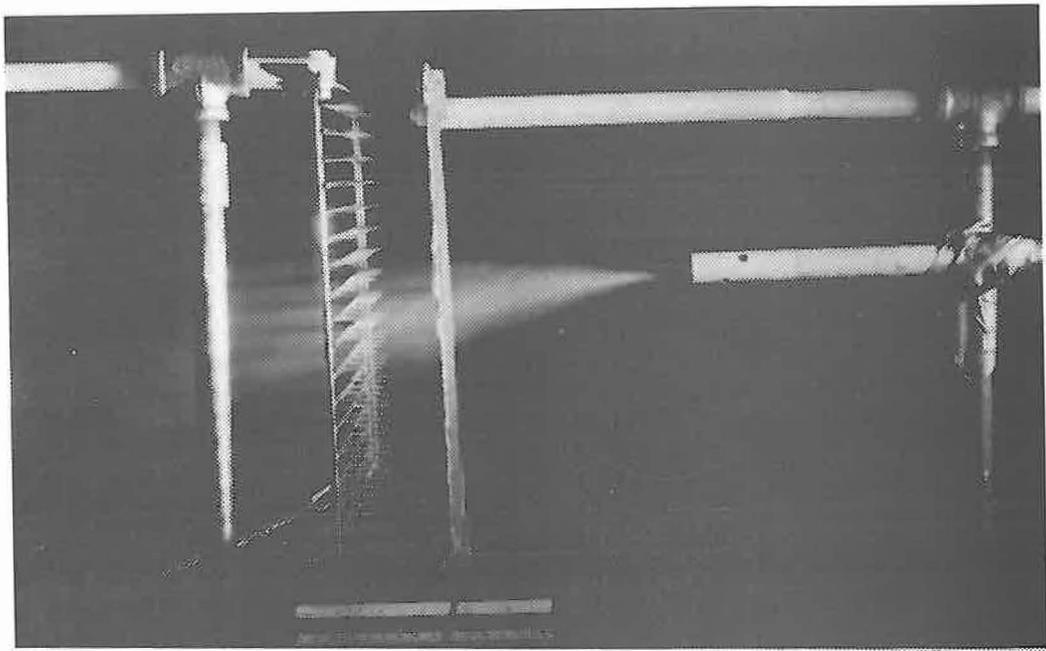
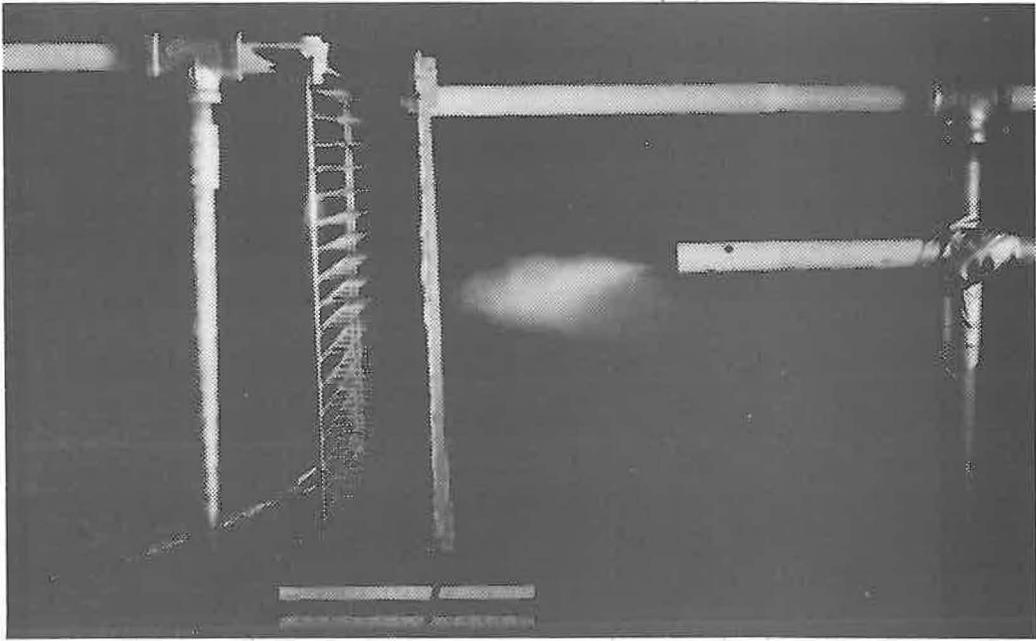


Figure 25. Electrostatic dust fence off (upper) and on (lower).

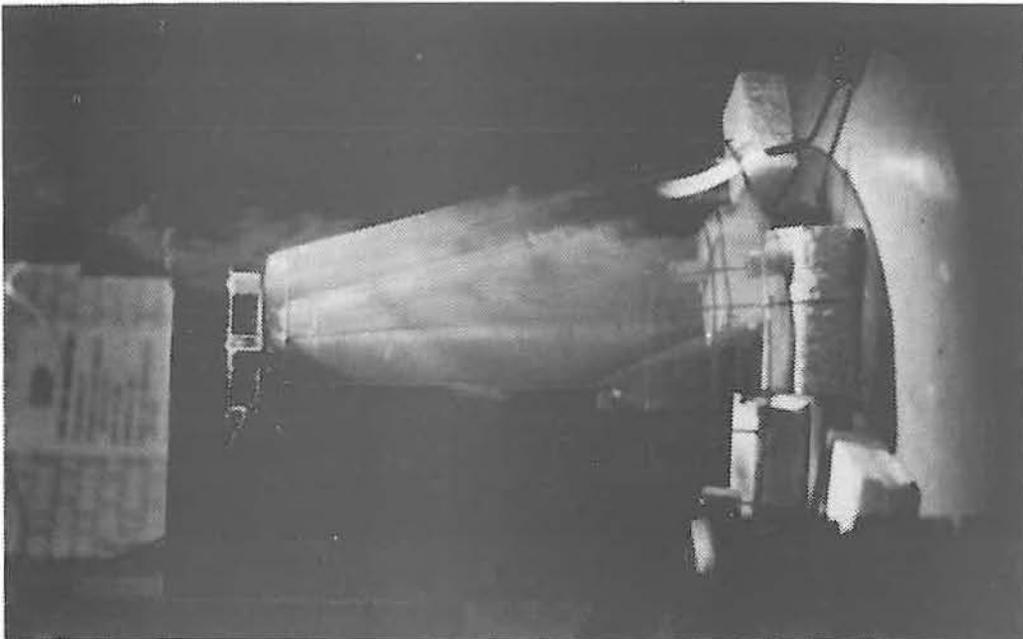
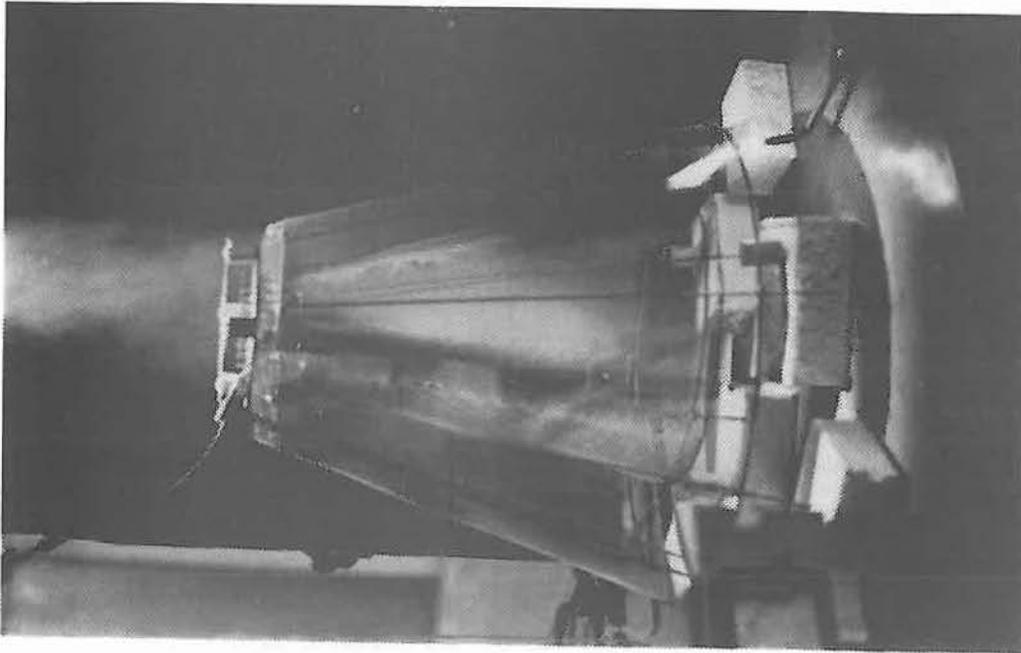


Figure 26. Electrostatic hood off (right) and on (left).

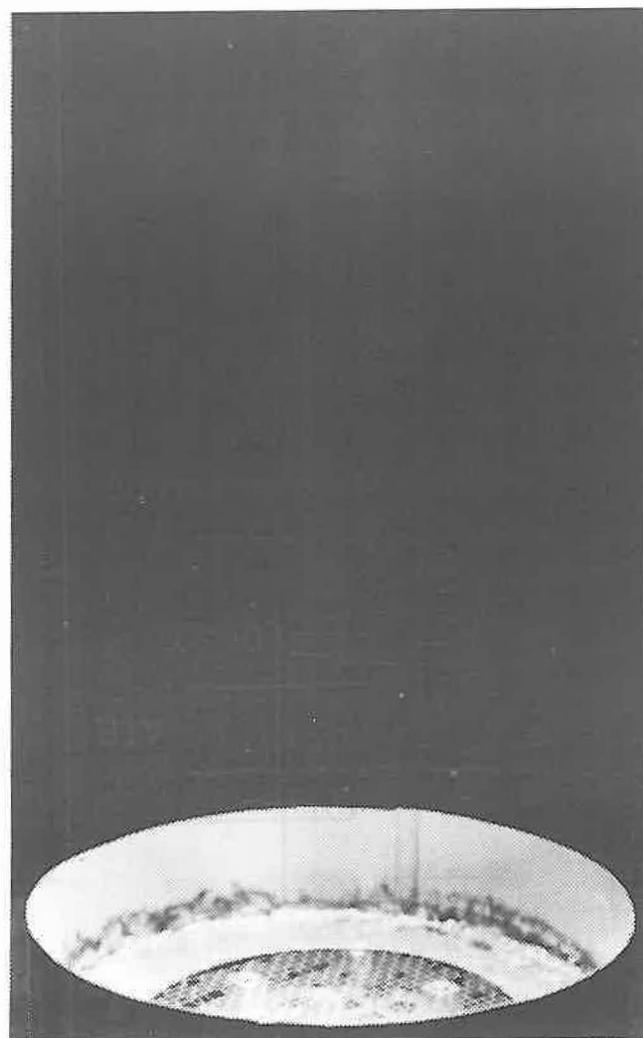
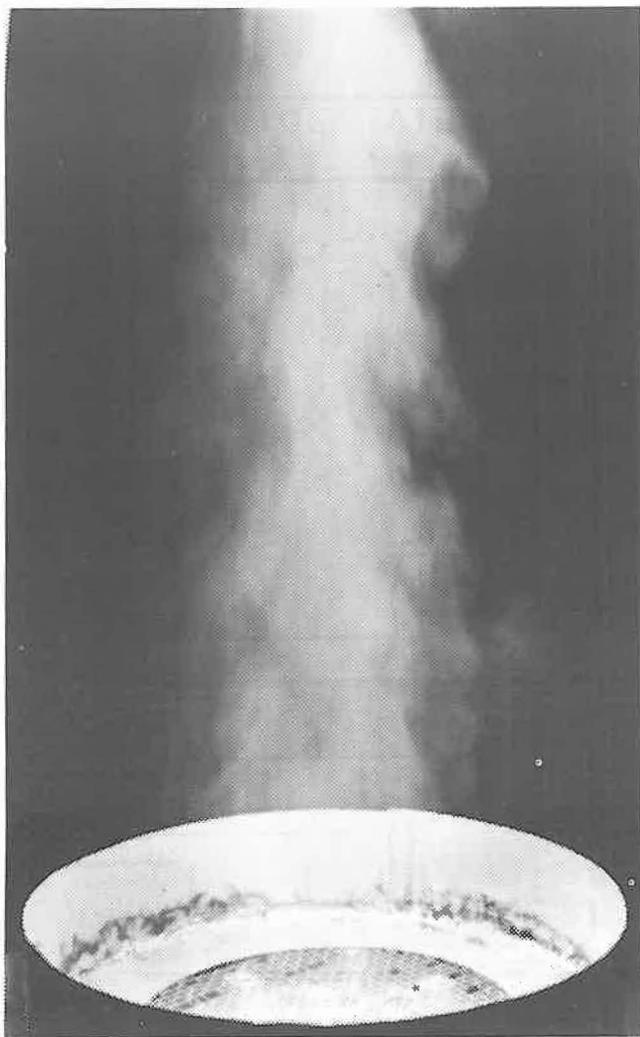


Figure 27. Electrostatic vapor collector off (left) and on (right)

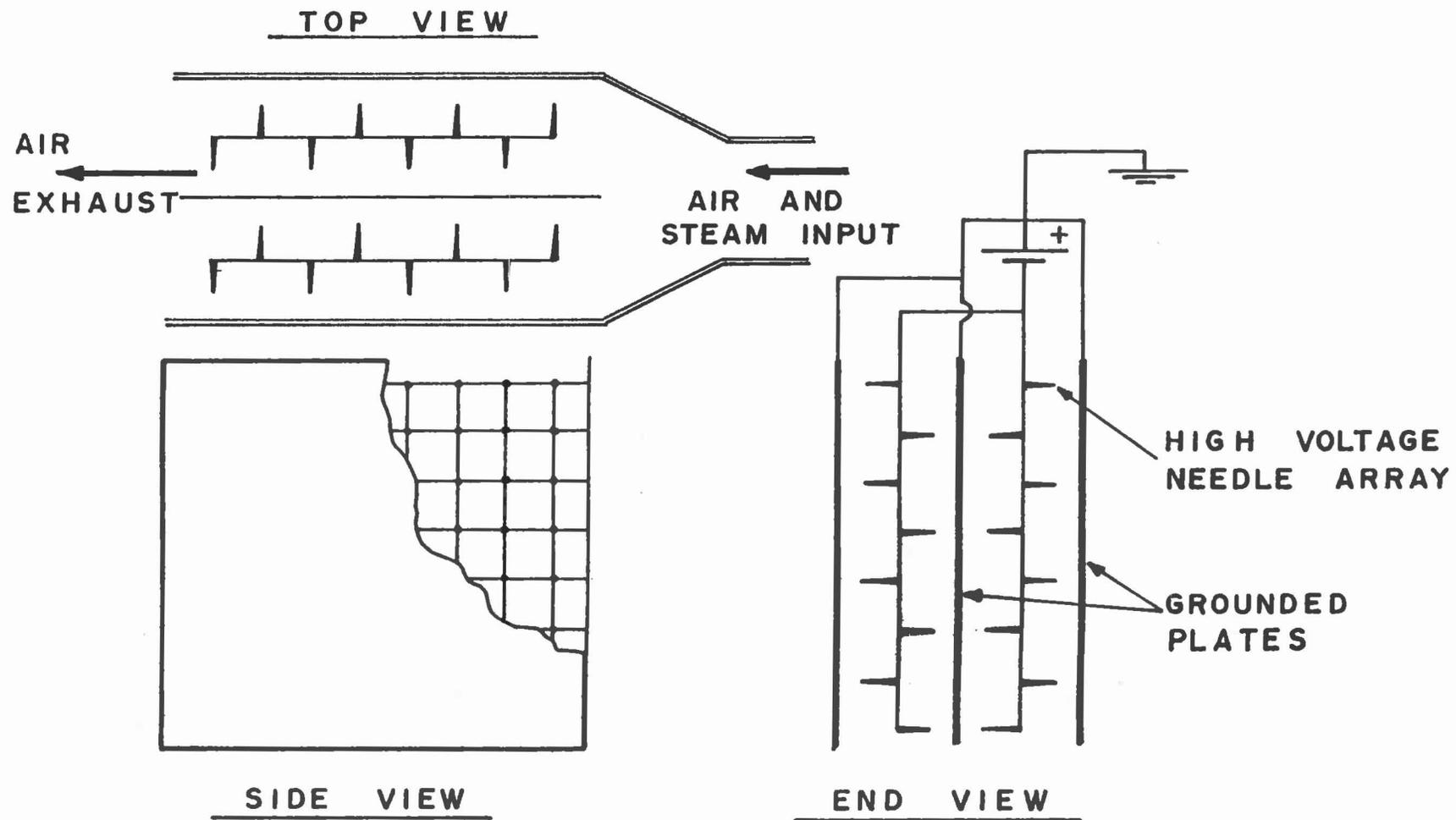


Figure 28. Schematic drawing of electrostatic demister system.

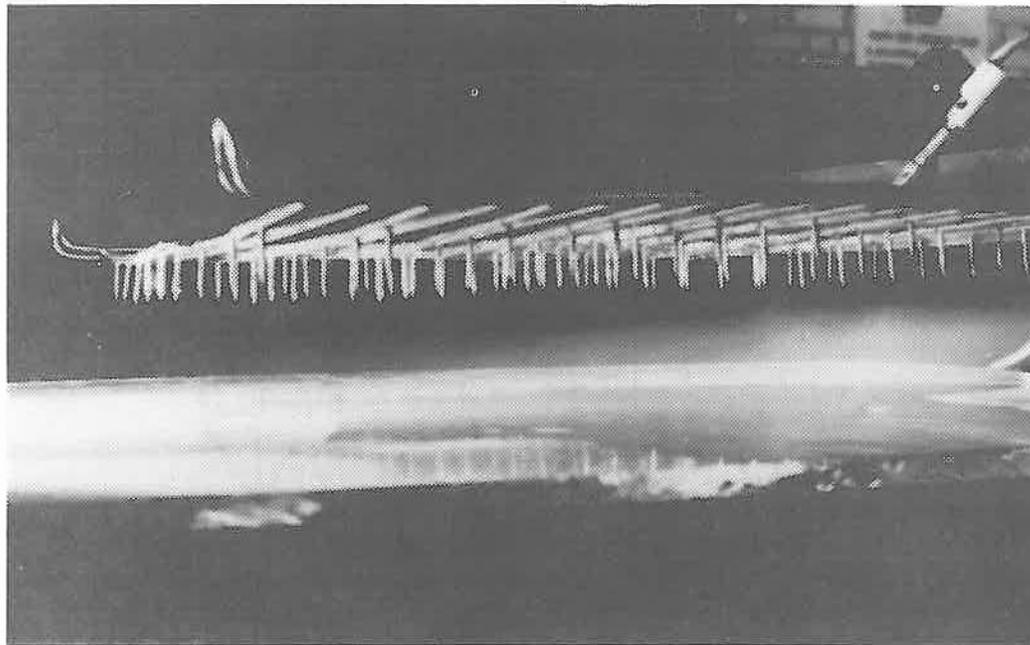
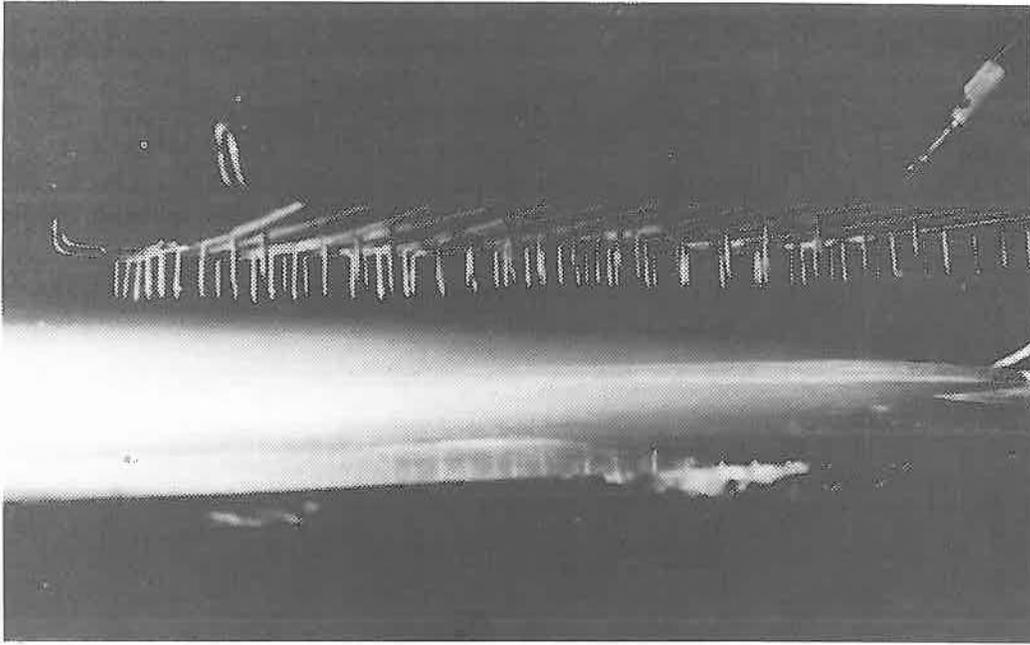


Figure 29. Electrostatic demister system off (upper) and on (lower).

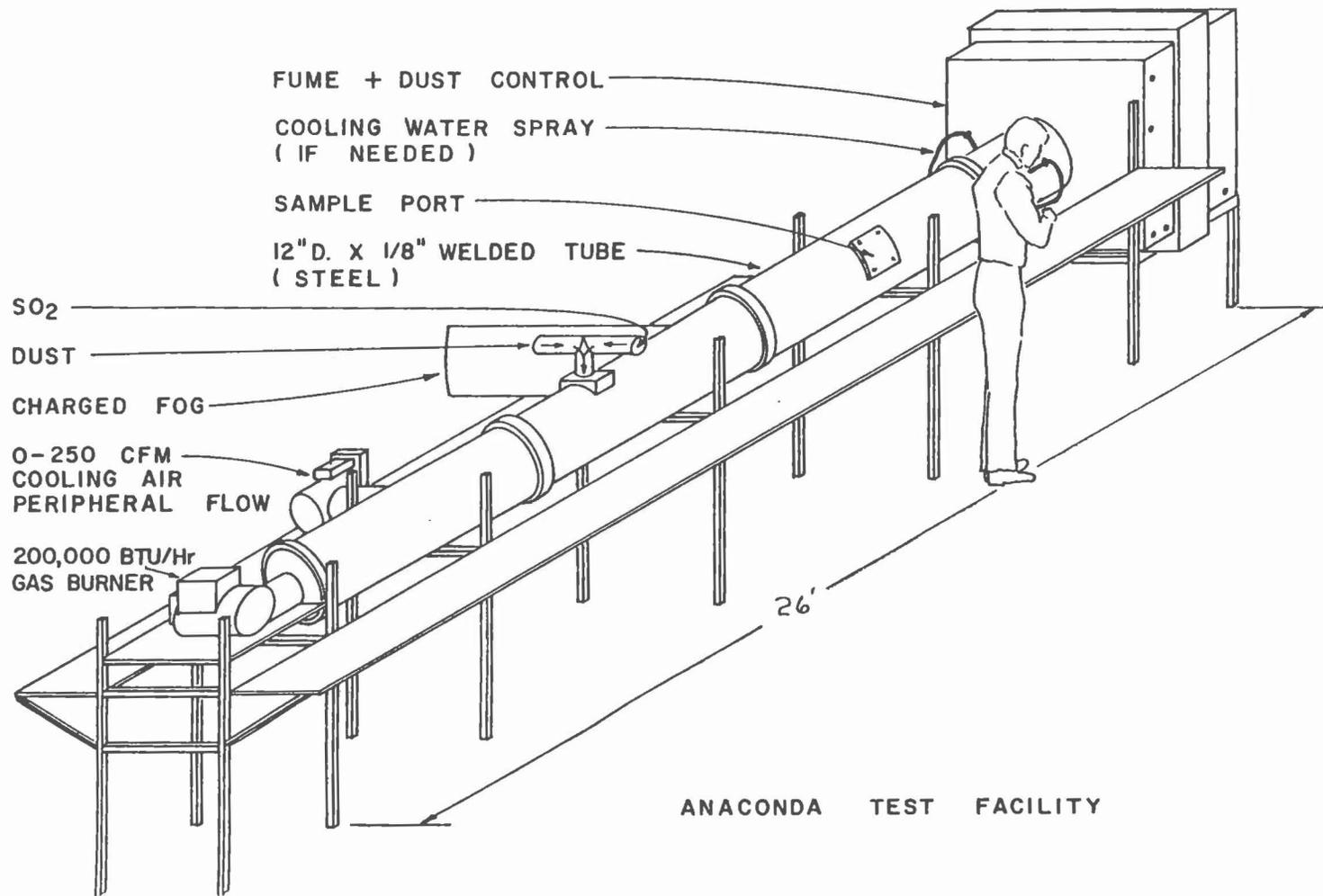


Figure 30. Anaconda stack simulator apparatus.

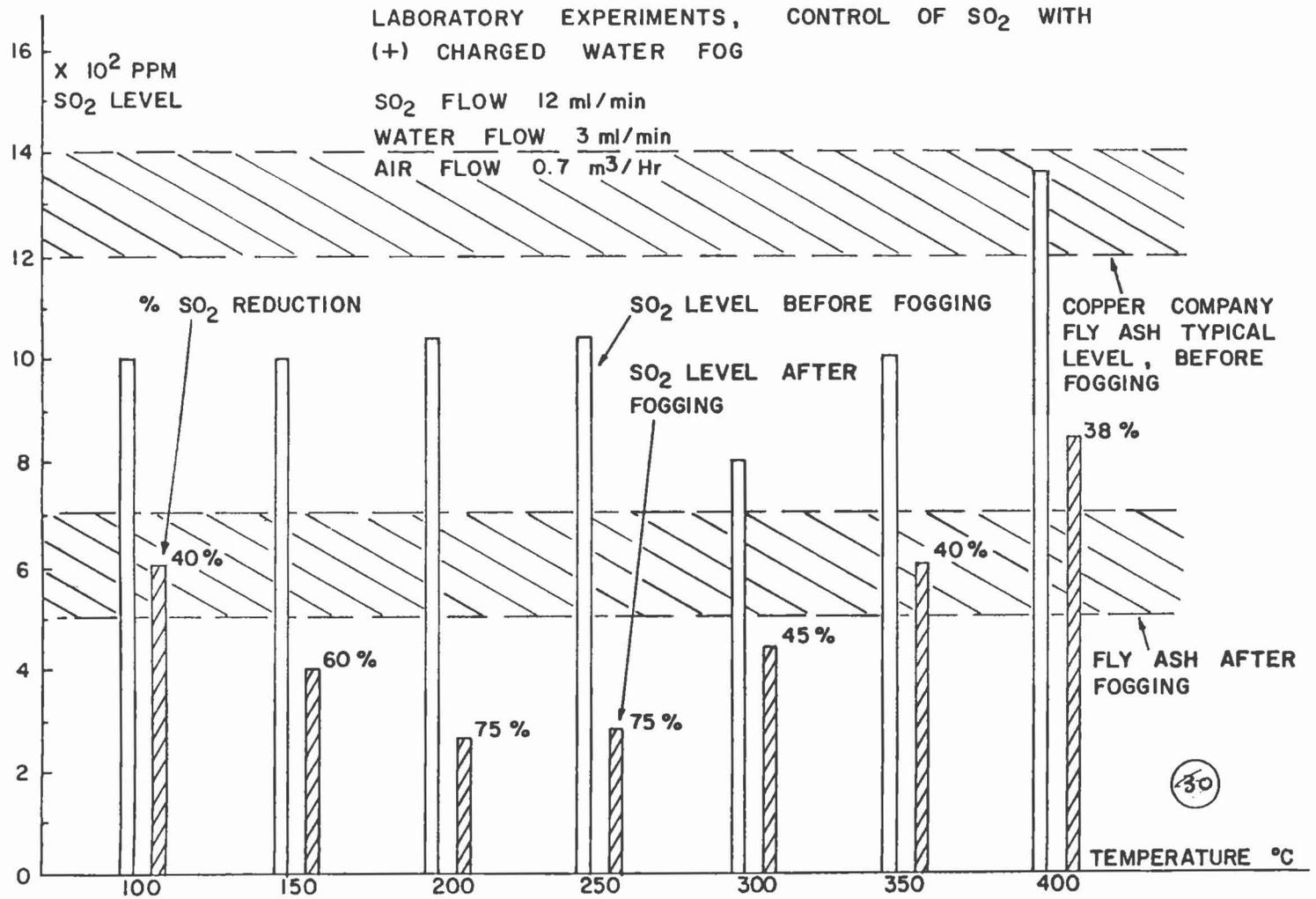


Figure 31. Control of SO₂ and fly ash with charged water fog.

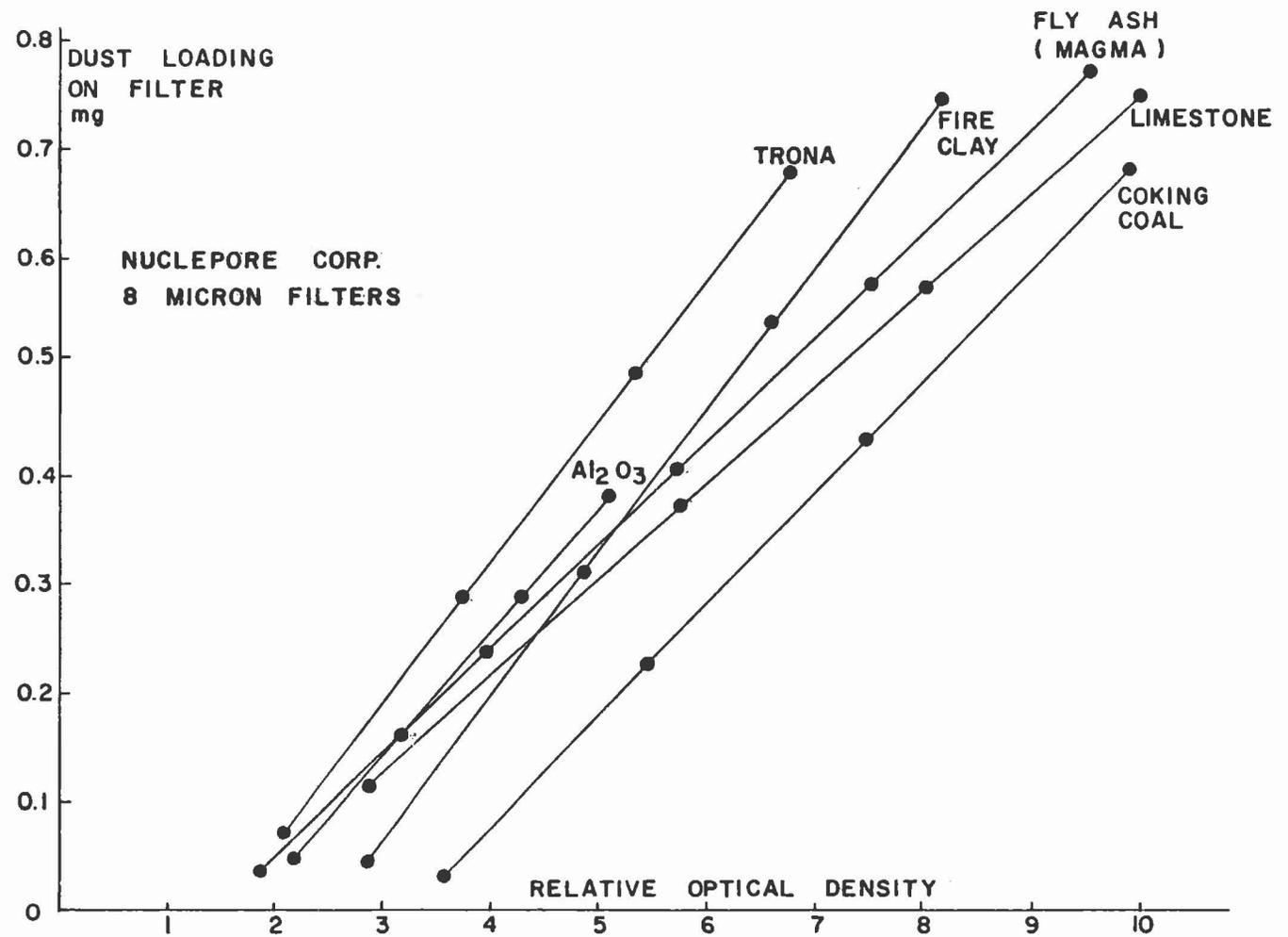


Figure 32. Calibration curve for converting optical data to actual dust loading, assorted dust materials.



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