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Slurry Spray Distribution Within A Simulated Laboratory Scale Spray Dryer

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Bachelor of Science in Chemical Engineering

by

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On my honor I pledge that this work is my own.

Peter C. Bertone

Approved ______________________ (Technical Advisor)

______________________ (Humanities Advisor)

DISCLAIMER

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PREFACE

I would like to thank Gerald Woolsey whose boundless enthusiasm and continual inspiration was surpassed only by that of my family.

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NOMENCLATURE

Symbol	Definition	Units
R_e	$\frac{D u_b p}{u}$	dimensionless
	where D is a characteristic diameter, u is a characteristic viscosity, p is a characteristic density, and u_b is a characteristic velocity.	
V_1	Volume of Liquid Striking the Test Surface.	ml/ft^2
M_d	Mass of Solid Striking Collector.	g/ft^2
C	Concentration of Dissolved Solid.	gmol/ml
M	Molecular Weight of Solid.	g/gmole
V_{1C}	Volume of Liquid Striking the Test Surface Corrected to 55ml of Feed.	ml
F	Volume of the Liquid Feed.	ml

ABSTRACT

The Savannah River Plant has generated millions of gallons of radioactive liquid waste in support of the nations defense. The Savannah River Laboratory is developing technology that could be used to solidify this waste. The reference solidification process consists of spray drying and vitrification. By 1978, a dryer developed at Battelle's Pacific Northwest Laboratories (PNL) was judged superior, but initial tests indicated that feed was striking the walls of the dryer while still wet, which made the design less than acceptable. This investigation sought a correction.

It was found that the distribution of liquid striking the sides of a simulated room temperature spray dryer was not significantly altered by the choice of nozzles, nor by a variation in nozzle operating conditions. Instead, it was found to be a function of the spray dryer's configuration. A cocurrent flow of air down the drying cylinder, not possible with PNL's closed top, favorably altered the spray distribution by both decreasing the amount of liquid striking the interior of the cylinder from 72 to 26 percent of the feed supplied, and by shifting the zone of maximum impact from 1.0 to 1.7 feet from the nozzle.

These findings led to the redesign of the laboratory scale spray dryer to be tested at the Savannah River Plant. The diameter of the drying chamber was increased from 5 to 8 inches, and a cocurrent flow of air was established with a closed recycle.

Finally, this investigation suggested an unique drying scheme which offers all the advantages of spray drying without many of its limitations.

INTRODUCTION

Since its construction by the E. I. DuPont De Nemours Company in 1953, the Savannah River Plant, located near Aiken, South Carolina, has been producing special nuclear materials primarily for national defense purposes. The plant has been operated exclusively by the DuPont Company, first for the Atomic Energy Commission and currently for the Department of Energy. Its production facilities include a nuclear fuel fabrication plant, three nuclear reactors, two fuel reprocessing plants, and a heavy water generating plant.[1]

In twenty-six years of operation, the Savannah River Plant has generated millions of gallons of highly radioactive liquid waste, which is stored in large underground tanks as an alkaline solution with a precipitated sludge layer.[2] In 1971, the Division of Waste Management and Transportation was created within the Atomic Energy Commission and was charged with evaluating methods of storing radioactive waste produced at the Savannah River Plant, as well as proposed commercial nuclear reprocessing plants.[3]

A reference process to solidify the Savannah River Plant's high level liquid waste was developed in 1977, after numerous drying processes were evaluated. The fact that the material to be dried was radioactive resulted in three major requirements for this drying process. First, to eliminate human exposure to radiation, it had to be adaptable to totally remote operation. Secondly, to ensure compatibility with later steps in the solidification process, it had to produce a product with a specific chemical composition and with specific physical properties. Finally, the volume of exhaust vapors, called off-gas, produced by the drying process had to be minimized, because it becomes radioactive and requires additional treatment. For these reasons, a slightly modified form of spray drying was chosen as the drying method, and was incorporated into the Defense Waste Disposal Process shown on the following page (see figure 1).[4] In the proposed Savannah River Plant Defense Waste Processing Facility, the sludge from the waste tanks is stripped of its aluminum and fed to the spray dryer. The dried product is mixed with glass-forming materials and placed in a glass melter, from which a molten product is poured into canisters to be cooled and shipped to a federal repository.

Spray drying, as conventionally performed, does not meet all three radioactive waste drying requirements. It has been shown capable of remote operation,[5] and certain product properties, including chemical composition, can be controlled, but it creates large volumes of off-gas.[6] Accordingly, the drying process was slightly modified with a unique dryer design first tested at Battelle's Pacific Northwest Laboratories (PNL). The PNL spray dryer design greatly reduced the volume of radioactive off-gas, but in doing so limited the dryer's inherent control over the product's chemical composition and physical

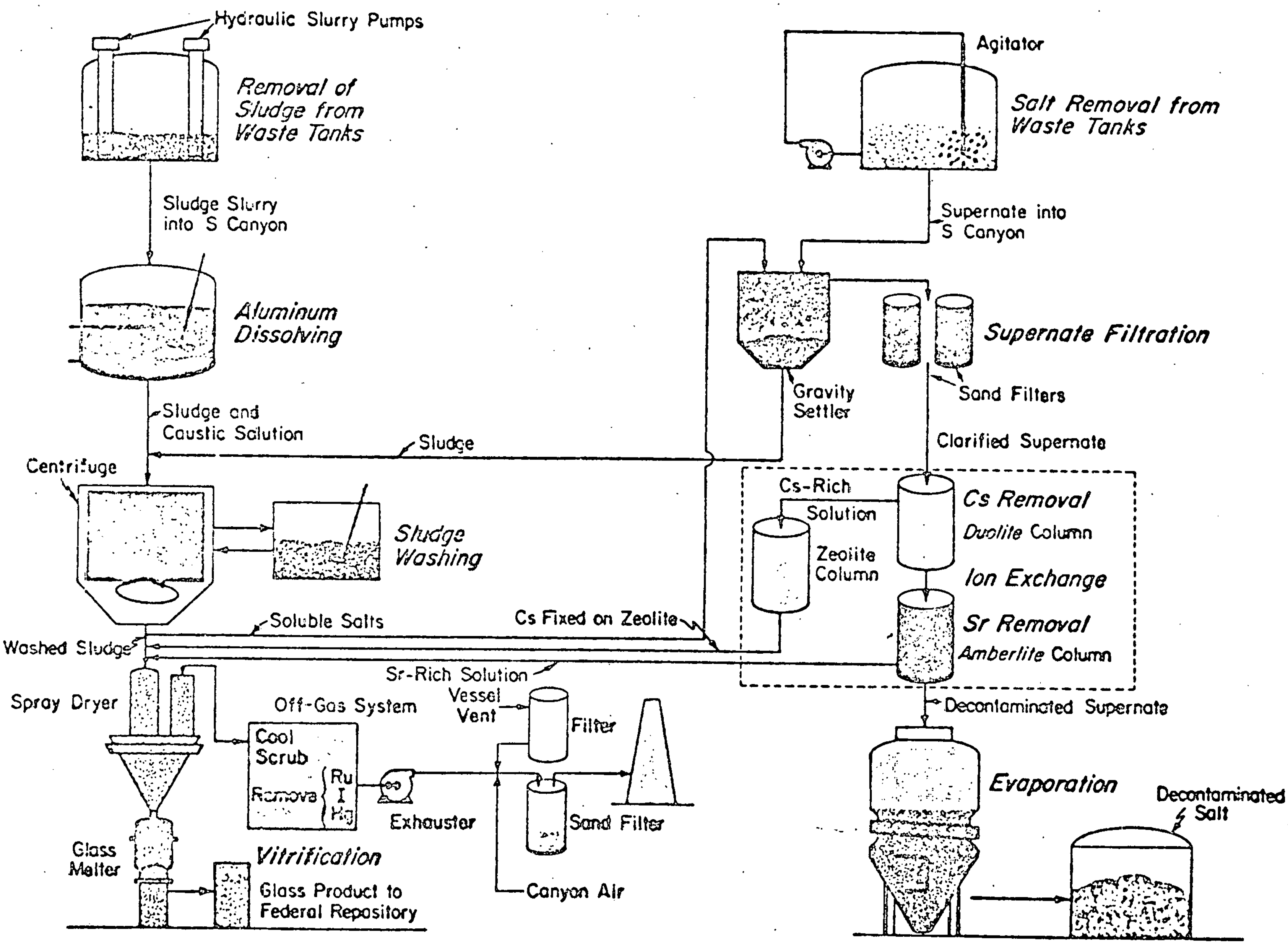

FIGURE 1. SRP Defense Waste Processing Reference Flowsheet[4]
~~Source: Landon~~

properties. Furthermore, PNL's modifications made the dryer less suitable for remote operation.

By mid-1980, the Savannah River Laboratory plans to have functioning, in its remotely operated High-Level Caves, a small scale spray dryer simulating the proposed defense waste drying process. To accomplish this, a spray dryer not plagued by the PNL problems is required. The initial purpose of this investigation was to determine if the PNL spray dryer's problems could be eliminated by the correct choice of operating conditions. It was experimentally determined, however, that these problems did not stem from an improper choice of operating conditions, but were inherent in the design itself. This realization resulted in a search for a new dryer design. This quest terminated when a simple, but novel modification was found which theoretically allows the simultaneous attainment of all three radioactive waste drying requirements.

SPRAY DRYING AND THE PNL DRYER

Spray drying is performed by introducing tiny solid-containing droplets into a heated environment, where they quickly evaporate, leaving a dried product. The unique advantages of spray drying stem from the fact that the droplets dry while freely suspended, which allows them to dry evenly at a regulated rate. In this manner, the physical and chemical makeup of the product can be controlled. Thus, it is imperative that the particles dry completely before they strike the inner surfaces of the dryer. Wet particles would adhere and dry there,and often accumulate as scale deposits. To prevent premature contact with the walls, a droplet must travel some minimum distance, which is an elusive function of many variables. To insure that all droplets travel this minimum distance, the drying chamber can be made unduly large, or, as prefered, the internal droplet spray pattern can be controlled by the introduction of air, or any other gas, into the drying chamber. This air entrains the tiny droplets and carries them, as they dry, in a predetermined pattern that insures premature contact is not made. Generally, this air serves a second important function. Normally, it is heated before entering the drying chamber, thereby supplying the drying force. This is called direct heating. Thus, spray drying is composed of three equally important operations: atomizing the liquid feed, drying the droplets, and controlling the droplets' trajectories.

The principle role of liquid atomization is to produce a high droplet surface to mass ratio, which results in high evaporation rates.[7] Because this ratio increases as the diameter of the droplet decreases, the atomizer's primary role is to produce relatively small droplets. Its secondary role is to influence the physical properties, and to some extent, the chemical composition of the dried product, which are functions of the droplet's initial size and velocity. Currently, the spray drying industry employs three atomization methods: pressure atomization, rotary atomization, and two-fluid atomization.

A pressure atomizer creates a liquid jet, which later breaks up, by forcing the liquid feed through a narrow orifice. The ensuing disintegration of the liquid jet into drops has been under investigation since Lord Rayliegh's studies in the early years of this century, but no mechanism has yet been found.[8] These and later studies have led to the following conclusions, however: if the liquid jet has a characteristic Reynolds Number greater than 2100, then it will break up without the application of any external force; if the Reynolds Number is less than 2100, than an external force, such as air resistance, is required. Generally, high liquid pressures are used to insure high liquid velocities, which inturn, result in high Reynolds Numbers and very small droplets.[9]

Rotary atomization is achieved by centrifugally accelerating the liquid feed to a high velocity before releasing it to the drying environment, where its disintegration into droplets occurs. This process can be seen in figure 2.

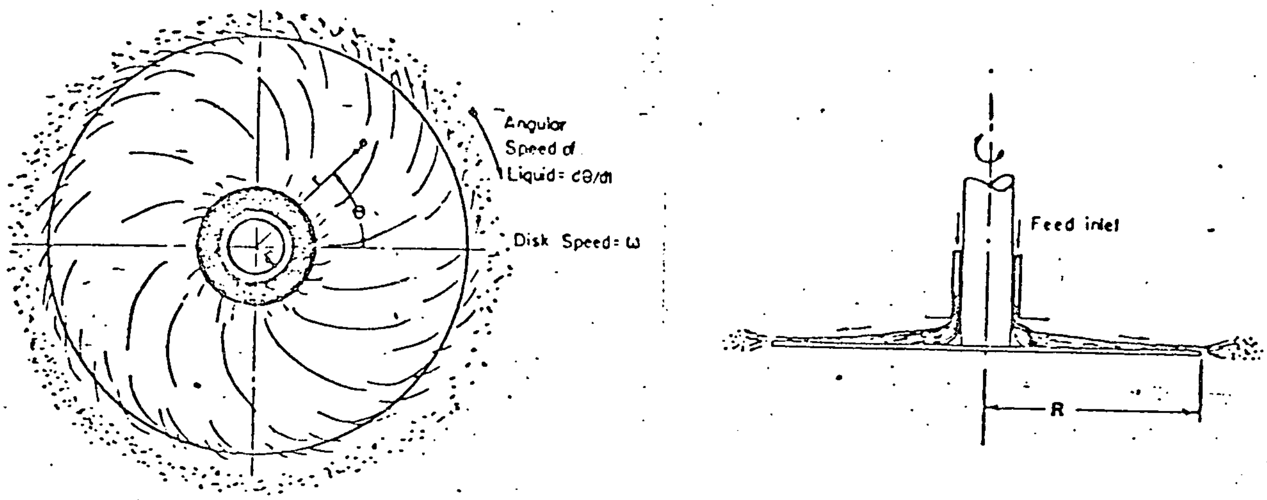

Figure 2. Rotary Atomizer.[10]
Source: Marshall and Seltzer.

The high release velocities are achieved without the high pressures required with a pressure nozzle.

In two-fluid atomization, a gas stream is used to break up the liquid feed stream. Because an external force is being used to bread up the liquid stream, extensive atomization is achieved with low liquid pressures and generally low liquid flow rates. A two-fluid nozzle, where the feed is liquid waste, and the atomizing gas is air, is shown in figure 3. There are four nozzle operating variables, any two of which are independent. They are the gas flow rate, the gas pressure, the liquid flow rate, and the liquid pressure. This type of nozzle is capable of producing very small droplets with low stream pressures.

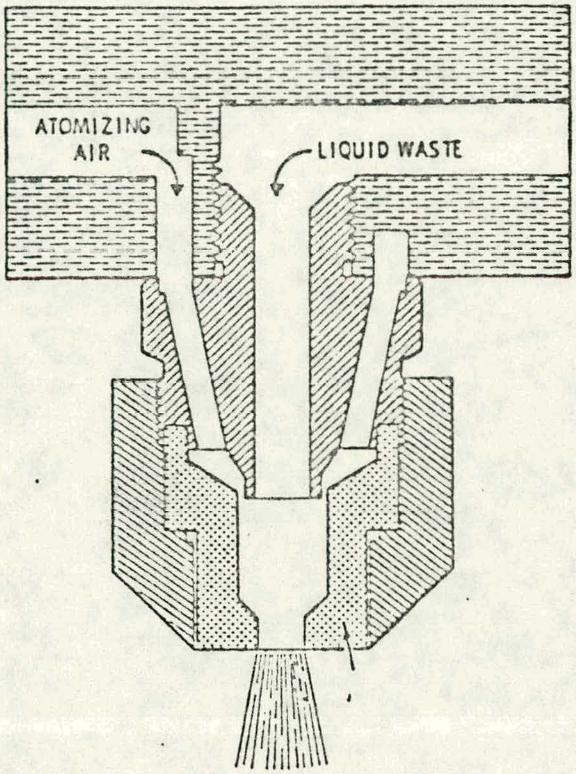

Figure 3. Two-Fluid Nozzle.[11]
Source: Larson and Bonner.

Generally, the degree of atomization increases with increasing gas flow rates and pressures, but decreases with increasing liquid flow rates and pressures.

The second phase of spray drying concerns the drying of droplets. Even though the droplets are injected into the drying environment at high velocities, sometimes reaching hundreds of feet per second, they very quickly acquire velocities nearly equal to those of the surrounding gas.[12] Furthermore, their initial diameters are usually less than 200 microns. The small sizes and low relative velocities of the droplets ensures that most of the drying occurs in a regime where their Reynolds Numbers are less than 2.[13] Under these conditions, the evaporation rates of pure water droplets can be correlated, and appear below in figure 4.

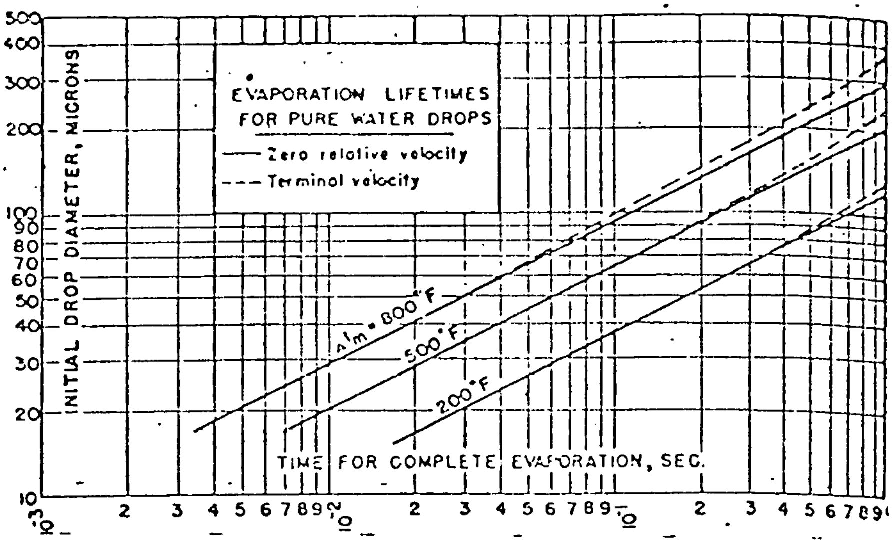

Figure 4. Evaporation Lifetimes For Water.[14]
Source: Marshall and Seltzer.

Few studies have been made concerning the drying of solid-containing droplets. Therefore, the correlations shown in figure 4 serve solely as initial approximations. These approximations are valid for droplets that have a low solid content, form porous product particles, or show little tendency to form solid shells which enclose the remaining water.[15]

The final important element of spray drying concerns the effective control of the droplets' trajectories in the drying chamber. As already stated, the injected droplets quickly acquire the velocities of the surrounding gaseous medium. Furthermore, as already mentioned, the unique advantages of spray drying occur because a material dried in a spray dryer does not contact solid surfaces until it has become dry.[16] For these reasons, the medium's flow pattern must not carry moist droplets directly to the walls of the dryer. As a result, spray drying is usually performed by introducing the atomized droplets into a well-behaved, that is not fiercely turbulent, flow of gas. A typical flow pattern can be seen in figure 5 on the following page.

The advantages of spray drying, due primarily to the fact that drying occurs at a controlled rate and prior to contact with solid surfaces, include:[17]

1. Certain product properties may be effectively controlled and varied.
    a. Product density.
    b. Product shape.
    c. Product size.
    d. Product chemical composition, when alterable.
2. It is suited to the drying of heat sensitive materials.
3. Its efficiency is comparable with that of other direct dryers.

The conventional spray drying process described above has many attractive features, including both adaptability to remote operation and effective control over the products physical

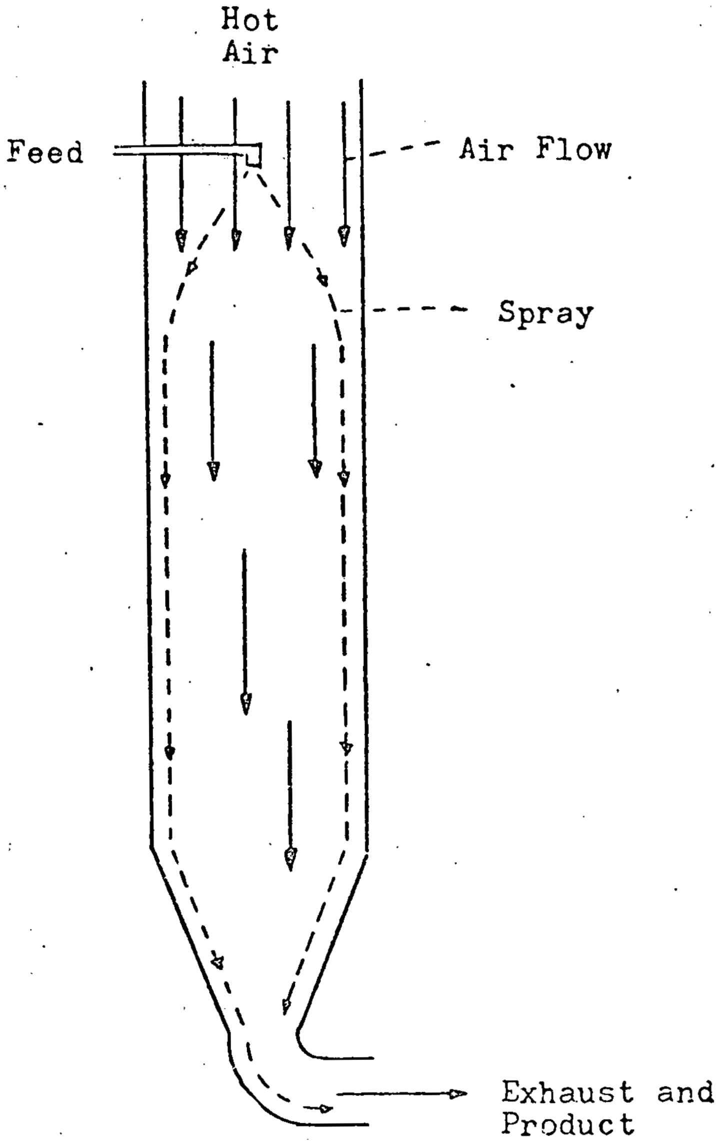

Figure 5. A Typical Flow Pattern.[18]
Source: Sloan, Wheelock and Tsao.

and chemical make-up,[19] but it is not entirely suitable for drying radioactive waste. Large volumes of radioactive exhaust have to be treated. Rising to this challenge, PNL developed a modified spray dryer which greatly reduced the volume of off-gas. The laboratory scale PNL dryer is depicted below:

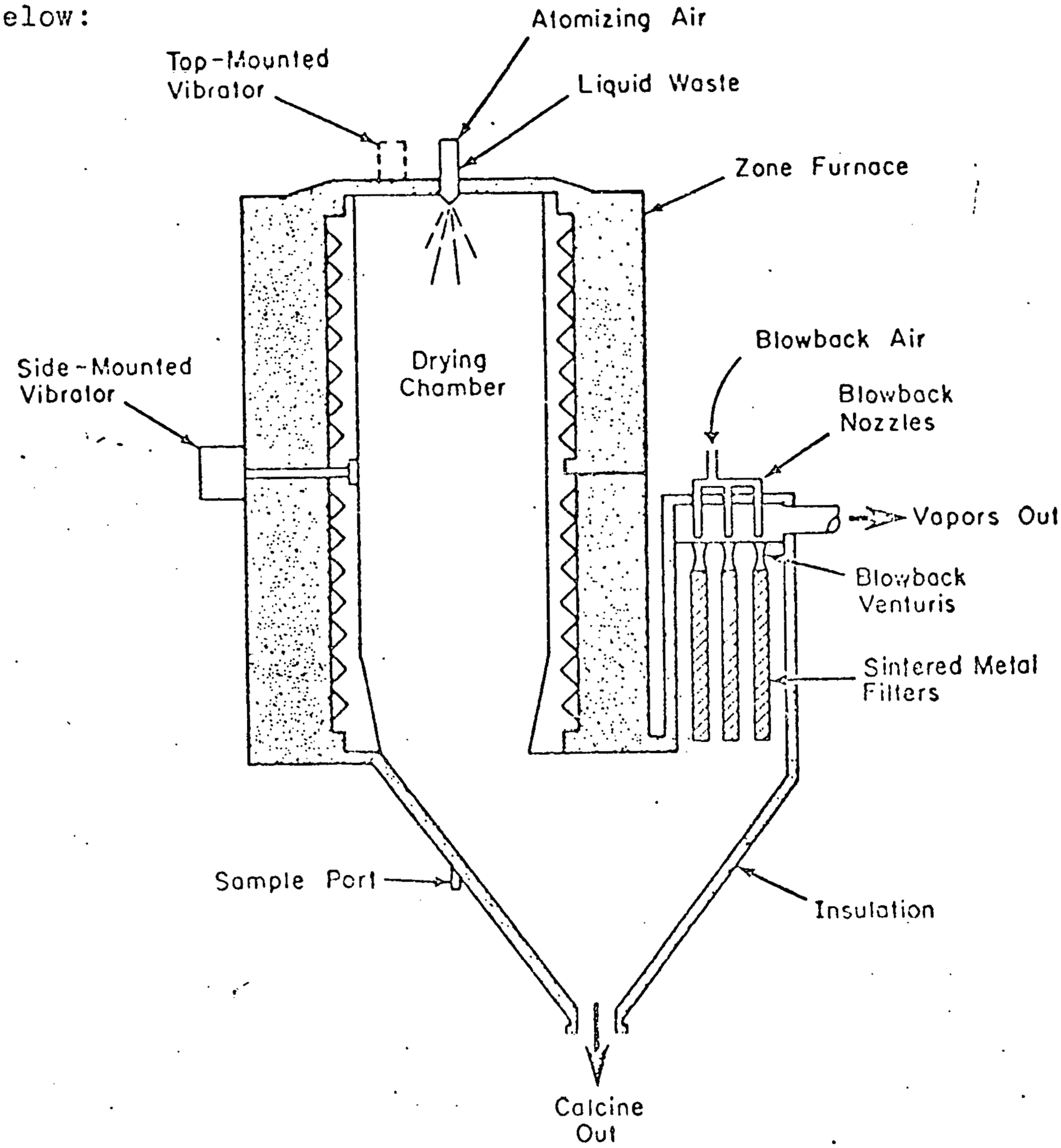

Figure 6. The PNL Dryer.[20]
Source: Landon.

As can be seen, only the water vapor, the atomizing air eminating from a two-fluid nozzle, and their contaminents compose the exhaust stream and need to be processed. The drying heat is supplied by radiation and convection from the dryer's inner walls, which are kept at approximately 600^{o} Celsius.

PNL's design, while greatly reducing the volume of off-gas, lessened the operator's control over the product's chemical composition and physical properties. This was due to the fact that the third key element of spray drying, control of the droplet's trajectory, was lacking. Initial tests at PNL indicated that large amounts of feed were striking the walls of the dryer while still wet, and adhering there. Because drying was taking place on the walls, many of the advantages of spray drying, including control of the product's chemical and physical makeup, were lost. Furthermore, to combat the accumulation of solids on the walls of the dryer, vibrators were attached to shake the deposits loose. Vibrating a massive, full scale, 600^{o} Celsius spray dryer is certain to weaken it, thereby making it less suitable for remote operation.

As previously mentioned, by mid-1980, the Savannah River Plant plans to have operating a small scale spray dryer simulating the Defense Waste drying process. A modified spray dryer, emitting low volumes of off-gas, and not plagued by the PNL problems is required. The initial purpose of this investigation was to determine whether a change in nozzles, or a change in the nozzle's two independent operating variables (liquid flow rate, and nozzle air pressure), could favorably alter the spray pattern in the PNL dryer, thereby eliminating the scaling and control problems. These factors were found to have little effect on the spray pattern. Therefore, a more satisfactory design was developed.

EXPERIMENTAL METHOD

Experimental Objective

Unfortunately, no reliable method of determining the spray pattern developed within an operating dryer is known.[21] Accordingly, only the distribution of liquid striking the sides of the dryer was sought. Furthermore, the spray distribution was sought for a room temperature dryer, which clearly, will be different from that of a dryer in normal operation. This approach was rationalized in a number of ways. First, if control of the spray pattern could not be achieved in a chamber void of heating and drying effects, control would be impossible under normal operating conditions. Significant improvements in the spray pattern, however, would be implementable. Finally, no operational dryer of PNL's configuration was available. Thus, the basic investigation initially entailed determining the spray distribution striking the sides of a room temperature dryer of PNL's dimensions and closed top configuration. Specifically, the effect of a change in nozzles, as well as a change in the nozzle's two independent variables, on the spray distribution was investigated. Additionally, the effect of a closed top was investigated.

Equipment

The test apparatus was composed of a constant speed Master-flex peristaltic pump (7014 pump head) supplying a 2.94 molar sodium nitrate solution, to one of three commercially supplied air atomizing nozzles, at flow rates between one and three liters per hour (see figure 7). The nozzles tested were produced by the Spraying Systems Company. These nozzles, chosen for their narrow conical spray pattern, fine atomization, and appropriate flow ranges, were types 1/8 JJ11, 1/8JJ12A, and 1/8 JJ12. (Information concerning the nozzles appears in Appendix I). A 20psig source supplied air to the nozzle through a Nullmatic pressure regulator (type 40-50) and a Manostat flow meter (type 36-541-23).

The nozzle, oriented in various configurations sprayed the resulting mist into a clear plexiglas cylinder (see Appendix II). The cylinder, similar to PNL's drying chamber, had a 4.94 inch inner diameter and a 53 inch length. A 90 psig auxiliary air source supplied air through a Brooks flow meter (type 1320-01ZIC) to the configuration 3 baffle chamber (see Appendix II).

The spray impacting the cylinder's inner surface was absorbed by Gelman glass fiber filters (type A/E) which were held in position by a plastic positioning strip (see figure 8). The area of the filter exposed was .938 square inches (1.5in. by .625in.). The filters were weighed on an Ainsworth balance (type 10).

Procedure

Initially, the glassfiber filters were cut into rectangles slightly larger than the collecting windows, weighed, and

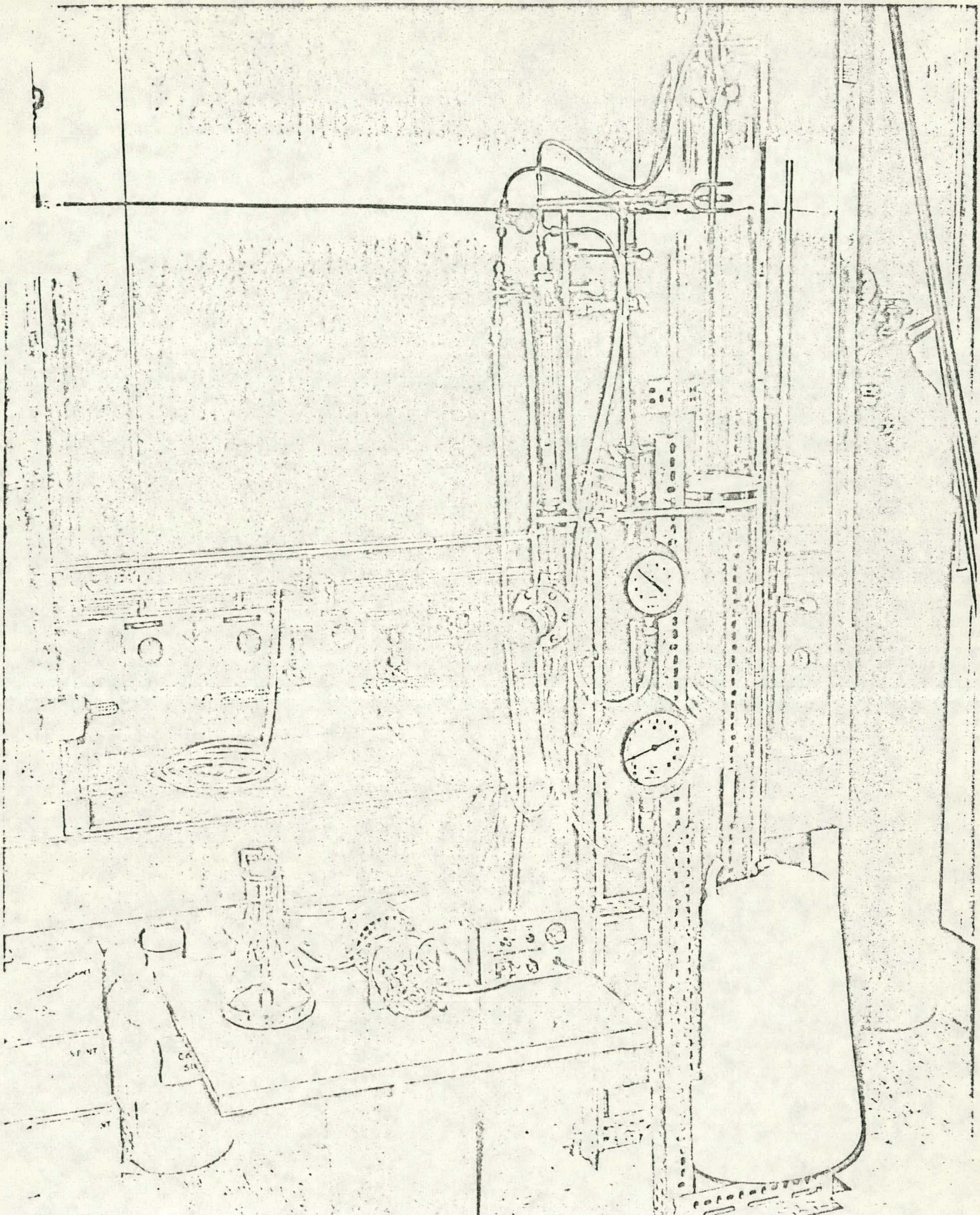

Figure 7. The Test Apparatus.

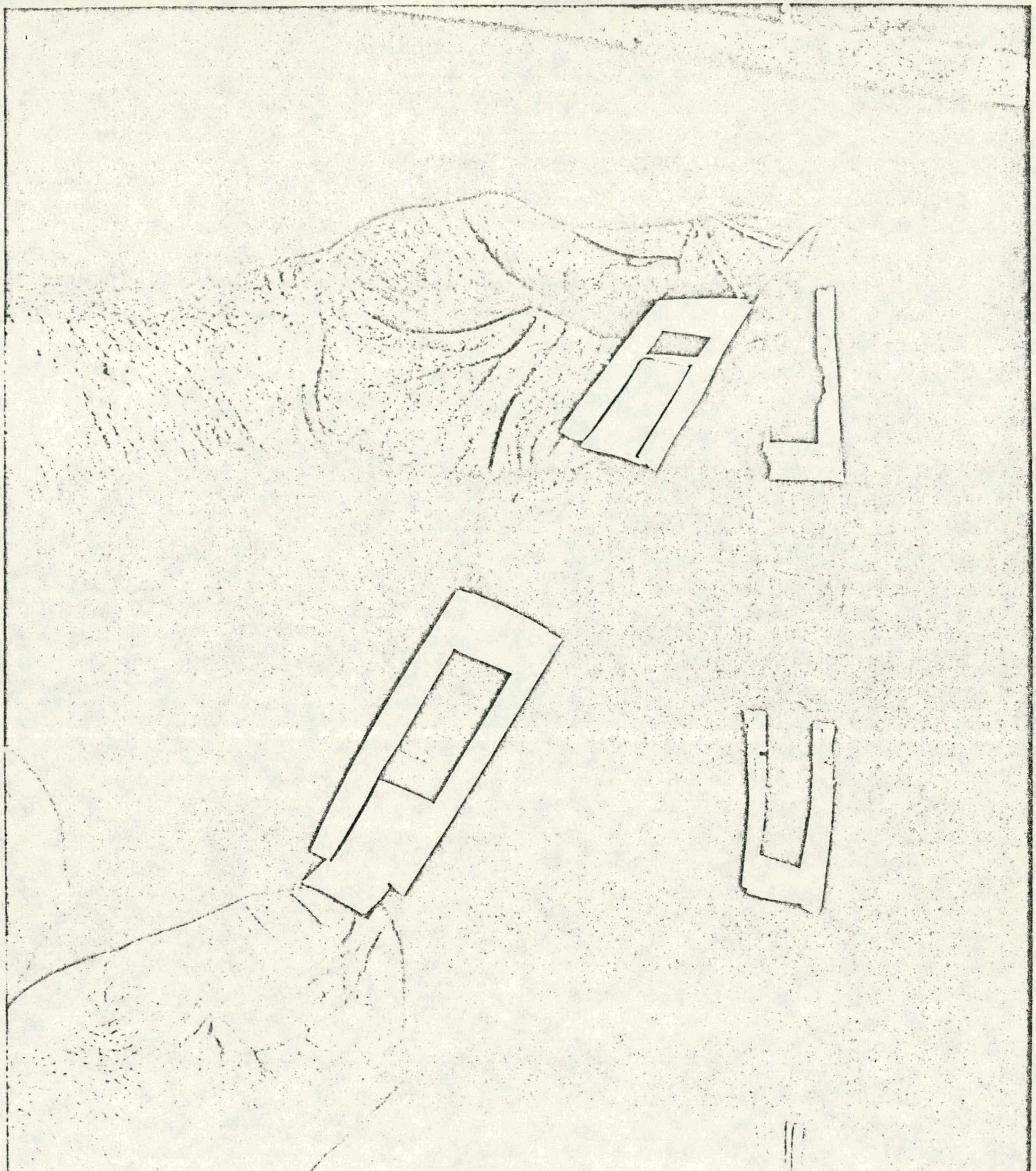

Figure 8. The Plastic Positioning Strip.

placed in the plastic positioning strip. This strip was then secured to the inner surface of the test cylinder which was set up in the desired configuration. If the closed configuration was being tested, a collector was positioned on the underside of the top.

After the air flows were established, the sodium nitrate solution was supplied to the nozzle at flow rates between one and three liters per hour. The liquid feed was continued only until the drops adhering to the surface of the test cylinder were about to break free. This generally required between one and three minutes. Finally, the air flows were shut off.

During the experimental run, nozzle flow rates, nozzle pressures, and the duration of the liquid flow were recorded. Visual observations, such as the distribution's maxima, were also noted.

After the run, the plastic positioning strip was gently lowered from the cylinder and the collectors were removed, dried and weighed. The solid remaining on the fiber collectors determined the distribution. Finally, the test cylinder was rinsed to prevent the accumulation of solid sodium nitrate on the cylinder's inner surface.

RESULTS

The spray distribution calculations are extremely straight forward. First, the amount of liquid striking the inner surfaces of the cylinder (i.e. the spray distribution) is a function of the vertical distance from the nozzle and can be calculated by:

$$V_1 = \frac{M_d}{C \cdot M}$$

where V_1 is the volume of liquid striking the test surface (ml/ft^2);

M_d is the mass of solid striking the collector (g/ft^2);

C is the concentration of dissolved solid (gmol/ml);

M is the molecular weight of the dissolved solid (g/gmol).

This volume is then readily corrected to correspond to 55 milliliters of liquid feed passing through the nozzle:

$$V_{1C} = \frac{V_1 \cdot 55ml}{F}$$

where F is the volume of liquid feed (ml).

The Distribution Is Only A Function Of Configuration

The distribution of liquid striking the interior of the test cylinder, as can be seen in figures 9 and 10, is nearly independent of the choice of nozzles, for both the open and closed configurations. Similarly, the spray distribution is nearly independent of the nozzles two operating variables, which are its flow rate and air pressure. Each nozzle was tested in at least one configuration, with typical results appearing in figure 11.

A comparison of figures 9 and 10 quickly reveals that the distribution is a function of the test apparatus' configuration. This relationship is more defined in figure 12, where the spray distributions are contrasted on the same graph. If, as postulated, the volume of liquid striking the walls of an operating dryer, which is proportional to the area under the distribution curve, is to be minimized, and the experimental trends are valid for normal operation, then the open configuration is superior. Apparently, the solid deposits formed in PNL's dryer, resulting from wet feed striking the inner surfaces, are due in part to its closed configuration. Visual observations indicated that severe turbulence was created in the test cylinder's upper region while operated in a closed configuration. This turbulence destroyed the nozzle's normal spray pattern and caused large amounts of liquid to strike the upper surfaces of the cylinder. The open configuration, on the other hand, allowed the spray to draw a more laminar flow of air down the cylinder, which preserved the spray pattern. Because the internal spray pattern could not be corrected by a change of nozzles or or a change in the nozzle's operating condition, a better dryer design was sought.

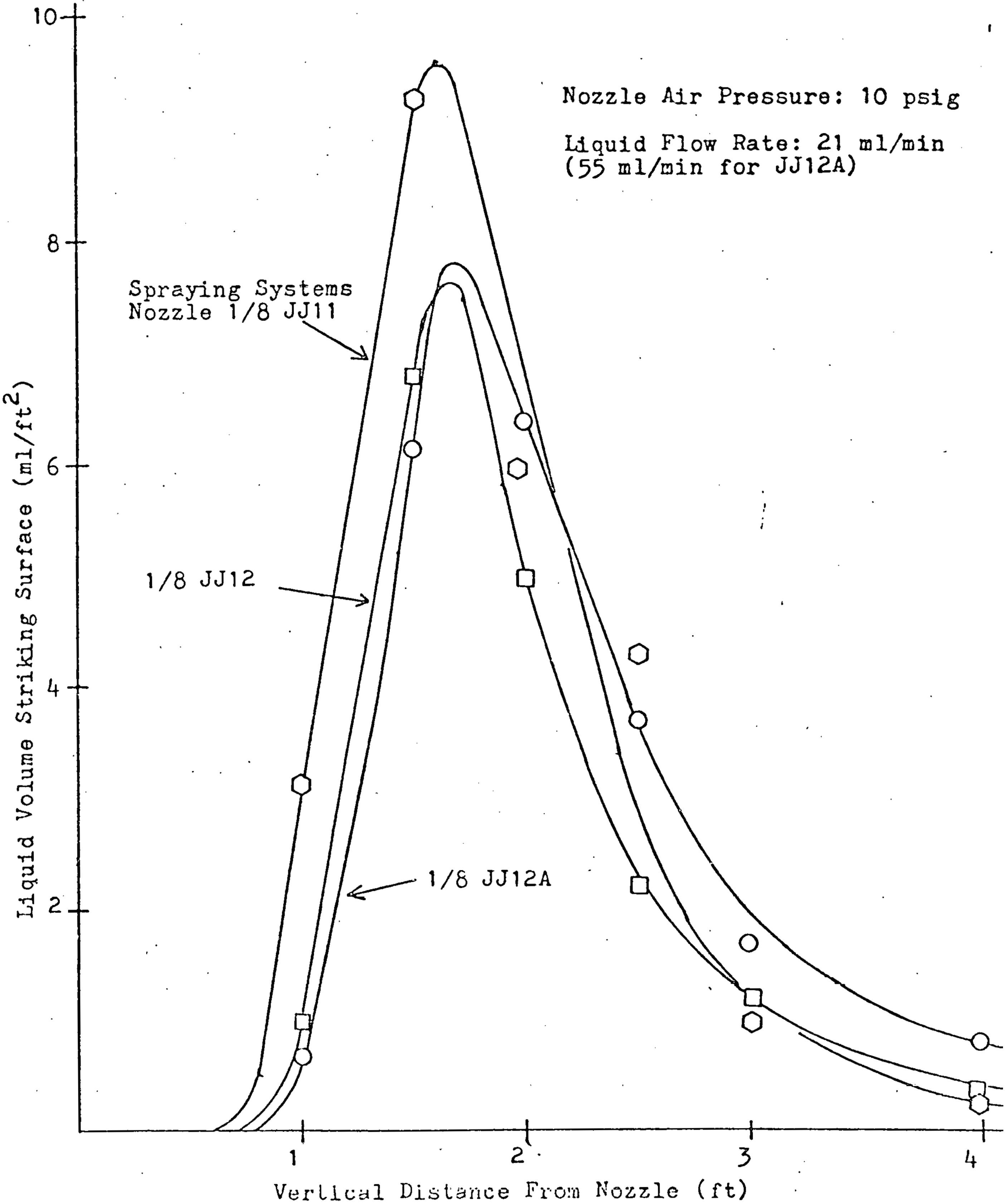

Figure 9. Spray Distribution in an Open Configuration for Different Nozzles.

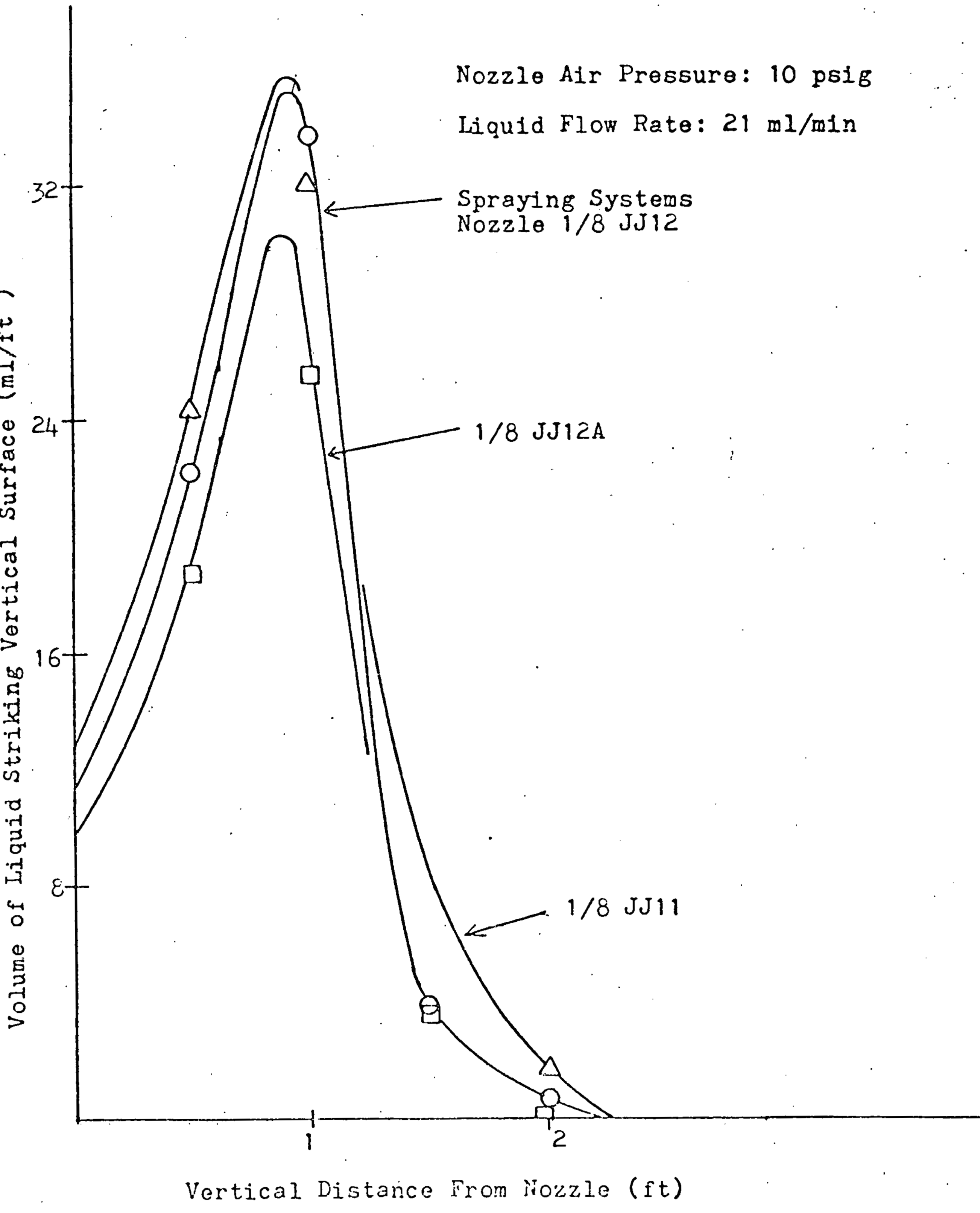

Figure 10. Spray Distribution in the PNL closed Configuration for Different Nozzles.

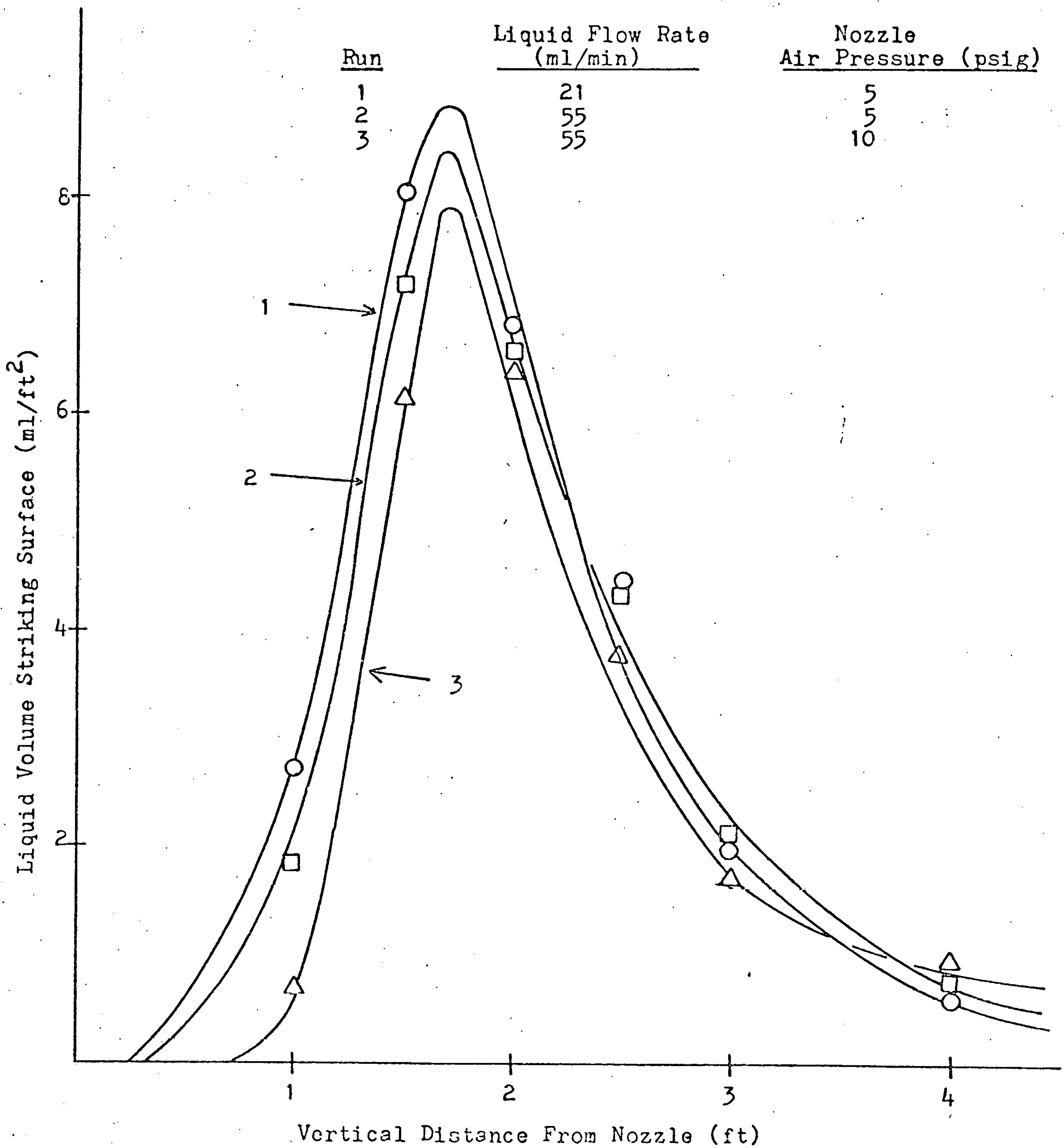

Figure 11. Spray Distribution for Spray Systems Nozzle 1/8 JJ12A in an Open Configuration.

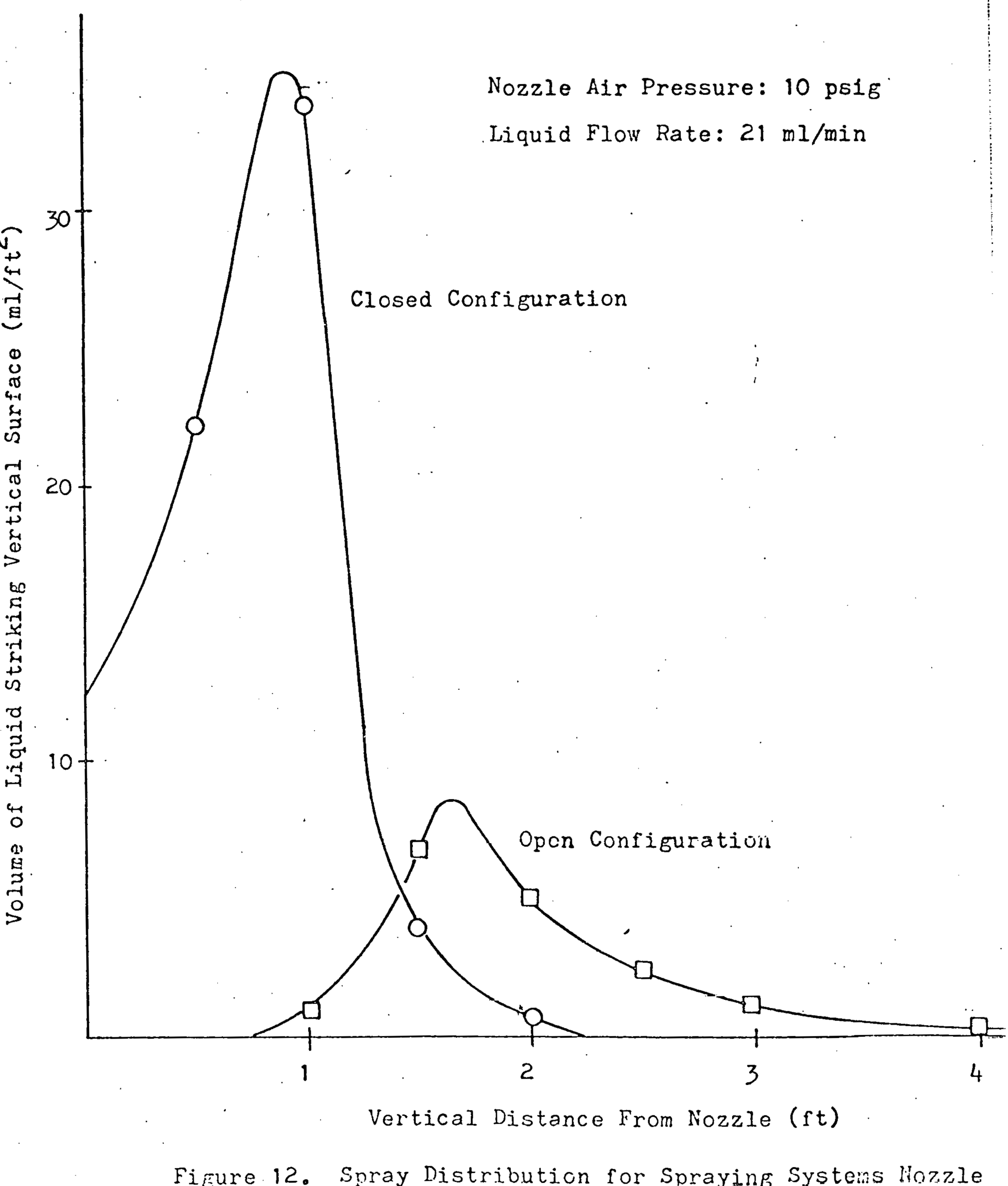

Figure 12. Spray Distribution for Spraying Systems Nozzle 1/8 JJ12 in Open and Closed Configurations.

Auxiliary Air Was Introduced

Numerous successful attempts were made to fabricate an operating configuration that would create a favorable spray distribution. Only a nonturbulent introduction of auxiliary air into the top of the cylinder was required (which should not surprise any veteran spray dryer designer). A controlled flow of nonturbulent air was introduced into the test cylinder using a baffle chamber, which reduced the turbulence caused by a sudden expansion (see configuration 3 in Appendix II). Auxiliary air flows between 6 and 20 standard cubic feet per minute (SCFM) were introduced, with the results appearing in figure 13.

As expected, the introduction of auxiliary air not only favorably altered the spray pattern from that of the closed configuration, but if heated would also aid in the drying process. The dryer would be, however, nothing more than a conventional spray dryer, and would require that the off-gas system handle a much larger volume of vapor. In a closed configuration small scale dryer , only 1 SCFM of atomizing air and 3 SCFM of water vapor need to be processed.

A Closed Recycle Was Proposed And Tested

The desirability of a cocurrent flow of air is clearly indicated by figures 12 and 13. If this air is not to increase the off-gas volume, it must be in the form of a closed

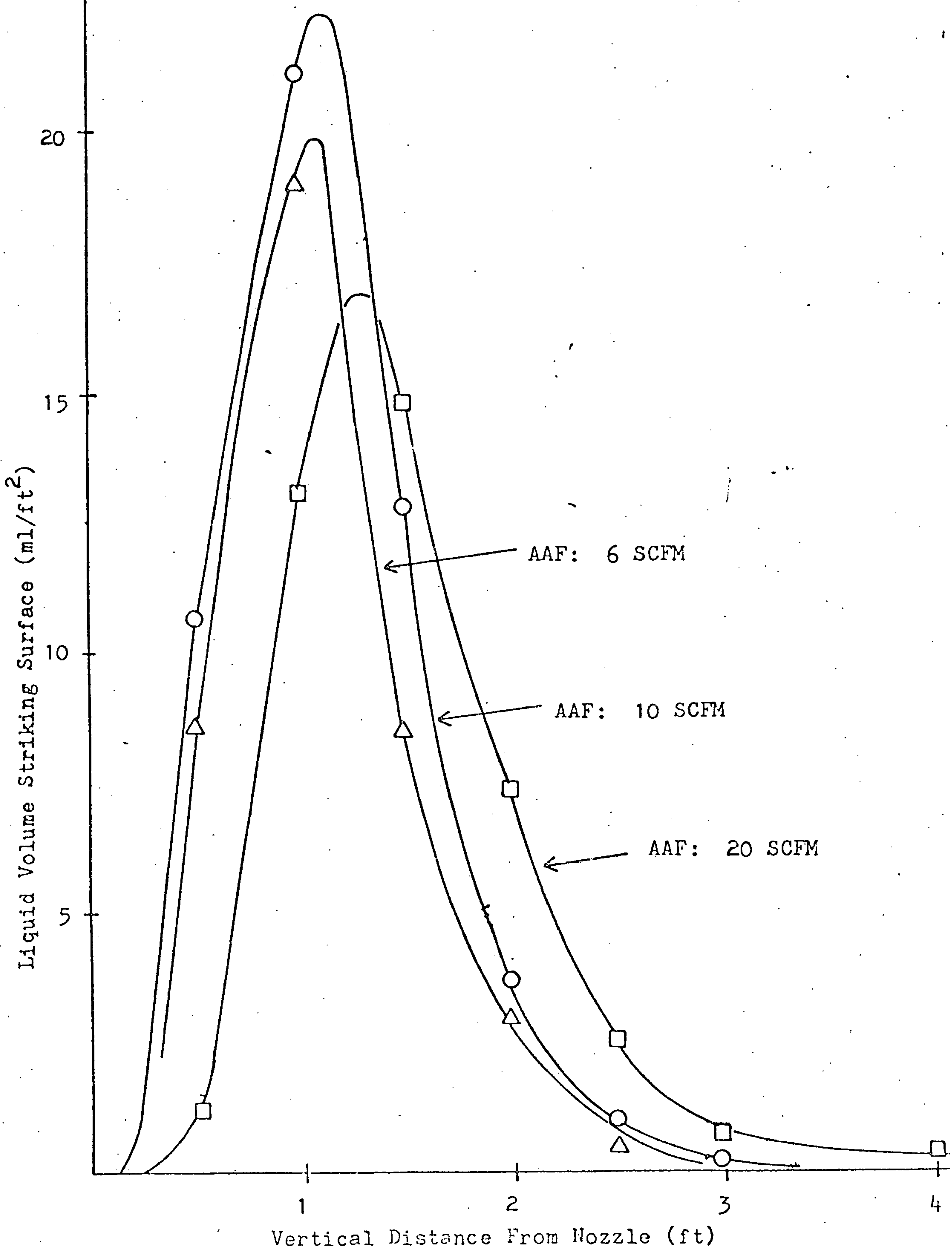

Figure 13. Spray Distribution for Spraying Systems Nozzle 1/8 JJ11 with Auxiliary Air Flow.

recycle. A dryer design shown in figure 14, would favorably alter the spray pattern, would not increase the volume of vapors to be processed, would not increase the dryer's overall size substantially, and would not require a pumping system. The energy supplied by the spray could be used to drive the recycle instead of being dissipated by creating damaging turbulence. The ability of the nozzle's spray to draw along a cocurrent flow of air was proven by its operation in the open configuration. Accordingly, three possible recycle configurations (configurations 4, 5, and 6 of Appendix III) were tested by drawing air from the surroundings. The corresponding spray patterns are shown in figure 15.

The Distribution Data Is Tabulated

The total volume of liquid striking the cylinder can be determined by numerically integrating the distribution function over the entire surface using Riemann sums.[22] These volumes appear in Table 1.

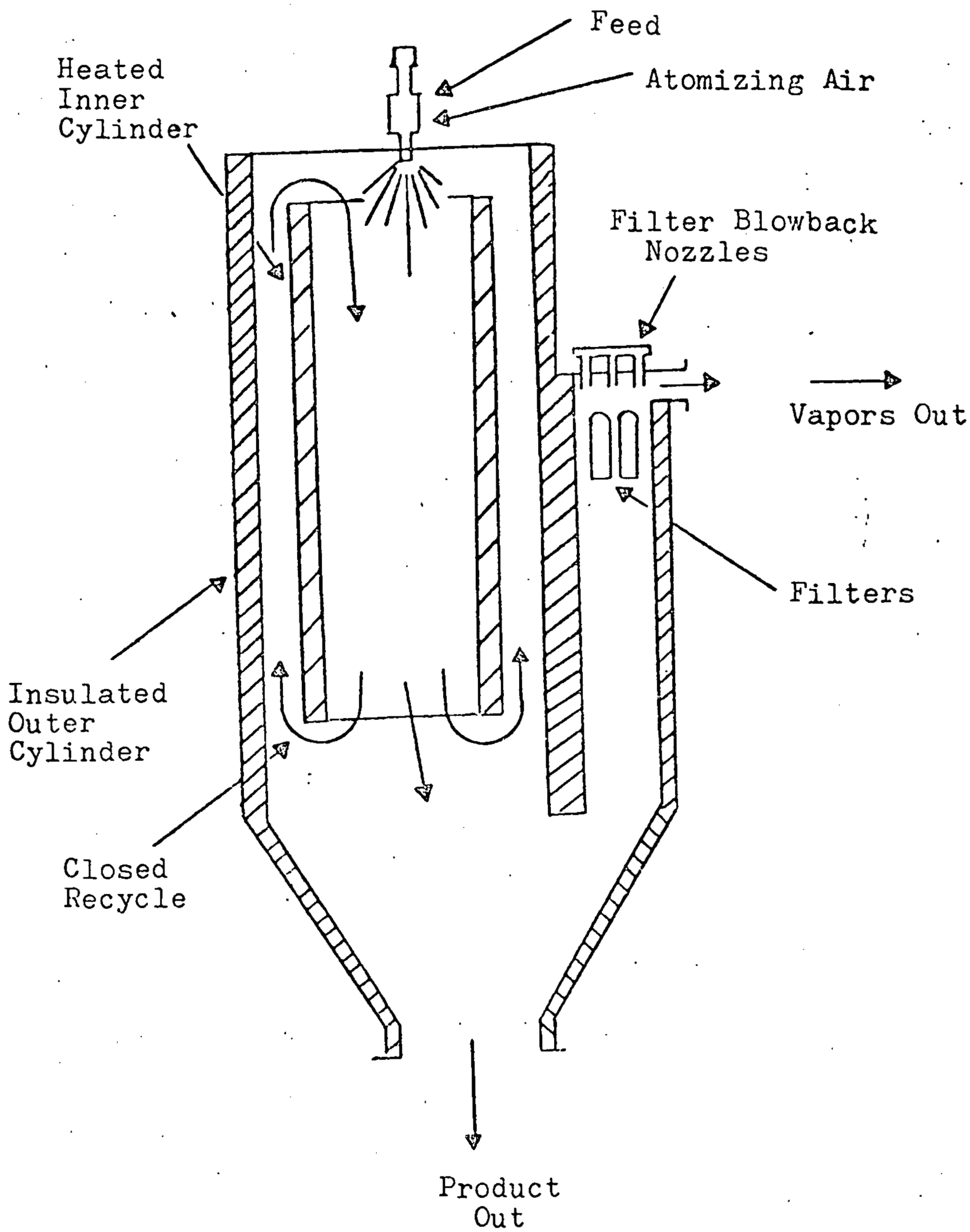

Figure 14. A New Design.

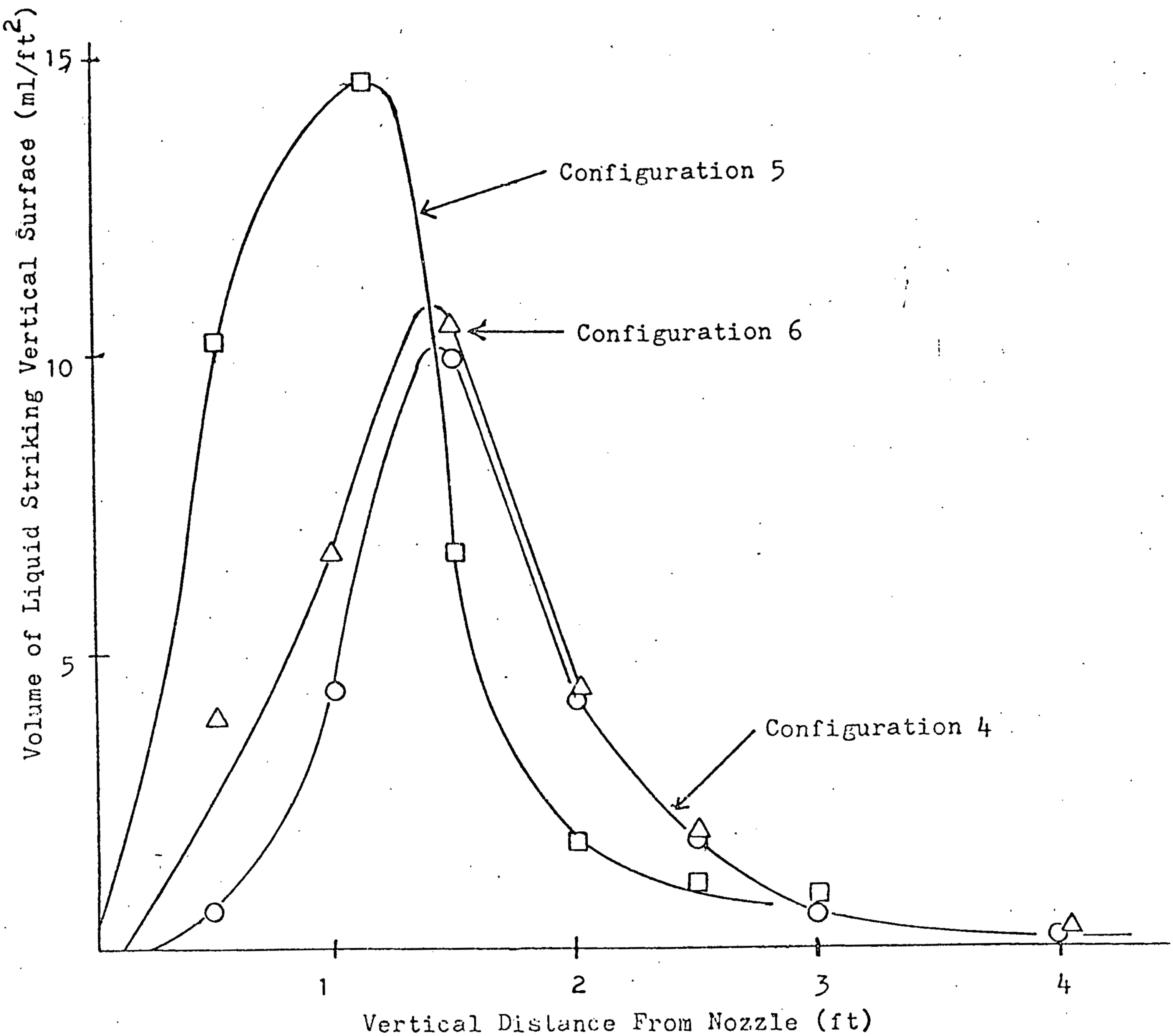

Figure 15. Spray Distribution for Three Recycle Configurations. Nozzle 1/8 JJ11 was used.

Table 1

Spray Distribution Data

Configuration	Average Volume of Liquid Striking Surface (Percent)[1]	Vertical Distance From Nozzle To Distribution's Maxima (ft)
1	26	1.7
2	72[2]	1.0
3	47	1.2
4	26	1.5
5	47	1.3
6	32	1.4

[1]Relative to 55 ml of feed.

[2]Includes the top.

CONCLUSIONS

This study indicates that the distribution of liquid striking the interior of the test cylinder was independent of the choice of nozzles as well as the nozzle's two operating variables (liquid flow rate and nozzle air pressure). It was, however, a strong function of the dryer's configuration. A nonturbulent cocurrent flow of air down the drying cylinder sufficiently and favorably altered the internal spray distribution. Therefore, a new dryer design incorporating such a flow was developed.

Two general methods can be used to ensure that the atomized particles dry before they contact the dryer's walls, and thereby eliminate many of the problems associated with the PNL dryer. Either the evaporation rate can be increased in the existing design, or the dryer itself can be modified.

The evaporation rate in the PNL laboratory scale dryer can be increased by simply increasing the drying temperature, or by introducing smaller particles. This is shown nicely in figure 4. Both of these alternatives, however, have severe complications. First, the wall temperature of the dryer already approaches 700° Celsius, which is just below the temperature at which it begins to glow. Thus, higher temperatures would greatly reduce the dryer's durability. Next, reduction of the particle size without reducing the liquid flow rate would require either a tremendous atomiz -

ing air flow rate or a smaller orifice in the nozzle's liquid cap. The former method would require a high air pressure and create a larger volume of off-gas, while the latter would result in severe nozzle plugging.[23] Finally, increasing the evaporation rate reduces control over the dried product's chemical and physical makeup.

To ensure successful operation, the PNL design was modified. First, increasing the dryer's diameter increases the path lengths to the walls of the dryer, and allows further evaporation. For this reason, the inside diameter of the planned dryer was increased from a nominal five inches to eight inches. The figure of eight enches was chosen because it facilitated the purchase of materials and allowed for convenient installation in the Savannah River Laboratory's High Level Caves. A more accurate determination of the required diameter could have been made if drying rate data and particle size distribution data were available. More importantly, a closed recycle was incorporated into the design of the laboratory scale spray dryer. A recycle configuration similar to configuration 6 of Appendix III was chosen because it favorably alters the spray distribution, allows for the quick removal of the nozzle, allows the nozzle and its feed lines to be water cooled if extreme heat causes clogging and material durability problems, and it is located below the recycle windows. As a result, the proposed dryer's configuration is given in figure 14.

The Assumptions Are Identified

These results rest on two major assumptions. First, it was assumed that the washed radioactive slurry will behave in much the same manner as the sodium nitrate test solution. This assumption not only seems plausible because of the spray distribution's insensitivity to a change in operating variables and the fact that any droplets quickly attain the surrounding air's velocity, which is primarily a function of the dryer's configuration, but was verified visually using simulated waste. Secondly, it was assumed that the experimental trends would not be destroyed by the heating effects. The effects of evaporation will certainly alter the internal spray pattern to some degree, but it must be recalled that only three SCFM of water vapor will be produced by evaporation, while figure 13 and direct observations indicate that the recycle rate will be much greater.

Further Research Is Proposed

The final design of the full scale spray dryer to be used in the proposed Defense Waste Processing Facility should be based on additional research. Many questions, thus far left unanswered, will be cleared up by the laboratory tests of an actual dryer to take place at the Savannah River Laboratory in 1980. These tests will indicate if a recycle of air will be established in the more turbulent environment existing within the operating dryer. Specific tests, however, should be developed to determine the distribution of wet solids striking the sides of the operating dryer. Furthermore, the particle size distribution should be determined and related drying models should be developed. These models, describing the evaporation of the liquid droplets, based on experimental studies, would prove invaluable in the design of the dryer.

The Investigation Suggests A New Drying Scheme

Finally, this investigation has resulted in an unique drying scheme, having all the advantages of spray drying without the conventional introduction of auxiliary air. The first element of this proposed scheme is simply that the drying energy is to be supplied through the walls of the drying chamber, just as in the PNL design. Any method of achieving this energy transfer is sufficient. The second, and unique, element of this proposed drying process is the establishment of a well-behaved flow pattern within the drying chamber without the introduction of auxiliary gas. The well-behaved pattern is in the form of a cocurrent recycle produced without the use of an auxiliary pumping system. Instead, the desired cocurrent flow of gas is drawn along by the spray eminating from any type of nozzle creating a conical spray pattern, such as a two fluid nozzle, or a pressure nozzle. As shown, these liquid sprays are capable of drawing along a substantial cocurrent flow, which greatly influences the internal spray pattern.

There are many advantages of the drying scheme described above. Some follow:

1. It has all the advantages of conventional spray drying.

2. Any type of heating energy capable of being transmitted through the walls of the drying chamber can be used.

3. The piping system carrying the drying gas has been eliminated, thereby reducing the dryer's size and heat loss.

4. The required cocurrent flow of gas is driven solely by the effects of the nozzle and requires no pumping system.

5. The well-behaved spray pattern allows the size of the drying chamber to be kept to a minimum.

The fact that a well-behaved spray pattern can be produced without the introduction of an auxiliary gas flow has led not only to a modified design for the Savannah River Laboratory's small scale spray dryer, but to an unique drying scheme which offers all the advantages of spray drying without possessing many of its limitations.

REFERENCES

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6. C.E. Sloan, T.D. Wheelock, and G.T. Tsao, "Drying," Chemical Engineering, June 19, 1967, p. 175.

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11. Larson and Bonner, p. 45.

12. K. Masters, Spray Drying, (N.Y.: John Wiley and Sons, 1976), p. 285.

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14. Ibid., p. 506.

15. Ibid., p. 507.

16. Ibid., p. 501.

17. Ibid.

18. Sloan, Wheelock and Tsao, p. 175.

19. Larson and Bonner, p. 38.

20. Landon, p. 5.20.

21. Masters, p. 252.

22.

23. Larson and Bonner, p. 45.

24. Industrial Catalog 27 (Wheaton, Ill: Spraying Systems Co. 1978).

25. Numbering System of Air and Fluid Nozzles (Wheaton, Ill: Spraying Systems Co., 1963) p. 1.

26. Comparative Particle Size Data For SSCO Spray Nozzles (Wheaton, Ill: Spraying Systems Co., 1977), p. 1.

APPENDIX I

Nozzle Specifications

Three two-fluid atomizing nozzles produced by the Spraying Systems Company were tested. These nozzles were chosen for their narrow conical spray patterns, fine atomizing properties, and appropriate flow ranges.[24] The expected mean particle diameter for these nozzles is less than 60 microns.[25]

These nozzles, portrayed in figure 3, have the following specifications:[26]

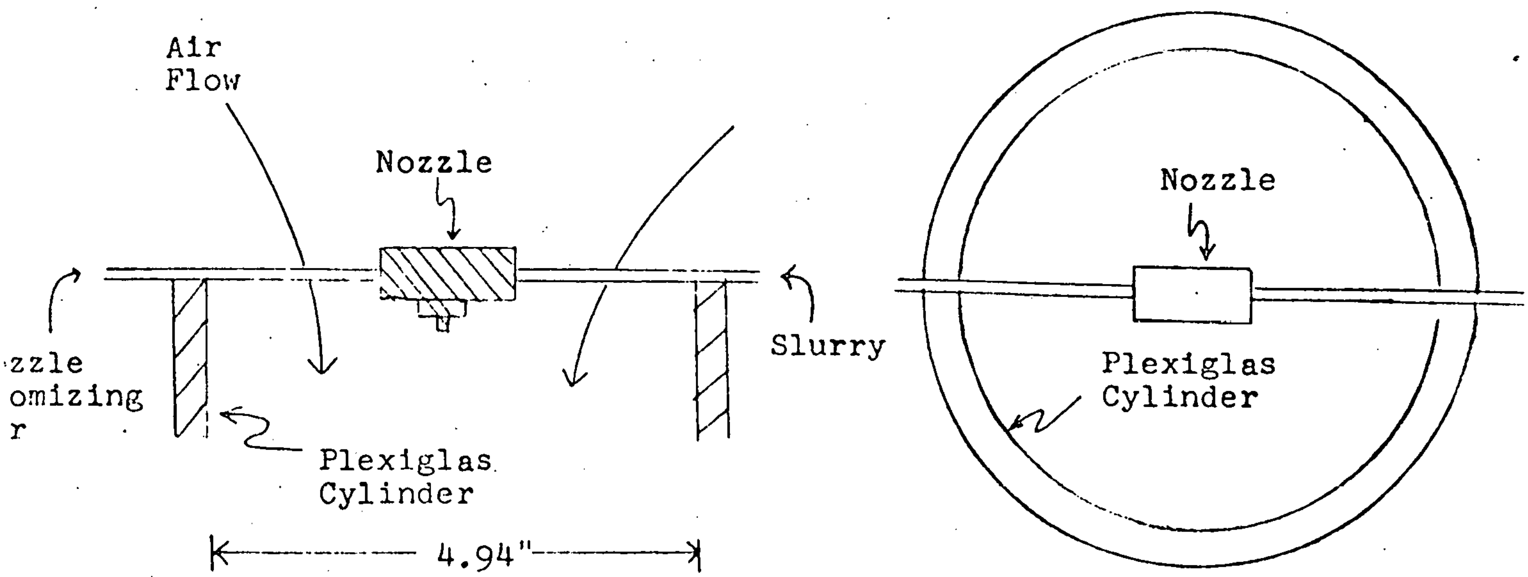
Table 2

Nozzle Data

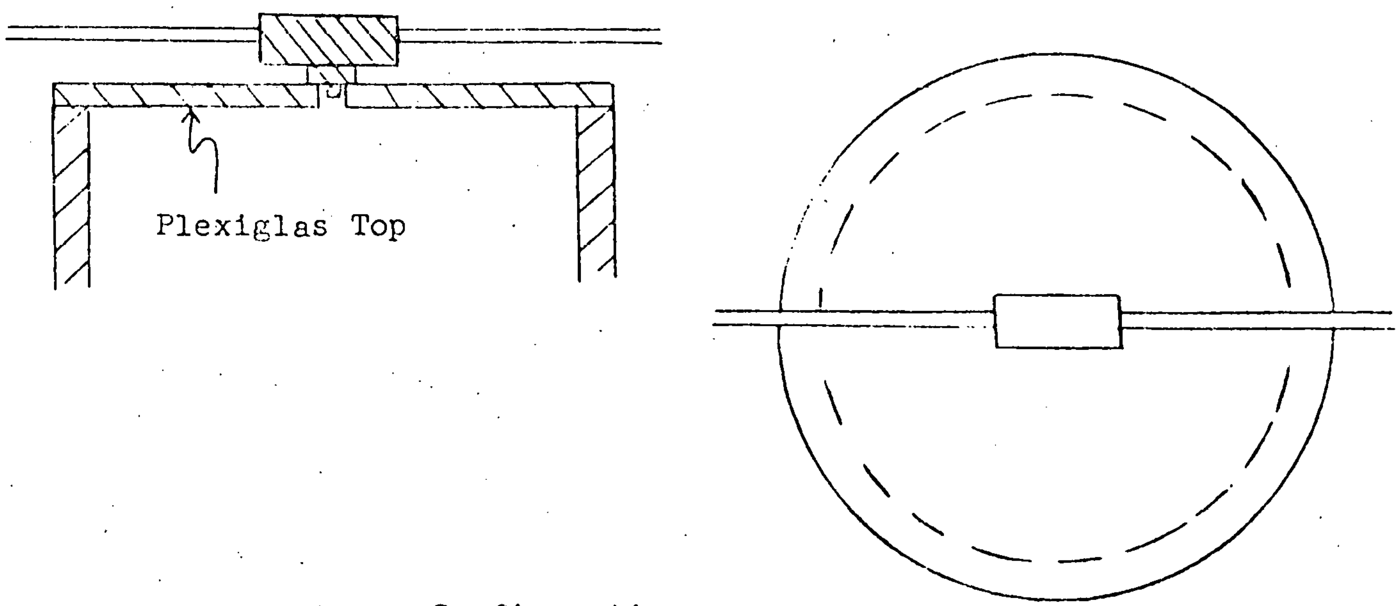
Spray Set Up	Liquid Orifice Diameter (in.)	Liquid Cap Tip Diameter (in.)	Air Cap Inlet Diameter (in.)	Air Cap Outlet Diameter (in.)
1/8JJ11	.020	.050	.067	.047
1/8JJ12A	.020	.050	.073	.060
1/8JJ12	.028	.050	.073	.060

APPENDIX II

Test Configurations



Configuration 1



Configuration 2

Figure 1. Test Configurations 1 and 2.
(1) Open Configuration.
(2) Closed, PNL type Configuration.
Scale: 1 inch ~ 2 inches

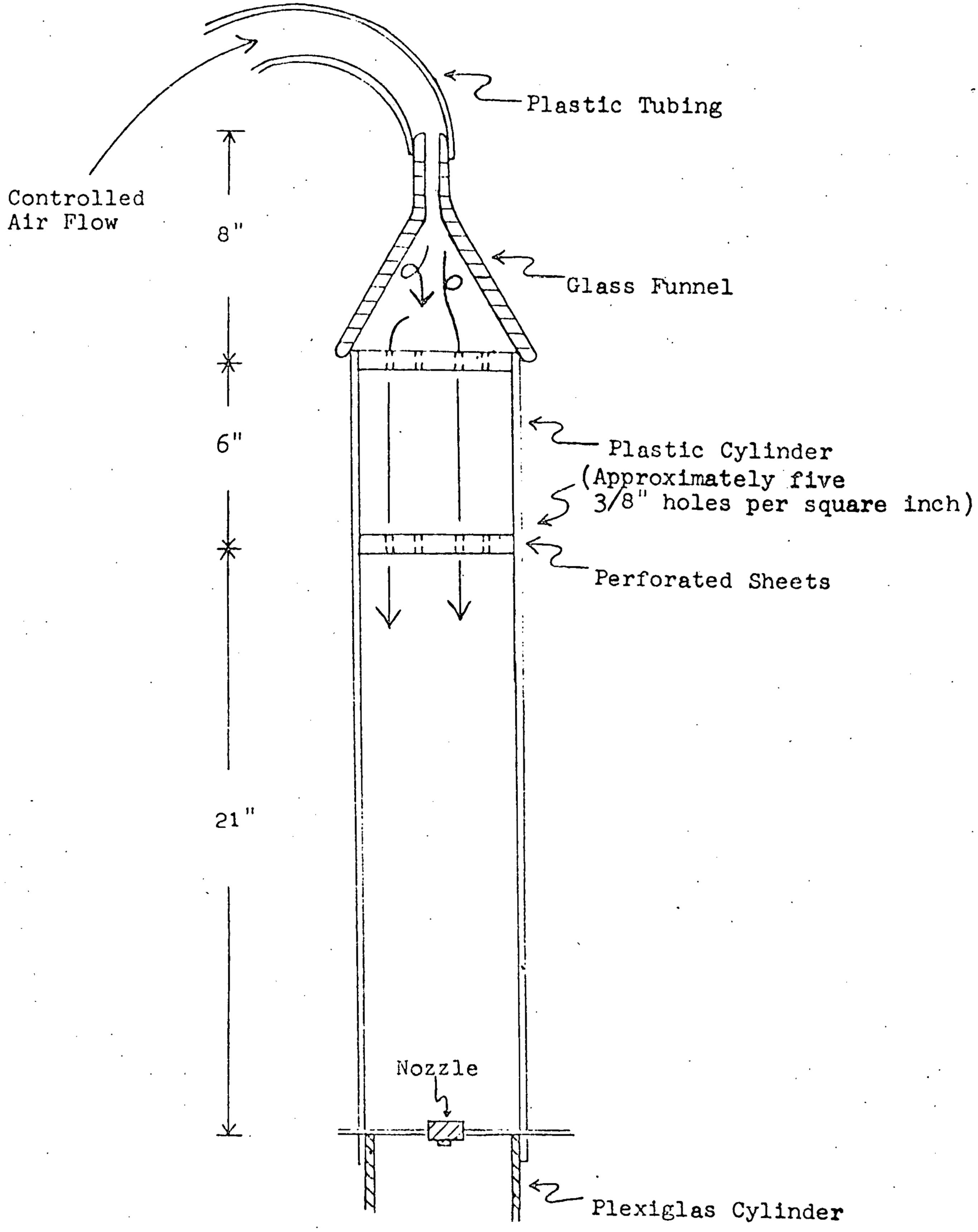


Figure 2. Configuration 3.
1 inch ~ 5 inches

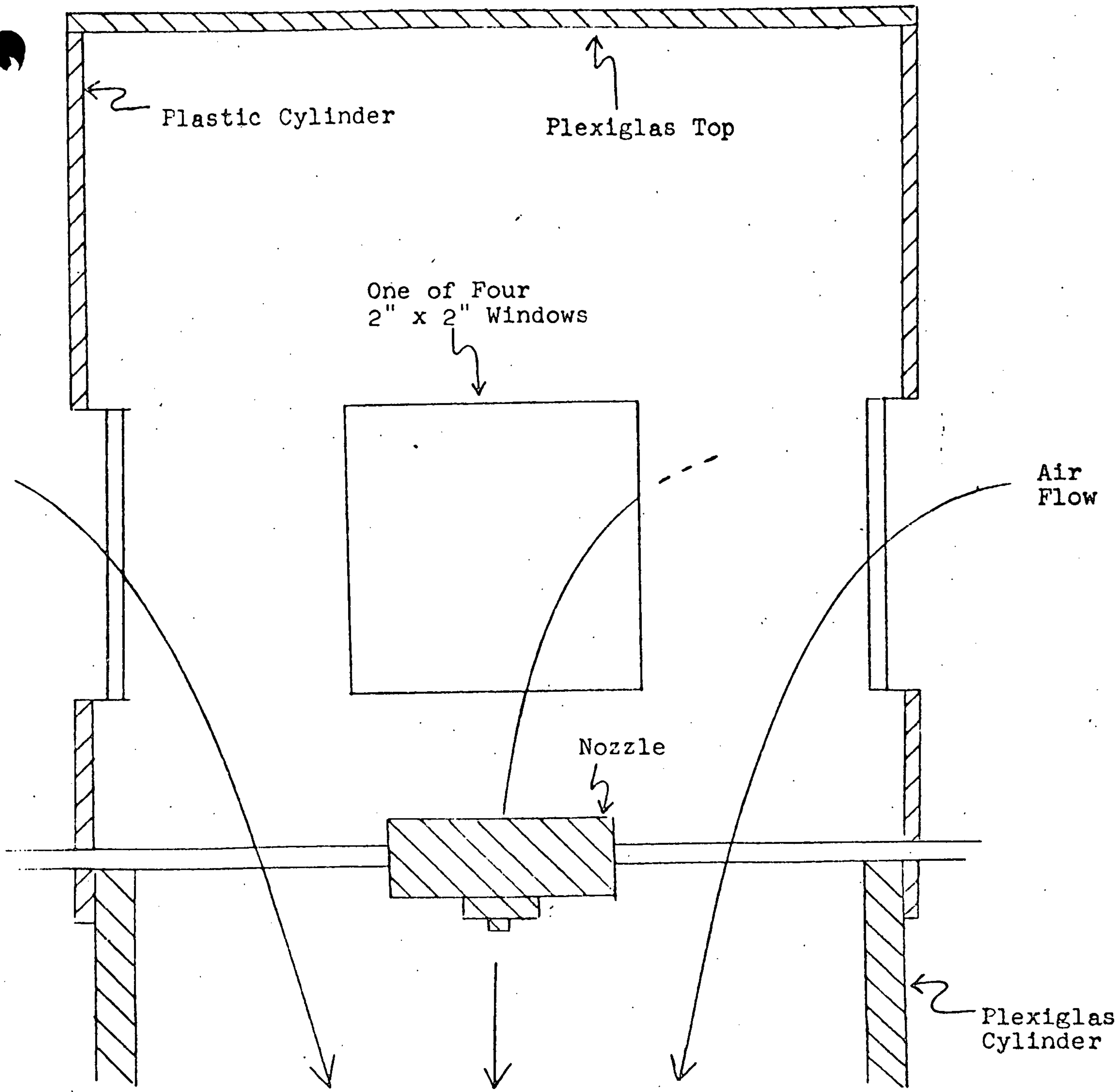


Figure 3. Configuration 4.
Actual Size

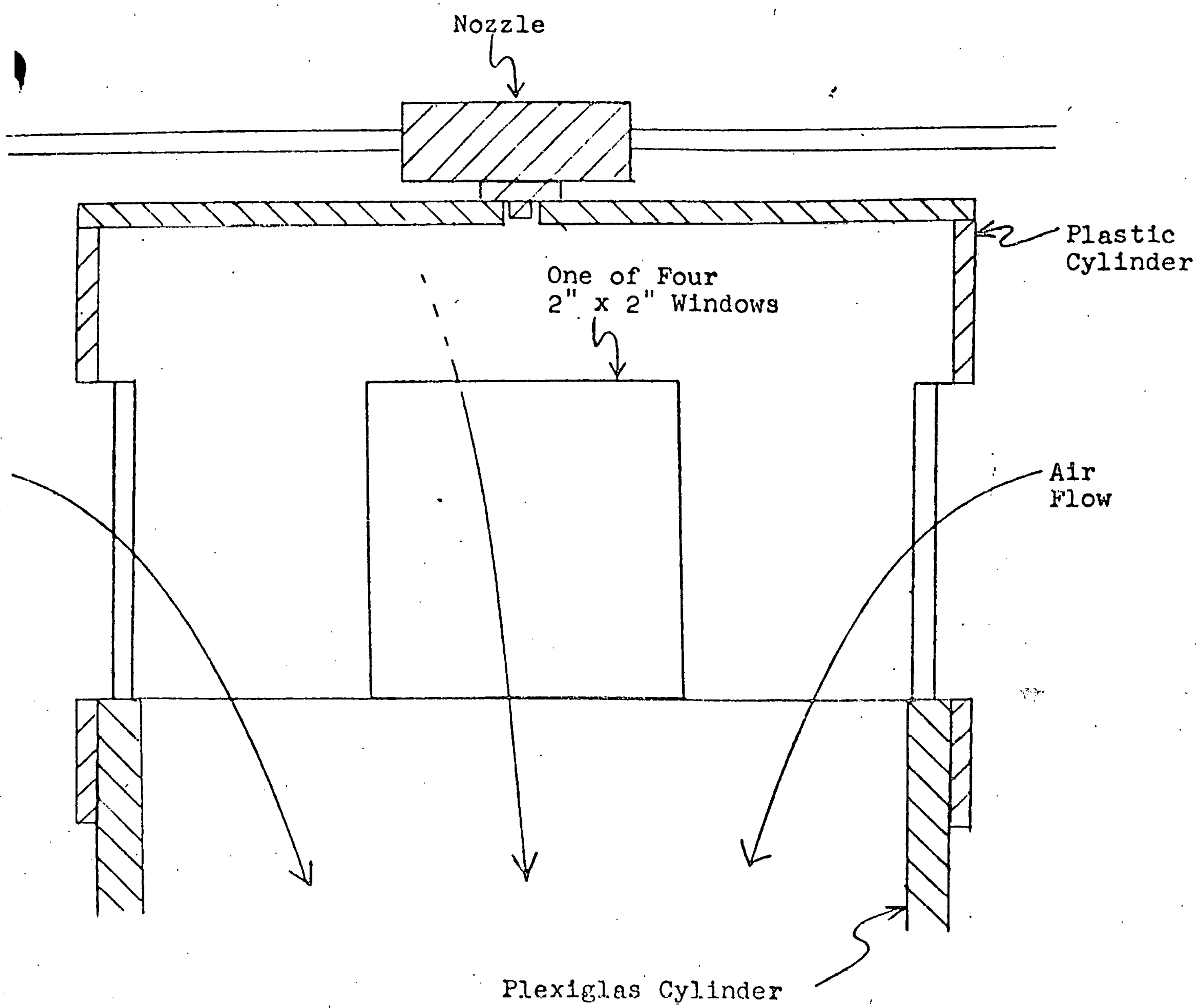


Figure 4. Configuration 5.
Actual Size

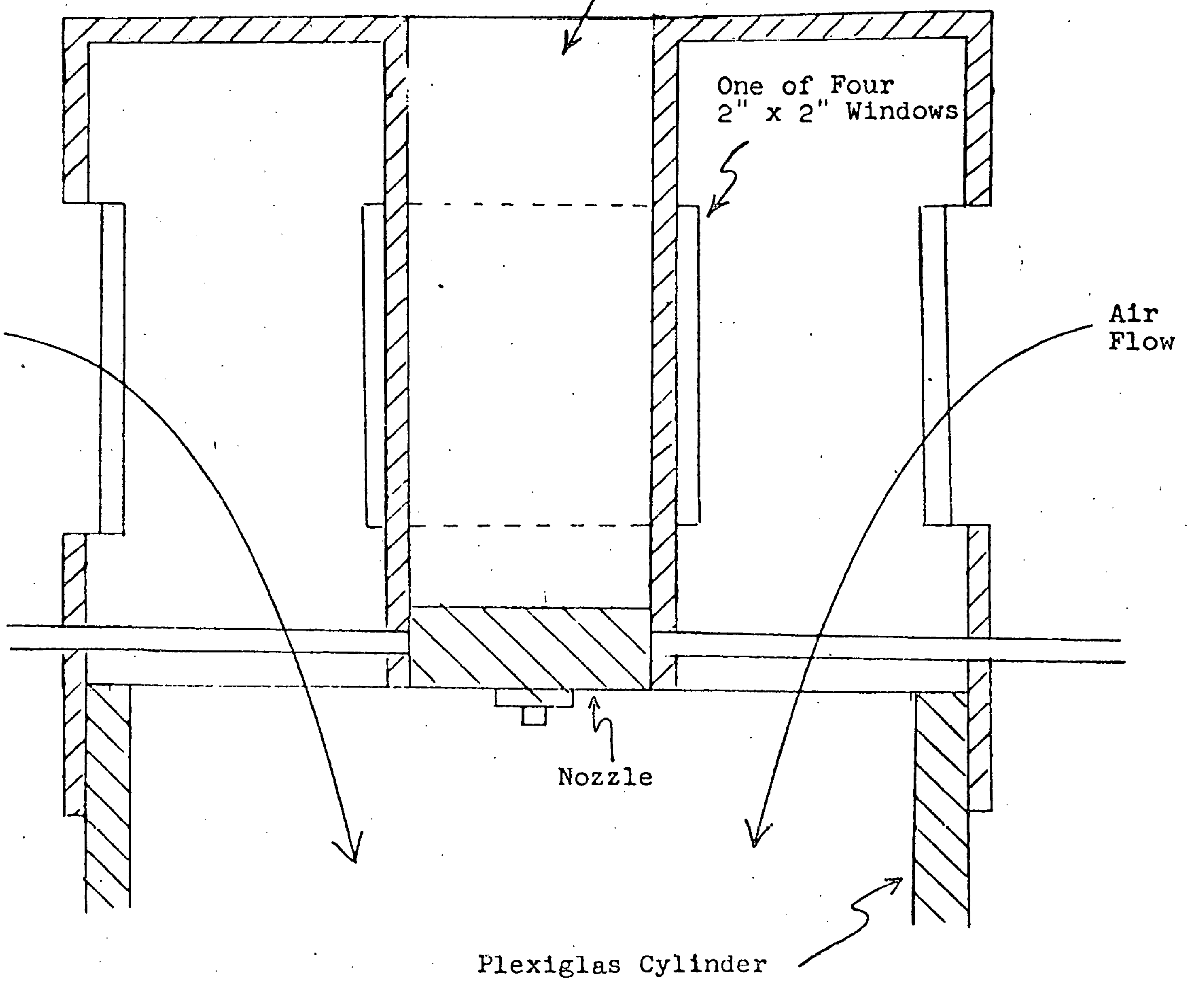


Figure 5. Configuration 6.
Actual Size