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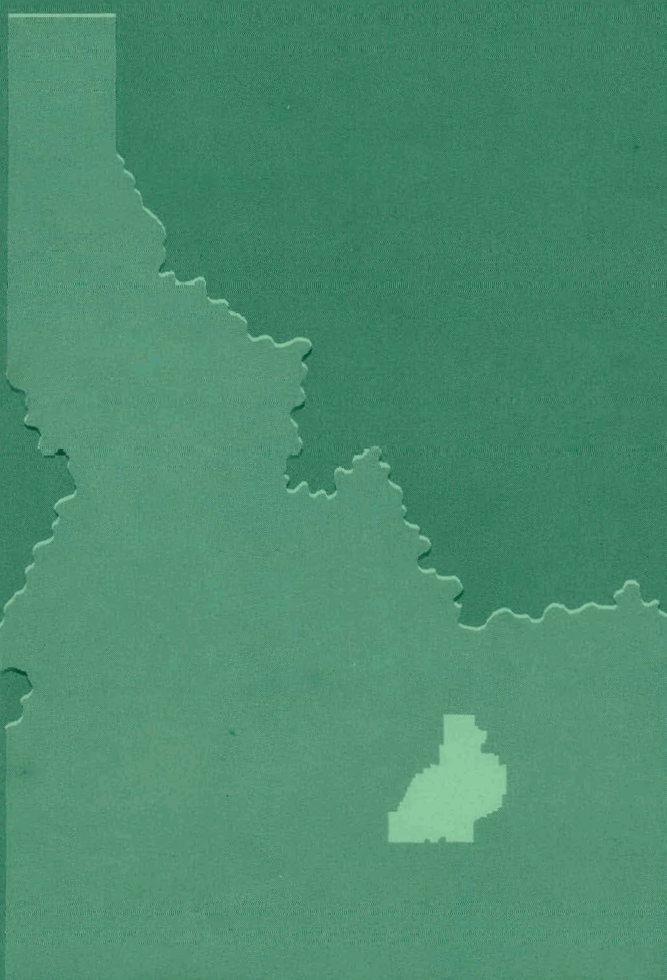
PNEUMATIC ATOMIZING NOZZLES IN FLUIDIZED BED CALCINING
I. CALIBRATION TESTS

B. M. Legler
J. I. Stevens

May 12, 1961



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by

B. M. Legler
J. I. Stevens

ABSTRACT

This report presents the results of test stand studies of a pneumatic atomizing nozzle to be used in the Demonstrational Waste Calcining Facility at the Idaho Chemical Processing Plant. Atomization and performance characteristics are described. The liquid feed control system for the Demonstrational Waste Calciner is compared with results of bench scale tests and recommendations are made for improving the system.

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I. SUMMARY

Test stand studies of a Type 1/2J atomizing nozzle, manufactured by Spraying Systems Company for the ICPP Demonstrational Waste Calcining Facility, were conducted to determine separately the atomization characteristics of the spray and the performance characteristics (flow rates, pressures) of the nozzle when spraying into air. Both atomization and performance characteristics were determined for water. Performance characteristics only were determined for aluminum nitrate solutions of 1.155 and 1.30 specific gravity. Feed rates from 10 to 50 gallons per hour and nozzle air-to-feed volumetric ratios from 300 to 1100 were investigated.

Excellent atomization of water in air was observed generally at nozzle air-to-feed volumetric ratios greater than 500. Changes in nozzle performance were shown to be caused by nozzle physical effects, such as erosion and installation technique, as well as by feed solution composition effects. The air flow rate of the nozzle was found to be a direct function of the air supply-to-discharge pressure ratio in absolute units and to be predictable by theoretical methods.

The original design of the system to control the feed rate to the Demonstrational Waste Calciner made use of the feed nozzle flow characteristics; i.e., at any selected liquid inlet pressure on the nozzle it was assumed that a given air pressure would atomize a specific volume rate of feed solution. Changes in nozzle performance found during the present studies indicate that the control of feed rate based simply on nozzle performance calibration is inadequate. A new feed control system which will not be affected by the demonstrated changes in nozzle performance is recommended.

Further nozzle testing in a pilot plant calciner is necessary before the effects of nozzle variables on the calcination operation can be defined.

II. INTRODUCTION

A semi-works scale Demonstrational Waste Calcining Facility[1, 2] being constructed at the Idaho Chemical Processing Plant (ICPP) will attempt to convert the radioactive aqueous wastes from reprocessed aluminum reactor fuel to granular alumina. The conversion to solid will be accomplished by spraying the aqueous waste solution through pneumatic atomizing nozzles below the surface of a heated and fluidized bed of solids. In previous pilot plant calcination studies[3], pneumatic atomizing nozzles, Type 1/4J, manufactured by Spraying Systems Company were used satisfactorily at feed rates up to 6.0 gallons per hour each and at nozzle air-to-feed volumetric ratios* as low as 280. These nozzles provided satisfactory feed injection to pilot plant calciners of six-inch diameter and two-foot square configurations. The variable nozzle air feature eliminates the need for a separate jet grinder which others[8] have found necessary to control particle size.

Based on these pilot plant results, a similar type nozzle was specified by the architect-engineer for the four-foot diameter calciner of the Demonstrational Waste Calcining Facility (DWCF). A minimum number of nozzles was desired to minimize piping and controls in the demonstrational facility. It was thus necessary for the architect-engineer[2] to specify a relatively large capacity nozzle having approximately seven times the liquid feed rate and twelve times the air rate of the small pilot-plant nozzles. The architect-engineer specified two nozzles for feeding waste solution plus recycled acid at 40 gallons per hour each to the four-foot diameter calciner. Because the included spray angle of the larger nozzles is nearly the same as the pilot-plant nozzles, it was feared that the greater density of the spray issuing from the larger nozzle might cause caking in the fluidized bed of the calciner. On the other hand, an increased nozzle air-to-feed volumetric ratio might cause an excessive production of particulate solids too small to serve as seed particles.

To be effective in the calcination operation, the spray droplets must lie within a size range as yet undefined. Below some extremely fine spray droplet size, alumina particles may be produced which are too small to act as seed particles and are subsequently either elutriated by the fluidizing gas or agglomerated by contact with liquid droplets of the spray to form a tacky mass. At the opposite extreme in spray droplet size, there is a possibility of bed caking from large liquid droplets or from liquid not completely atomized. Large particles result in poor heat transfer to the fluidized bed. Satisfactory operation of a fluidized bed must lie somewhere between these two extremes.

At a given feed rate, the size range of liquid droplets produced by two-fluid atomizing nozzles is controlled by the rate of atomizing

---

*Air-to-feed volumetric ratio is based upon air at the metered temperature and calciner vessel pressure.

air supplied to the nozzle. As a result of unknown effects of the large nozzle on the calcination process, a test program was initiated to determine these effects. The tests described herein constitute the initial effort conducted on a test stand in the open air in order to define nozzle performance and atomization characteristics. The test results of this large atomizing nozzle in a pilot plant fluid bed calciner are beyond the scope of this report and will be reported separately.

Shown in the inset of Figure 1 is a cross section of the nozzle specified for the demonstrational calciner. These nozzles are manufactured by Spraying Systems Company and are designated as Type 1/2J two-fluid, external-mixing, atomizing nozzles. Nozzle parts are fabricated of titanium; air and liquid supply connections are of Type 347 stainless steel. Liquid to be atomized issues from a central 0.25-inch diameter orifice which is surrounded by a concentric annular air orifice 0.375-inch I.D. and 0.437-inch O.D. A cleanout plunger is provided for removing plugs from the liquid orifice if necessary. The initial installation of the nozzles will be in the wall of the calciner six inches below the predicted level of the fluidized bed.

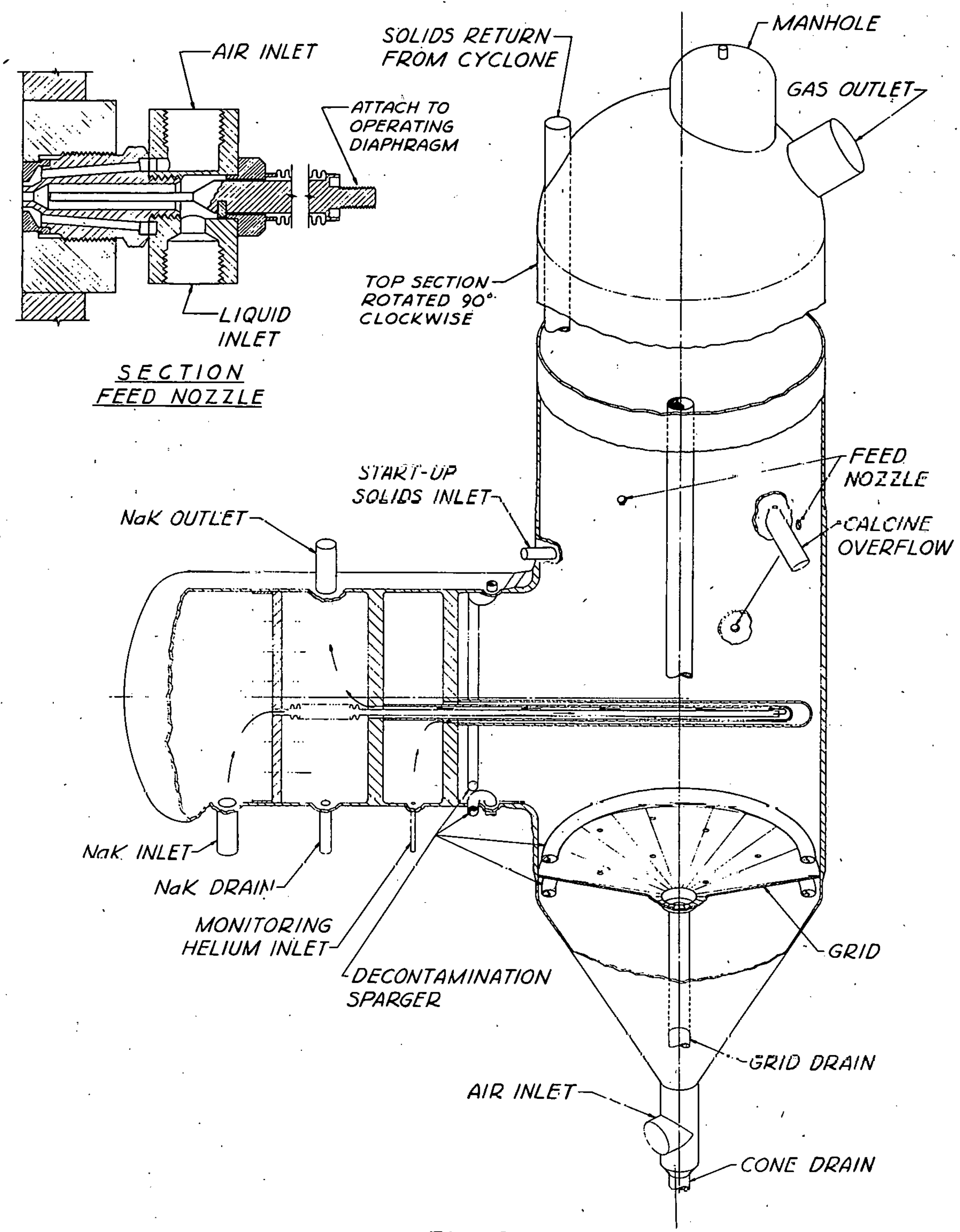


Fig. 1

Demonstrational Calciner and Feed Nozzle Cross Section

III. TEST STAND EXPERIMENTS

The atomization characteristics and the performance characteristics such as flow rate and pressure drop as well as the secondary effects of nozzle erosion and method of installation are important to the understanding and operation of pneumatic atomizing nozzles in a fluidized bed calciner. Therefore, a test stand program was undertaken to determine these characteristics and effects.

A. Atomization Tests

Two-fluid, external mixing nozzles have been used in the pilot plant to atomize a simulated radioactive liquid waste solution beneath the surface of the fluidized bed. The solution thus atomized coats the fluidized particles present in the calciner and possibly produces additional "seed" particles for future growth. Consequently, characteristics of the spray are all-important in the calcination process. A "wet" spray can produce agglomeration resulting in bed caking while an excessively fine spray can produce spray drying resulting in high elutriation losses. Water was chosen for the initial bench investigation of the atomization characteristics of the nozzle because it could be used without elaborate preparation of auxiliary equipment. The bench atomization tests also permitted rapid visual comparison of various nozzle tip designs.

Good atomization is defined by the manufacturer as any condition at which atomized droplets in the center of the spray pattern do not exceed 200 microns in diameter. In Figure 2 is shown a plot of the manufacturer's performance data based on spraying water at 70° F into the atmosphere at 14.7 psia. All points shown in this figure are in the manufacturer-defined region of good atomization. Neither actual distribution of droplet sizes nor minimum droplet size in the nozzle spray pattern is given. Furthermore, the reported data are for a standard nozzle without a cleanout plunger, so this calibration may not be directly applicable to the demonstrational calciner nozzles which contain cleanout plungers.

In a further effort to define effective atomization, two independent investigations were made using the same nozzle. One of these investigations[5] involved a cursory visual atomization study in which water was sprayed into the atmosphere. After establishing a selected rate of water flow, the air flow was started and the rate increased until good atomization was obtained. In this case, good atomization was defined as any condition which provided uniform droplet size and distribution on a "Lucite" plate when passed through the spray in a direction perpendicular to the spray axis. Photographs of good and poor atomization are shown in Figure 3. Figure 4 attempts to show the boundary between good and poor atomization as defined above. Because of data scatter resulting from visual observations, a definite demarcation between good and poor atomization was not obtained. It can only be said that the region above the broken line in Figure 4 should represent conditions at which good atomization is definitely assured. In conducting this atomization test, pressure conditions at the nozzle liquid inlet were not determined, so a performance curve similar to Figure 2 could not be constructed.

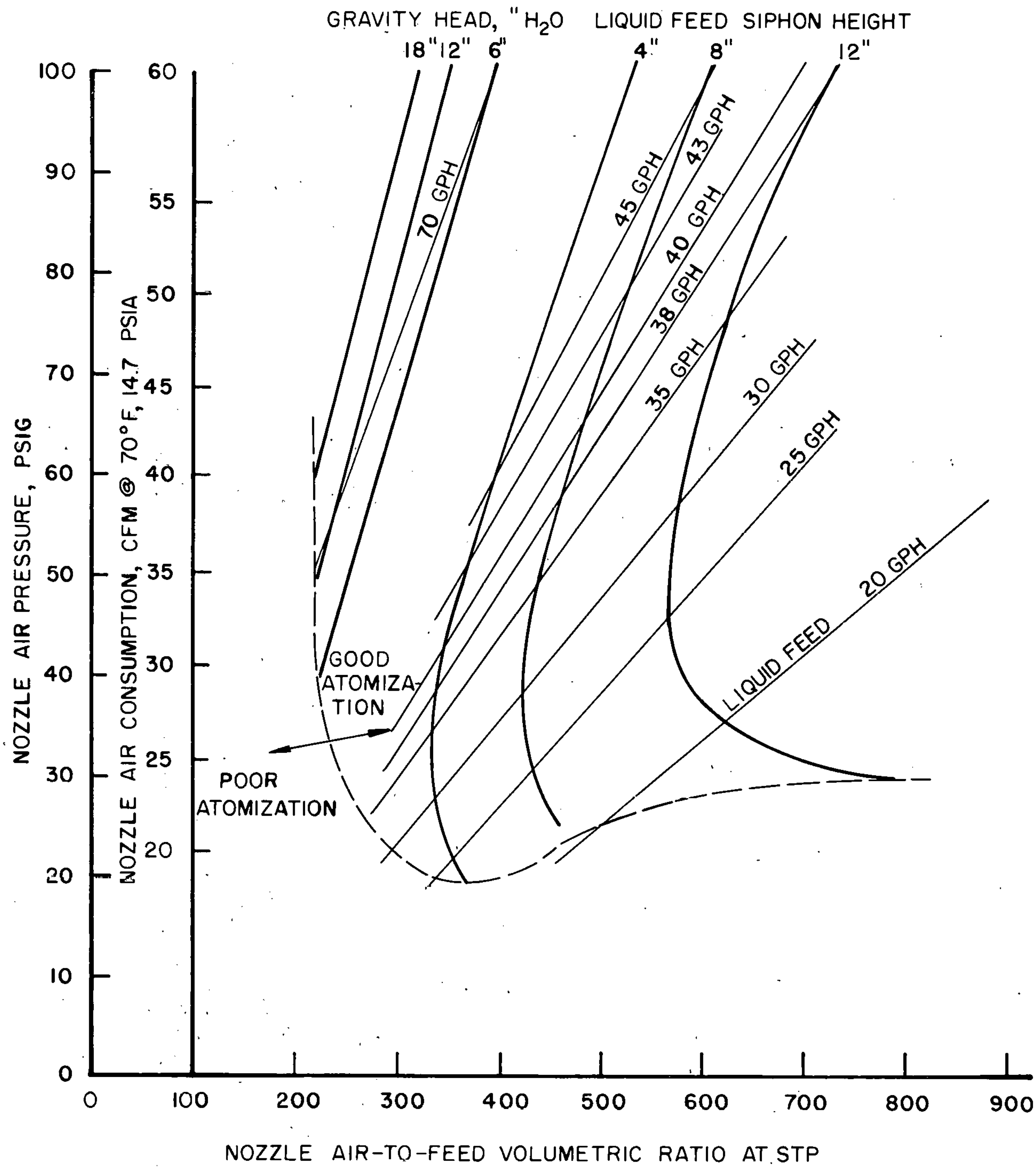
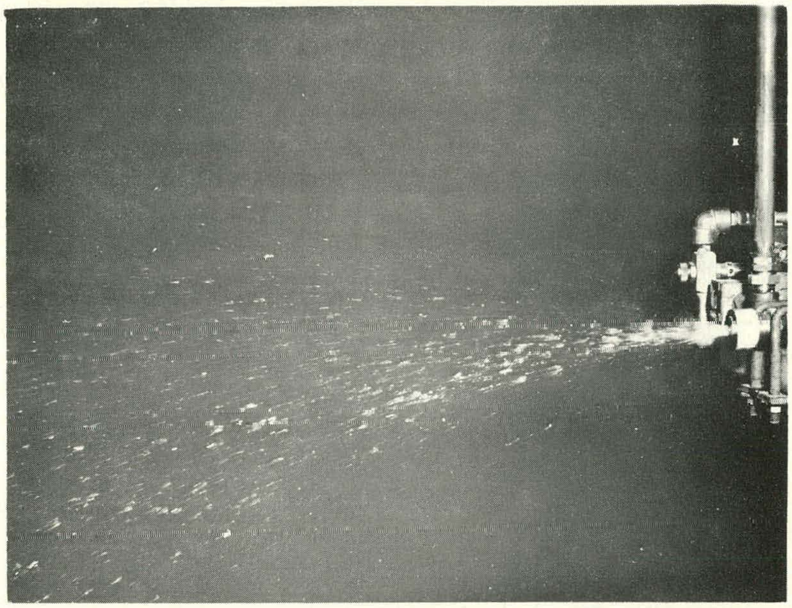


Fig. 2
Vendor Performance Data for
Atomization of Water in Demonstrational Calciner Feed Nozzle



Poor Atomization

Good Atomization

Fig. 3
Photographs Comparing Poor Atomization to Good Atomization

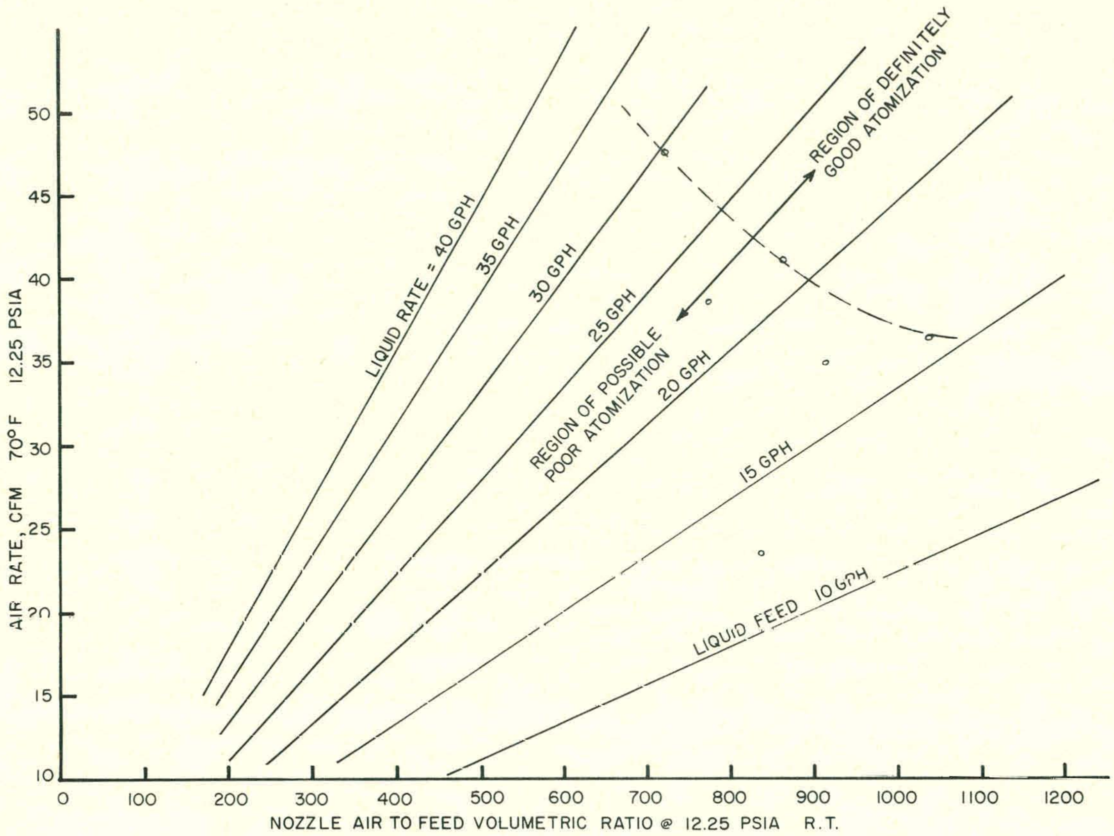


Fig. 4
Nozzle Atomization Characteristics for Water
Using a Plane Spray Collector

In the second investigation(6), complete calibration data as well as atomization characteristics were obtained and are presented in Figure 5. In this case good atomization was defined, with the aid of a wide beam spotlight, as any condition at which no rivulets were visible in the spray. At a given air rate, the water rate was decreased from a point where obviously poor atomization prevailed until complete atomization was obtained. The demarcation between good and poor atomization zones is indicated by a broken line.

B. Performance Tests

The manufacturer's performance data shown in Figure 2 were assumed by the DWCF architect-engineer to be precise enough so that feed rate control could be accomplished by making use of the feed nozzle flow characteristics. An independent performance check(6), Figure 5, showed that the manufacturer's data were not duplicated. The differences in performance may be attributable to the different atmospheric pressure base for each calibration and to the absence of a cleanout plunger in the nozzle calibrated by the manufacturer. Also, performance calibrations(6) were made for two different aluminum nitrate concentrations. These data are plotted in Figures 6 and 7. These plots differ significantly from those for water shown in Figures 2 and 5 and show that performance is dependent upon solution density and/or viscosity.

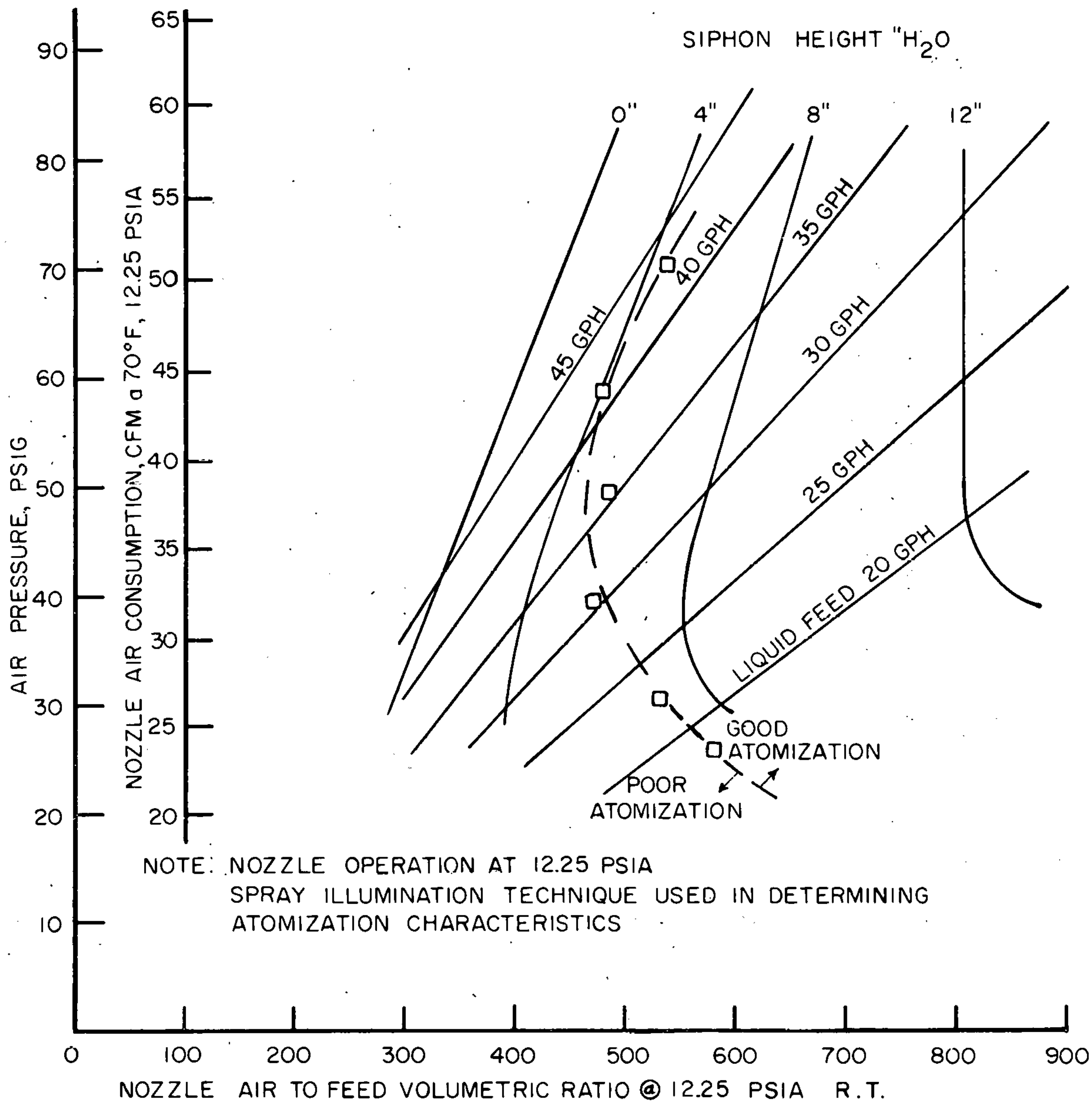


Fig. 5

Nozzle Performance Characteristics for Water

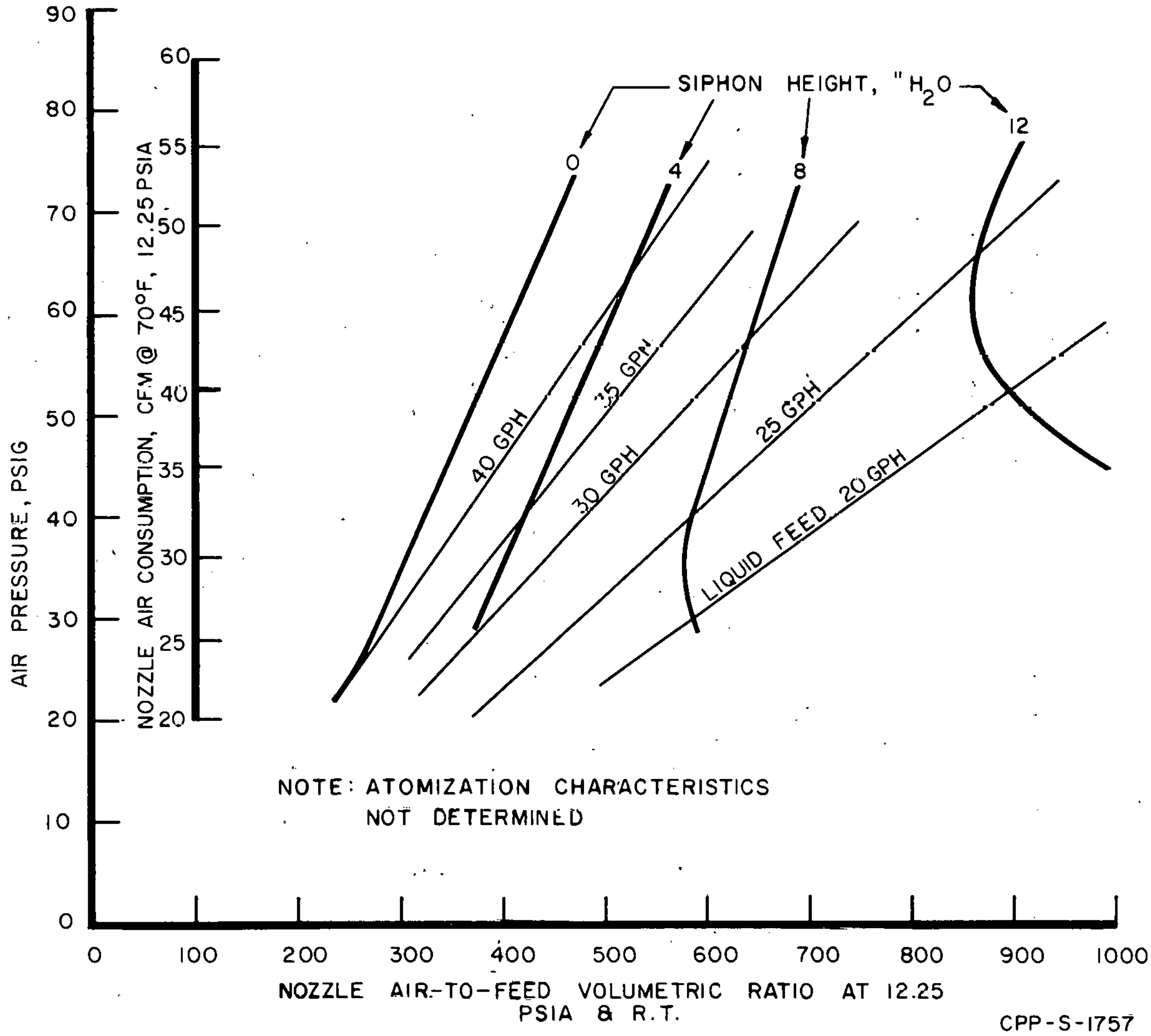


Fig. 6
Nozzle Performance Characteristics for 1.155 Sp. Gr. $Al(NO_3)_3$

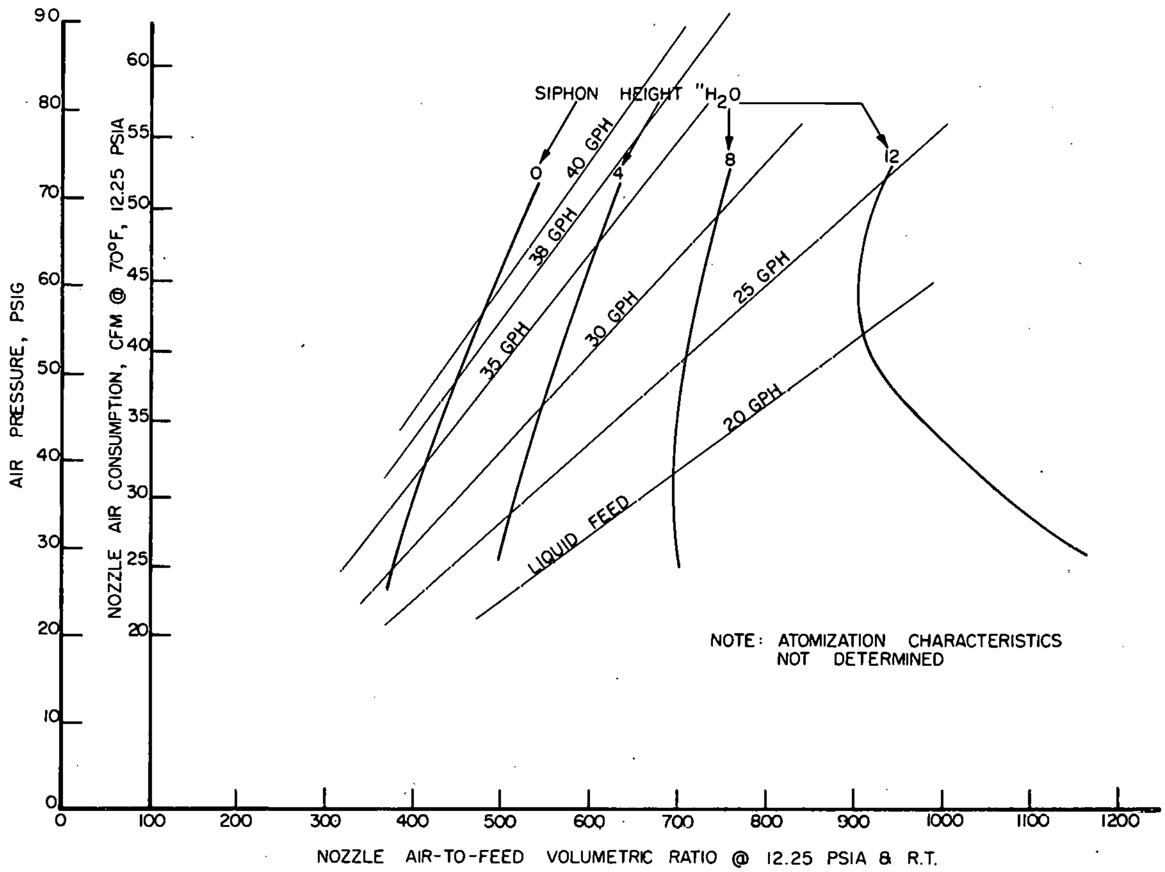


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Fig. 7
Nozzle Performance Characteristics for 1.30 Sp. Gr. $Al(NO_3)_3$

Based on performance data shown graphically in Figures 2, 5, 6, and 7, two independent nozzle variables must be fixed before a particular nozzle performance point is known. For example, when feed rate and nozzle air-to-feed volumetric ratio are specified, then the performance is defined and the dependent variables (air rate or air pressure, and feed pressure - in this case) can be obtained from a plot of the calibration data. Air rate and air pressure are related as explained in Section IV and as shown in Figure 9.

C. Erosion Effects on Nozzle Performance

It is obvious from the nozzle cross section shown in the inset of Figure 1 and the aforementioned manner of installation that the flat face of the nozzle is exposed to the fluidized particles of the calciner bed. These fluidized alumina particles can be expected to provide a very erosive environment, especially in regions of violent agitation and impingement. During one test of 275 hours duration in the pilot plant calciner, a nozzle suffered severe erosion which affected both the liquid and air orifices. Pertinent orifice dimensions before and after erosion are given in Table 1.

TABLE 1

Atomizing Nozzle Orifice Dimensions

Orifice	Original Condition, In.	Eroded Condition, In.	Dimension Change, In.
Liquid I.D.	0.250	0.252	0.002
Air I.D.	0.375	0.375	0
Air O.D.	0.437	0.4385	0.0015

In addition to the orifice wear indicated in Table 1, considerable erosion occurred on the flat face of the air nozzle. This annular surface (0.437" I.D., 0.97" O.D.) is concentric with and perpendicular to the axis of the liquid orifice. The most severe erosion on this surface occurred immediately adjacent to the annular air orifice. The erosion diminished at increasing radial distance from the annular air orifice, becoming negligible in the outer radial two-thirds of the air nozzle face.

Calibration of the eroded nozzle showed that the rate of liquid delivery had increased at otherwise identical conditions. Table 2 presents a comparison of calibration data before and after the erosion occurred.

TABLE 2

Effects of Nozzle Erosion on Performance

Liquid Feed Pressure	Nozzle Air Pressure, PSIG	Liquid Delivery, GPH Original Nozzle	Eroded Nozzle
-8" H_2O	60	33	39
-4" H_2O	60	41.5	48
0" H_2O	60	49.7	56

The changes due to erosion obviously were sufficient to negate the original calibration.

D. Effects of Installation on Nozzle Performance

During nozzle calibration, it was noted that slight changes in position of the liquid nozzle cleanout plunger resulted in a significant change in the liquid feed inlet pressure. This is tantamount to a calibration change.

Installation technique also was found to have an effect on nozzle performance characteristics. In one test, loosening the nozzle only one-fourth turn from finger tight resulted in a 50 per cent increase in liquid flow at otherwise identical conditions. The difficulty of assuring a uniform installation of each nozzle makes it doubtful that test stand calibration based on air and liquid pressures can be used with confidence when a nozzle is installed in the wall of the calciner.

IV. THEORETICAL ASPECTS OF ANNULAR AIR NOZZLE

The volumetric air rate through the annular orifice of the nozzle is measured both in the pilot plant and the DWCF. However, a rapid method of checking the accuracy of the measurement should be possible from the pressure drop across the orifice. The theoretical aspects of the air orifice are considered in the following paragraphs.

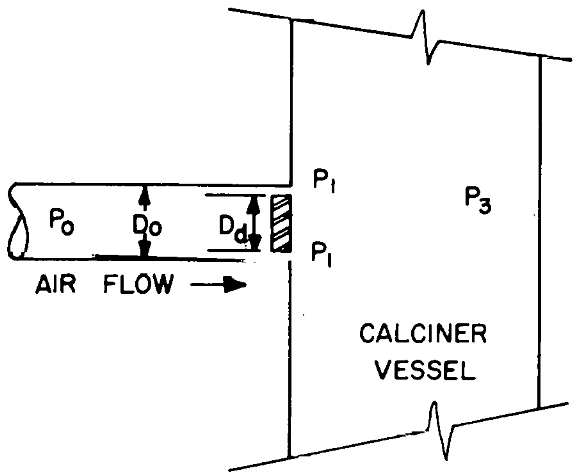

Fig. 8
Schematic Representation of Air Nozzle Annular Orifice

An annular orifice representing the nozzle air orifice is shown schematically in Figure 8.

In this figure, P_o represents the upstream pressure, P_1 the pressure at the vena contracta, and P_3 the calciner vessel pressure, all expressed in pounds per square foot absolute.

At a given set of calciner conditions, the gas discharge rate from the annular orifice will increase as the upstream to calciner pressure ratio, P_o/P_3, increases. The increase in gas discharge rate will continue until the linear velocity in the vena contracta reaches the acoustic velocity at the specific conditions of the vena contracta. At this point the critical pressure ratio $(P_1/P_o)_c$ is attained. At still further increases in the ratio of upstream to calciner pressure, P_o/P_3, the vena contracta pressure, P_1, remains equal to the critical pressure, P_c, and the velocity in the vena contracta remains at the acoustic velocity. However, there will be some increase in the area ratio of vena contracta to orifice thereby effecting some increase in the mass discharge rate of air through the annular orifice. This is the same as saying that the orifice coefficient increases because the vena contracta area increases. However, the increase in the vena contracta area is relatively small and the change in the orifice coefficient may usually be neglected. The mass flow rate increases even though the volumetric flow rate remains essentially the same because the density increases at the vena contracta as the upstream to calciner pressure ratio, P_o/P_3, increases.

The critical pressure ratio, $(P_1/P_o)_c$ or P_c/P_o, is given by the following equation:[7]

$$\frac{k+1}{\left(\frac{P_1}{P_o}\right)_c^{2/k}} - \frac{2}{\left(\frac{P_1}{P_o}\right)_c^{(k+1)/k}} - \frac{(k-1)}{(A_o/A_a)^2} = 0 \qquad (1)$$

where:

- $k = C_p/C_v$, ratio of specific heat at constant pressure to that at constant volume
- P_1 = Vena contracta pressure, lb/ft^2 absolute
- P_o = Pressure upstream from orifice, lb/ft^2 absolute
- P_c = Critical pressure at vena contracta, lb/ft^2 absolute
- A_a = Orifice cross sectional area, ft^2
- A_o = Upstream channel cross sectional area, ft^2

For large values of A_o/A_a the above equation reduces to:

$$\left(\frac{P_1}{P_o}\right)_c = \frac{P_c}{P_o} = \left[\frac{2}{k+1}\right]^{k/(k-1)} \qquad (2)$$

For air, k = 1.4 and

$$P_c = 0.528\ P_o \qquad (3)$$

Thus, for values of calciner pressure to upstream nozzle air pressure ratio, P_3/P_o, equal to or less than 0.528, the vena contracta pressure, P_1, is identical to the critical pressure, P_c, and the linear velocity in the vena contracta is the acoustic velocity.

A typical orifice flow equation[7] is:

$$w = CY_oA_a\sqrt{\frac{2\ g_c\ (P_o - P_1)\rho_o}{1 - \alpha^2}} \qquad (4)$$

where:

- w = Weight rate of flow, lb/sec
- C = Discharge coefficient
- Y_o = Expansion factor $= 1 - \frac{(P_o - P_1)}{P_o k}(0.41 + 0.35\alpha^2)$
- A_a = Orifice cross sectional area, ft^2
- g_c = Gravitational constant, 32.17 ft/sec^2
- P_o = Upstream pressure, lb/ft^2 absolute
- P_1 = Throat pressure, lb/ft^2 absolute
- ρ_o = Upstream fluid density, lb/ft^3
- α = Fractional open area
- $k = C_p/C_v$

A discharge coefficient of 0.645 is quoted by Lapple[7] for a sharp-edged annular orifice for ratios of blocked diameter to channel diameter, (D_d/D_o), in the range of 0.7 to 0.9. This ratio for a demonstrational calciner nozzle annular air orifice is 0.86. Even though the air orifice configuration cannot be considered as sharp-edged, a coefficient of 0.645 will be used in the following derivation.

It has been found[7] that the expansion factor, Y_o, may be taken as unity when the density, ρ_o, is taken at the calculated vena contracta critical pressure, P_c(where $P_c = 0.528\ P_o$), at values of $P_3/P_o \leq 0.528$. For this particular condition the orifice equation becomes:

$$w = CA_a\sqrt{\frac{2g_c\ (0.472\ P_o)\ \rho_c}{1 - \alpha^2}} \qquad (5)$$

where:

ρ_c = Density at vena contracta

Substituting actual values for the demonstrational calciner nozzle gives:

$$w = 1.205 \times 10^{-2}\sqrt{p_o\,\rho_c} \qquad (6)$$

where:

p_o = Upstream pressure, psia
ρ_c = Vena contracta density, lb/ft^3
(Note the change from psfa to psia.)

Weight rate is easily converted to volume rate, V in cfm, at calciner pressure by the following equation:

$$V = \frac{60w}{\rho_3} \qquad (7)$$

where:

ρ_3 = Density at 70° F and calciner pressure, p_3

Combining equations (6) and (7):

$$V = \frac{0.723}{\rho_3}\sqrt{p_o\,\rho_c} \qquad (8)$$

Assuming the perfect gas law for air, equation (8) can be simplified further to:

$$V = 7.36\,\frac{p_o}{p_3} \qquad (9)$$

where:

V = Nozzle air flow rate at 70° F and calciner pressure, cfm
p_o = Nozzle air supply pressure, psia
p_3 = Calciner pressure, psia
$p_3/p_o \leq 0.528$

Equation (9) is plotted in Figure 9 along with experimental and vendor data. It is seen that both theoretical and experimental correlations show nozzle air consumption to be a direct function of the nozzle air supply-to-discharge pressure ratio. Since the theoretical relationship expressed by equation (9) yields air volume at 70° F and calciner pressure, it should be especially useful in regulating the nozzle air-to-feed volumetric ratio which also is based on this temperature and pressure.

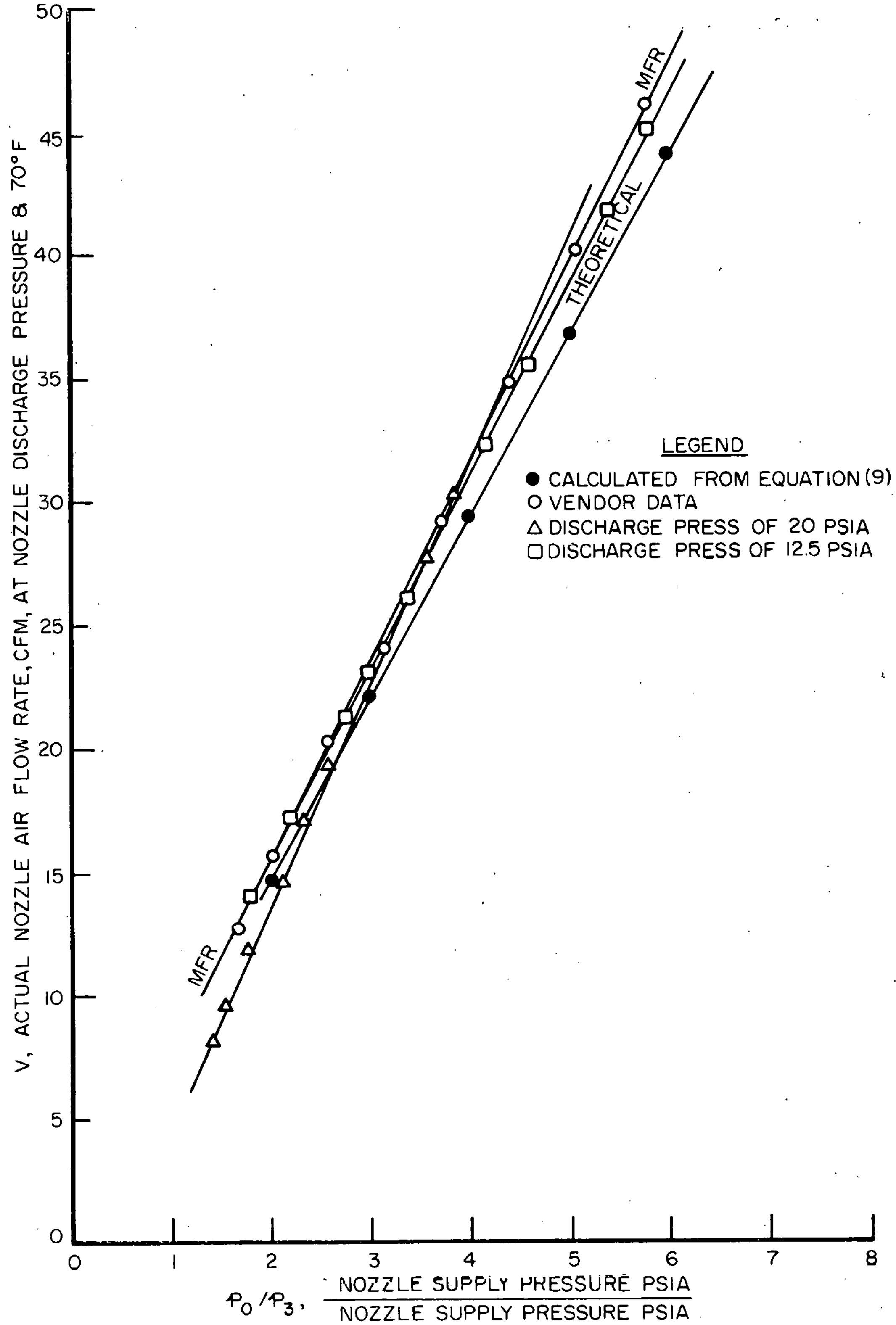

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Fig. 9

Nozzle Air Rate Versus
Inlet-to-Discharge Absolute Pressure Ratio

V. NOZZLE FEED RATE CONTROL FOR THE DEMONSTRATIONAL CALCINER

Simplicity and gravity flow constituted the design criteria for nozzle feed rate control to the demonstrational calciner(2). Pumping was avoided to eliminate dependence upon mechanical devices in a radioactive processing area. Flow control is based simply on feed nozzle performance characteristics. For example, at any specific liquid inlet pressure to the nozzle, a given air pressure will atomize a given amount of feed solution as shown by the manufacturer's data plotted in Figure 2. Feed rate control is thus indirect and depends upon a valid nozzle calibration.

Fresh waste solution, mixed with a recycle stream containing particulate alumina, is fed by gravity from a constant-head feed tank through a common header to three feed nozzles, one of which is an installed spare. A nozzle cross section is shown in the inset of Figure 1. Each individual nozzle feed line contains an automatic throttling valve upstream from the nozzle. Between the throttling valve and the nozzle is a pressure tap which senses the nozzle inlet liquid pressure. This pressure is transmitted to a pressure controller which regulates the throttling valve. The automatic throttling valve in each feed line is designed to provide any required constant inlet liquid pressure to the nozzle. This control depends upon the calciner pressure being maintained constant by another pressure control system.

Periodic direct feed rate determinations can be made with an installed calibrated metering pot. Such determinations will yield only the total flow, rather than individual nozzle flow, over a finite time period. This is also true of overall rate checks obtained from level differences in the waste hold tanks.

Calibration data provided by the manufacturer, Figure 2, and those obtained in this investigation, Figure 5, are significantly different. During calibration it was noted that any change in position of the liquid nozzle cleanout plunger resulted in a significant change in the liquid feed inlet pressure. Nozzle wear also resulted in a significant calibration change as shown in Table 2. Furthermore, installation technique was found to have an effect on nozzle performance characteristics.

Since any one of these several factors can lead to a calibration change which would be imposed on the feed rate control that is in turn dependent upon the control of the three variables, calciner pressure, nozzle air pressure, and nozzle liquid inlet pressure, it is obvious that difficulties are to be expected in maintaining the desired equal and constant liquid rates through individual calciner feed nozzles. Any plugging, wear, or other nozzle changes will result in changing the liquid feed pressure and departing from nozzle calibration data upon which operational control depends.

VI. CONCLUSIONS AND RECOMMENDATIONS

Although the nozzle tests reported herein were conducted on a test stand and not in a calciner, several conclusions which are applicable to calciner operation can be made.

Calibration changes in nozzle performance can be caused by several factors. Among these are: nozzle erosion, cleanout plunger misalignment, installation technique, plugging, and changes in feed solution properties.

Precise feed rate control, based simply on feed nozzle performance characteristics, is unlikely because of calibration changes.

Both theoretical and measured correlations show that nozzle air rate is a direct function of the air supply-to-discharge absolute pressure ratio.

Nozzles should be calibrated in place in the demonstrational calciner before the calciner is operated. Periodic calibrations should be performed to determine the extent of changes in nozzle performance characteristics.

It is recommended that a direct feed control system be installed in each nozzle feed line. The recommended system consists of an electromagnetic flowmeter transmitter and a flow controlling recorder containing a pneumatic controller assembly for throttling the automatic control valve already installed in each feed line. The proposed control system will obviate dependence upon those individual feed nozzle characteristics which are subject to change.

Feed nozzles should be thoroughly tested in a pilot plant calciner to determine the effects of nozzle variables on calciner operation.

VII. ACKNOWLEDGMENT

Data presented in this report were obtained by D. R. Evans of the CPP Process Development Branch, R. E. Commander of the CPP Operations Branch, and J. L. Lockard of the CPP Staff Engineering Projects Branch.

VIII. REFERENCES

1. MacQueen, D. K., and J. I. Stevens, Design Bases for ICPP Waste Calcination Facility, IDO-14462, April 22, 1959.

2. Operating Manual - Waste Calcination Facilities, The Fluor Corporation, Ltd., February 3, 1960. (Undocumented AEC sponsored report published by the Idaho Operations Office under AEC contract AT(10-1)-883 and Fluor Contract 5775.)

3. Grimmett, E. S., Calcination of Aluminum-Type Reactor Fuel Wastes in a Fluidized Bed, IDO-14416, August 1, 1957. (Also Ref. 4)

4. Stevenson, C. E., Technical Progress Report for January through March 1959, Idaho Chemical Processing Plant, IDO-14471, August 27, 1959.

5. Evans, D. R., Private Communication.

6. Commander, R. E., Private Communication.

7. Lapple, C. E., Fluid and Particle Mechanics, University of Delaware, 1956.

8. Dunlop, D. D., L. I. Griffin, Jr., J. F. Moser, Jr., Particle Size Control in Fluid Coking, Chemical Engineering Progress, Vol. 54, No. 8, 39 - 43 (1958).

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