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Moyer,J.C.; Comstock,A.B.; Wooster,G.D.; Saravacos,G.D.

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Progress Report

Spray Drying of Soy Milk Whey

J. C. Moyer, A. B. Comstock, G. D. Wooster and G. D. Saravacos

Department of Food Science and Technology

New York State Agricultural Experiment Station

Geneva, New York

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Summary

An attempt was made to dry soy milk whey at 400°F with outlet temperatures ranging from 210° down to 120°F in a pilot scale spray dryer using a 2-fluid nozzle. Efforts to achieve outlet temperatures of 140°F and lower by restricting the air flow through the drying chamber and using relatively high liquid feed rates were unsuccessful. The retention time was too short for complete drying of the droplets and the air flow was insufficient for conveying the product from the drying chamber to the cyclone separator.

Some of the difficulties encountered were due to an inadequate knowledge of air velocities in the dryer and methods of controlling them, and to an appreciation of the degree of control of liquid and air nozzle pressures required to maintain the liquid feed rate within critical limits. Before pursuing further studies on the effect of spray drying conditions on nutritive quality of dried milks, a system was developed for monitoring the air flow in the dryer, determining the minimal velocity required to convey the product to the cyclone and the relationship between dry particle size and air velocity for good separation in the cyclone. More information is required on the interaction between liquid and air nozzle pressures, feed characteristics, evaporation rates in the dryer, and particle size in the dried product.

Introduction

A process has been developed in this laboratory for making a soy milk beverage having an improved flavor. Whole soybeans are soaked for 2 hours in 0.06N NaOH, at 50°C. After draining to remove the excess alkali, the soaked beans are ground with hot distilled water in a ratio of 1:10 (W/W) in a Rietz disintegrator equipped with a screen having 0.023" diameter holes. Steam is also injected into the grinding chamber to insure a temperature of 195°F or higher in the discharged slurry. This is filtered in a plate and frame filter and the filtrate then is either canned or dried as a soy milk beverage.

To date, the nutritive value and flavor of the alkali soak procedure have been evaluated using sterilized (canned) samples of soy whey. The purpose of the present study was to determine the acceptability of a spray dried whey and to evaluate the nutritional quality of spray dried powder using several drying temperature schedules. These temperature schedules are listed in Table 1.

Table 1

Temperature Schedule for Spray Drying Soy Milk Whey

Sample No.	Dryer Temperatures Inlet °F	Outlet °F
1	400	120
2	400	140
3	400	180
4	400	210

Samples No. 3 and 4 represent reasonably conventional spray drying schedules but Samples 1 and 2 have lower than normal outlet temperatures. To achieve these low temperatures, it is necessary to reduce substantially the air flow through the dryer and to use a maximal liquid feed rate consistent with obtaining a dried product. The present report deals with a study of the operational conditions in a small spray dryer needed to produce a dried product with low outlet air temperature.

Description of Spray Dryer

The main components of this spray dryer are shown schematically in Figure 1. The drying chamber consists of two parts: A main chamber 54" in diameter, 60" high that sits on a conical bottom having a 60° slope for delivery of the dried material at the discharge opening. On top of the cylinder, there is an extension 42" in diameter by 6' high. The total height of the drying chamber is then approximately 15 feet. The product is withdrawn from the bottom of the cone into a cyclone where the dried product drops into a collection drum and the air is discharged outdoors by the fan. The whole dryer is under a negative pressure and outdoor air is drawn into a gas fired furnace before entering the head section on top of the dryer. From the plenum chamber in the head section, the hot air descends into the dryer chamber through an annulus around the nozzle. In the center of this annulus is a cylinder of stagnant air that protects the liquid feed and compressed air

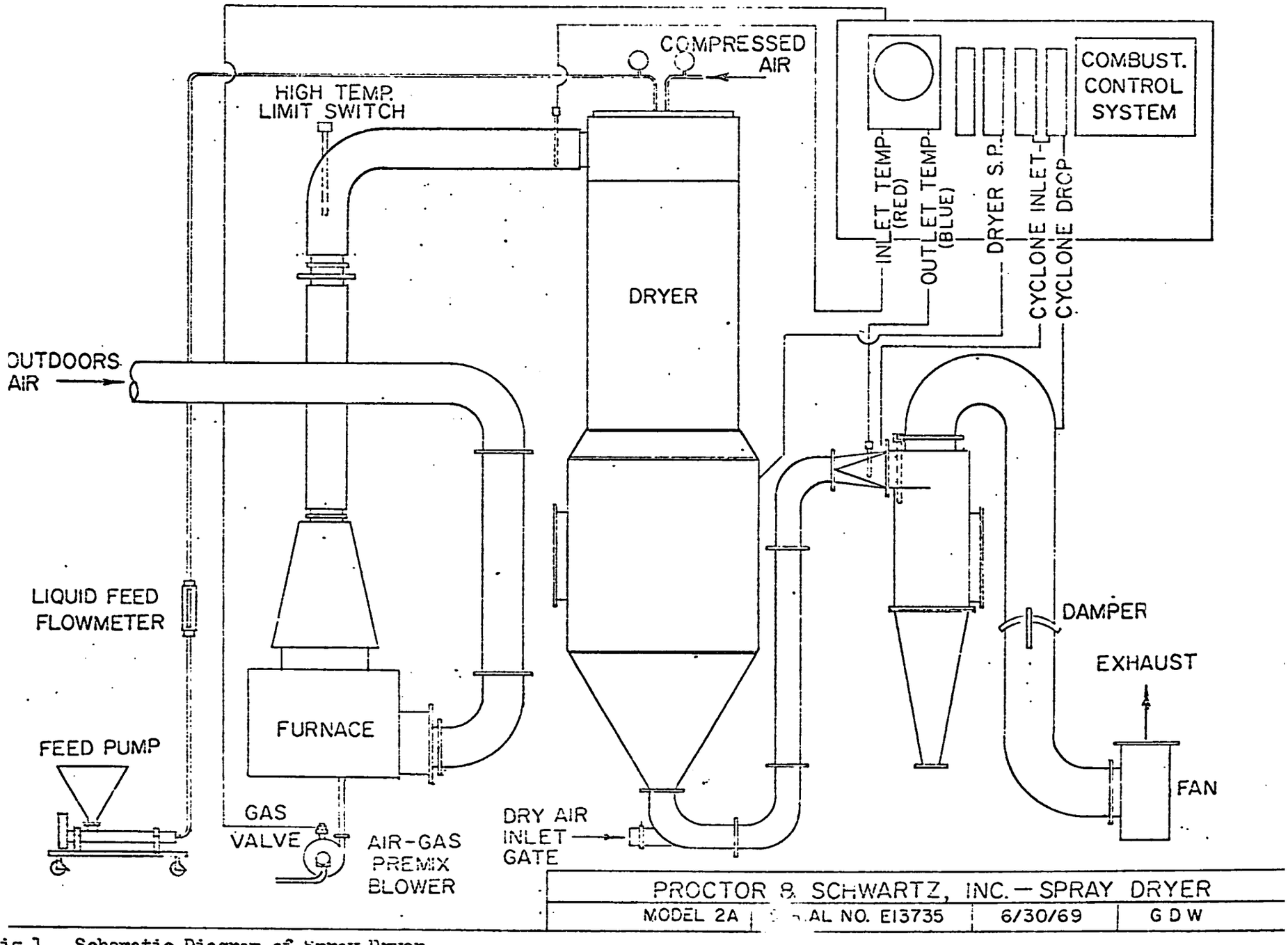


Fig.1. Schematic Diagram of Spray Dryer

lines to the nozzle from the heat of the drying air. This annulus has an open area of 1.66 sq. ft. and a number of straightening vanes for directing the air vertically downward. In practice, these straightening vanes have not provided a uniform curtain of air and it has been necessary to lay a sheet of perforated metal having 5/16" diameter holes staggered on 7/16" centers over the vanes. The actual opening into the drying chamber is then 0.78 sq. ft. With a volume of 1560 cfm air entering the drying chamber, the velocity of the air around the nozzle is approximately 2000 ft./min., and at a minimal air flow of 380 cfm, the velocity is reduced to 485 ft./min.

The amount of air flowing through the ing chamber can be controlled by the fan speed and a damper in the duct leading to the fan. The speed of the fan is controlled by varying the size of the sheaves on the motor and fan shafts. Performance curves for the fan at different speeds are shown in Figure 2. Throughout the present study, a fan speed of 1950 rpm was used and the air flow through the drying chamber was controlled by adjustment of the damper. The handle of the damper moves through a 90° arc and the attachment plate for locking the damper handle in place had crude markings for indicating the damper position. Later in the study, the damper position was better indicated by attaching a pointer to the damper shaft and adding a scale on which the 90° arc was marked off in percentages. These percentages are arbitrary markings and

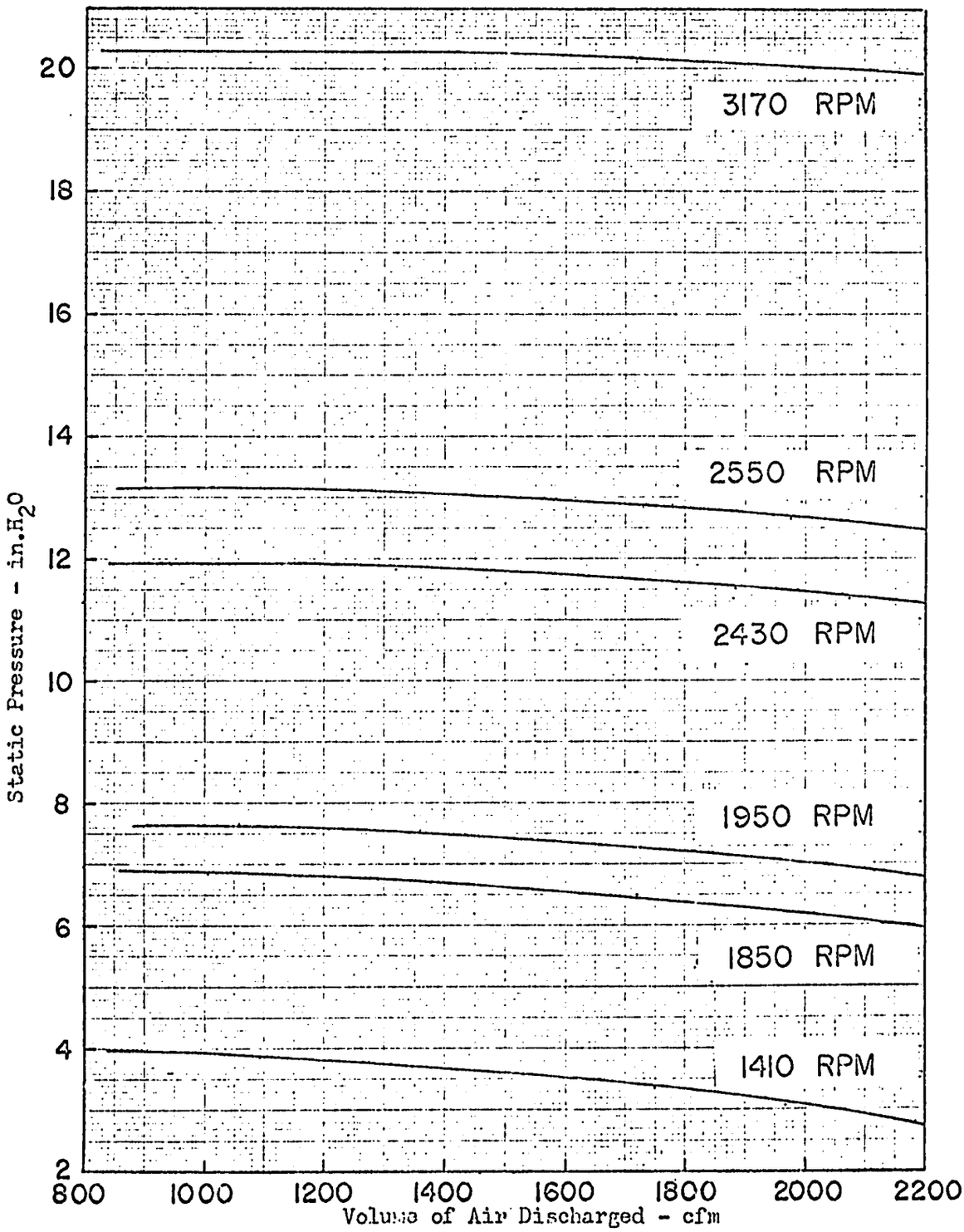


Fig.2. Fan Performance Curves

do not represent the percent of maximum air flow.

Air may also be admitted to the connecting duct to the cyclone through a secondary inlet that is controlled by a blast gate type damper. The purpose of this opening is to introduce cool air that reduces the temperature of the product before it enters the cyclone.

The temperature of the air entering the dryer is sensed by a bulb in the duct leading into the plenum chamber and recorded by one of the pens on a dual controlling thermometer which operates the pneumatic valve in the natural gas line to the furnace. A second bulb monitors the air temperature leaving the dryer.

The static pressures in the drying chamber, in the duct before the cyclone, and the pressure drop across the cyclone are measured by manometers mounted on the control panel.

Selection of the Spray Nozzle

A pneumatic atomizing nozzle was selected for dispersing the feed liquid into the drying chamber since it is the type commonly recommended for use in small spray dryers. These pneumatic nozzles disperse the liquid finely, providing a large surface for the rapid evaporation of water in the limited space of a small spray dryer. Their spray pattern is a relatively narrow full-cone which reduces the danger of coating the walls with product which would be scorched upon prolonged exposure to high temperatures. If particles of

this scorched material drop to the air stream, the general quality of the dried product is downgraded.

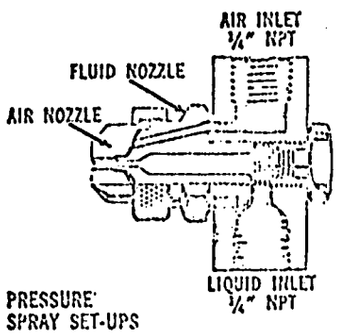
The pneumatic nozzle assembly contained two internal nozzles; one through which compressed air was admitted and another for the fluid. In this way, the air and fluid are mixed internally before discharge into the drying chamber as a spray pattern having a relatively narrow angle of 18°-21° and a length of 16 to 30 feet depending on the air and fluid pressures. The amount of liquid discharged is governed by the liquid and air pressures and by the ratio of these pressures. A schematic diagram of such a nozzle combination or pressure spray set-up and a chart giving the amounts of liquid discharged under different fluid and air pressures is shown in Figure 3. The liquid capacities of two of these pneumatic atomizing nozzles are shown graphically in Figures 4 and 5.

Pressure Spray Set-Up
...round spray

PNEUMATIC
ATOMIZING
NOZZLES

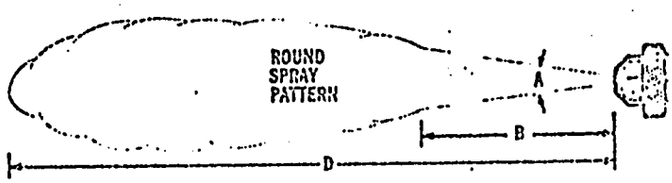
ROUND SPRAY AIR NOZZLE

Air Nozzle employed in these Spray Set-ups produces a full cone round spray.



PRESSURE SPRAY SET-UPS

Liquid is supplied to nozzle under pressure. Liquid and compressed air, gas or steam are mixed *internally* to produce a completely atomized spray.



General shape and pattern of round spray is shown above. Angle "A" is maintained throughout distance "B" by laminar-type atomized spray projection. Beyond "B", projected atomized spray becomes turbulent in form. Dimension "D" is total distance of spray projection from nozzle to maximum dispersal point. Tabulated in "Spray Dimensions" below.

Pneumatic Atomizing Nozzle with	Fluid and Air Nozzle combination	LIQUID CAPACITY in GPH (gallons per hour) and AIR CAPACITY in SCFM (standard cubic feet per minute) — WATER PRESSURE in p.s.i. (pounds per square inch)															SPRAY DIMENSIONS				
		10 p.s.i.			20 p.s.i.			30 p.s.i.			40 p.s.i.			60 p.s.i.							
		Air Press. p.s.i.	GPH	KG/HR	Air Press. p.s.i.	GPH	KG/HR	Air Press. p.s.i.	GPH	KG/HR	Air Press. p.s.i.	GPH	KG/HR	Air Press. p.s.i.	GPH	KG/HR	Air p.s.i.	Water p.s.i.	Spray Angle A deg.	B inches	D feet
Spray Set-Up No. 22B	Fluid Nozzle 40100 / Air Nozzle 1401110	16	3.44	13.0	23	5.03	19.0	40	6.10	23.1	43	7.75	29.3	65	10.70	40.5					
		20	2.35	8.9	32	3.70	14.0	44	5.03	19.0	55	5.95	22.5	75	8.67	32.8	24	10	18°	25″	16′
		22	1.90	7.2	36	2.64	10.0	48	3.95	14.9	65	3.55	13.4	80	7.65	28.9	40	20	20°	30″	20′
		24	1.54	5.8	40	1.85	7.0	55	2.30	8.7	75	1.95	7.4	85	6.55	25.2	55	30	20°	32″	22′
		26	1.23	4.7	44	1.30	5.0	60	1.55	5.9	80	1.40	5.3	90	5.64	21.3	75	40	21°	35″	26′
		28	.96	3.6	48	.90	3.4	65	1.03	4.1	85	1.00	3.8	95	4.63	17.5	85	60	21°	38″	30′
		30	.72	2.7	50	.76	2.9	70	.73	2.8	90	.72	2.7	100	3.62	13.7					
Spray Set-Up No. 22	Fluid Nozzle 60100 / Air Nozzle 1401110	12	8.1	30.6	20	13.6	51.4	30	16.3	61.7	38	19.5	73.8	54	25.7	97.2					
		14	6.6	25.0	22	12.0	45.4	34	13.1	49.6	42	16.5	62.4	60	21.8	82.5	14	10	17°	24″	16′
		16	4.9	18.5	24	10.2	38.6	38	9.9	37.5	46	13.6	51.4	65	18.5	70.0	26	20	18°	27″	19′
		18	3.4	12.9	26	8.6	32.5	40	8.7	32.9	50	10.8	40.9	70	15.2	57.5	40	30	20°	30″	22′
					28	7.2	27.2	42	7.6	28.8	52	9.6	36.3	75	12.2	46.2	50	40	20°	31″	23′
					30	5.9	22.3	44	6.6	25.0	54	8.6	32.5	80	10.0	37.8	70	60	21°	36″	28′
					32	4.6	17.4	45	5.5	21.2	56	7.6	28.8	85	8.0	30.3					

Fig. 3. Capacity of 2-fluid nozzles used in spray dryer

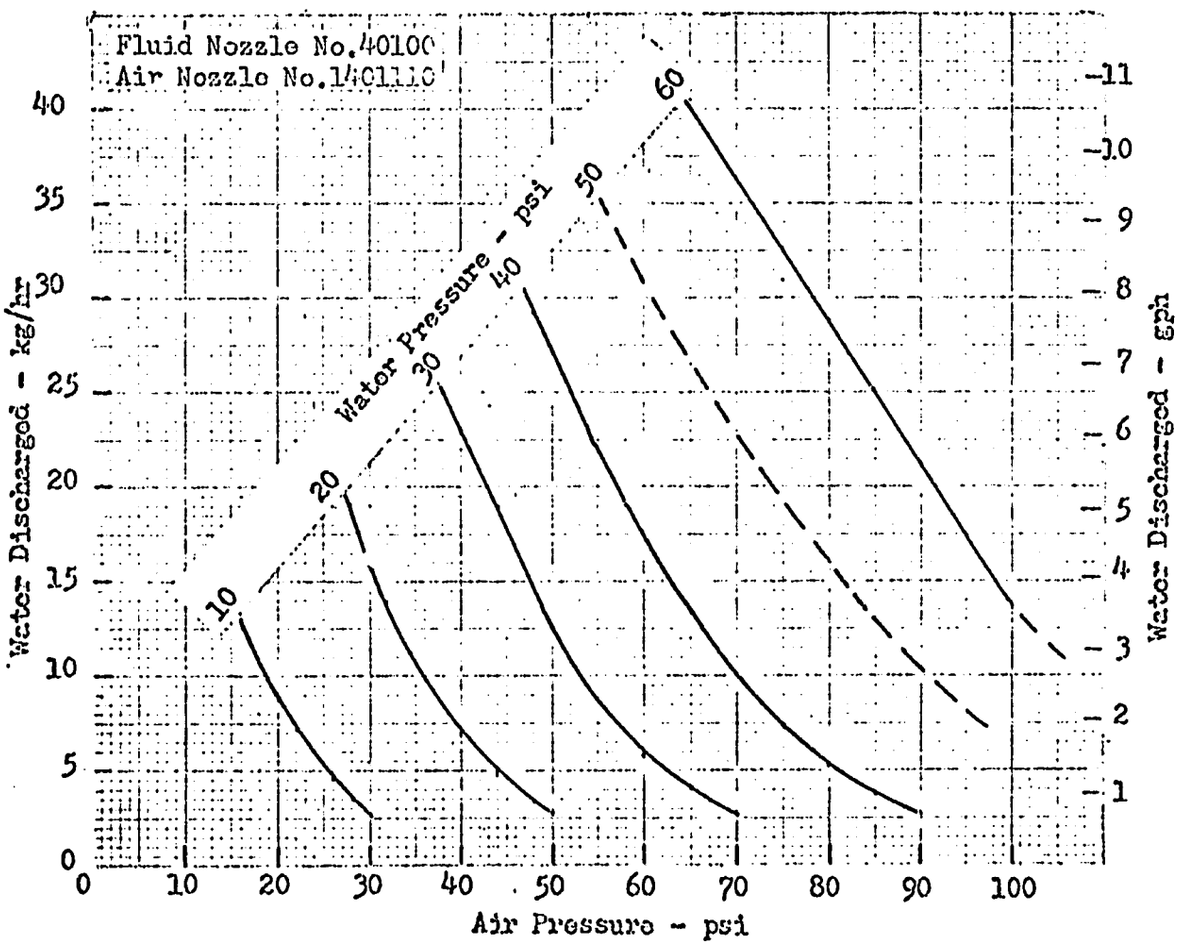


Fig.4. Capacity of 2-Fluid Nozzle Set-Up No. 22B

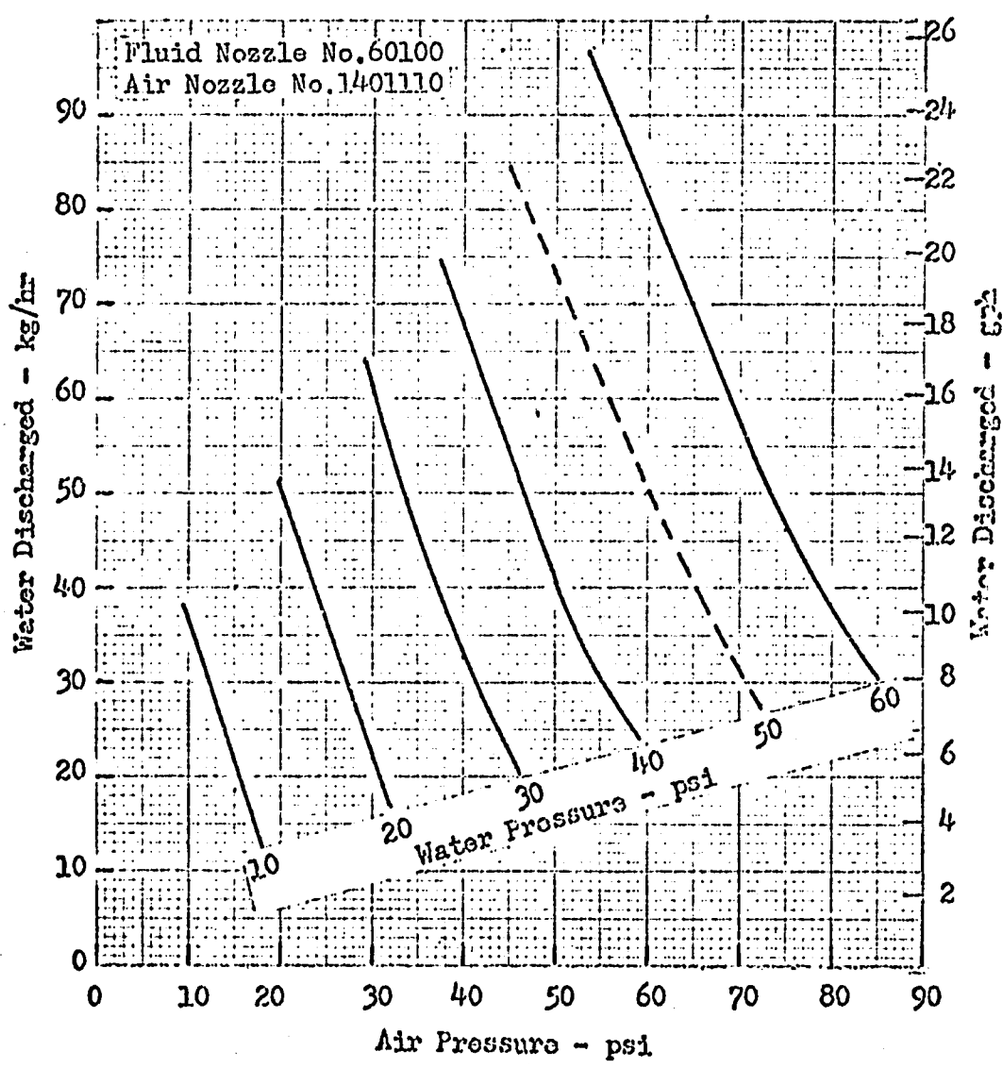


Fig.5. Capacity of 2-Fluid Nozzle Set-Up No. 22

Calibration of the Spray Nozzle

Initial nozzle tests were conducted with water when the spray dryer was operated at an inlet temperature of 400°F. Using Spray Set-Up No. 22B, it was possible to evaporate approximately 41 kg/hr water before water was observed at the base of the cone. Since this capacity was nearly maximal for Spray Set-Up No. 22B, subsequent tests were conducted with Spray Set-Up No. 22. The increased capacity of the water nozzle was easily obtained by substituting fluid nozzle No. 60100 for No. 40100, without changing the air nozzle.

Using Spray Set-Up No. 22, a series of tests were carried out to determine the combination of damper settings and nozzle capacities required to achieve the outlet temperatures listed in Table 1. The water pump speed was adjusted to give a desired pressure reading on a gauge near the base of the dryer and the flow rates were obtained from frequent weighing of the supply tank mounted on a scale. The air pressure to the nozzle was regulated according to the gauge on a pressure reducing valve.

The liquid flow rates were lower than the nozzle capacities shown in Fig. 5. The cause of these lower liquid flows was due to a pressure drop of 13 psi through the small 3/8" dia. tubing connecting the pump and the nozzle, and to a lack of sensitivity in the air gauge. These difficulties were overcome by placing pressure gauges in both the fluid and air lines immediately before the nozzles and then regulating the pump speed or the

air pressure until the desired gauge readings were obtained. Accurate control of the air pressure was found to be very important; a variation of 1 psi in air pressure caused a difference in water discharge of 5 kg/hr. The evaporative capacity of the dryer was determined by adjusting the water and air pressures until the water feed rate was so great that unvaporized water dripped from the joints in the ductwork under the drying chamber. The maximal amount of water that could be evaporated with an air inlet temperature of 400°F was 45.8 kg/hr at an outlet temperature of 220°F, and water and air nozzle pressures of 30 and 40 psi respectively. This capacity was attained when the damper was 100% open.

An attempt was then made to obtain an outlet temperature of 120°F by restricting the water feed to the nozzle and reducing the damper opening to minimize the air flow through the drying chamber. By reducing the air flow through the dryer, it was hoped that the maximal amount of heat would be dissipated in evaporating the water. With the damper opening restricted to 12½%, an outlet temperature of 125°F was achieved although the air nozzle pressure had to be increased to 43 psi which, in turn, reduced the feed ra to 36.8 kg water per hour.

Preliminary Trials on Spray Drying of Soy Milk Whey

In the first trial, soy whey was successfully dried with an outlet temperature of 210° by using a damper opening of 37½%, a liquid nozzle pressure of 30 psi, and an air nozzle pressure of 41 to 42 psi. Under these conditions, the feed rate was 32.5 kilograms per hour and a substantial quantity of the material was collected in the drum under the cyclone. An attempt was then made to depress the outlet temperature using the same damper setting by decreasing the air nozzle pressure to 40 psi and increasing the whey feed rate to 40.6 kg/hr. However, the powder that settled in the duct between the dryer and cyclone was wet, indicating too short an exposure of the spray in the drying chamber. An attempt was then made to increase the retention time in the drying chamber by restricting the damper opening to 12½%. The feed rate was also reduced by increasing the air nozzle pressure to 42 psi. These adjustments reduced the outlet temperature to 140°F but little dried product was conveyed to the cyclone or receiving drum. Most of the product accumulated on the drying chamber wall, the cone, and in the pipe below the cone. The material in the pipe was wet.

These trials yielded the following information:

a. Evaporation rates are lower from droplets of soy whey than water. Consequently, in relating dryer performance with water to the spray drying of water, allowances must be made for probable differences in size of liquid droplets, and to the moisture retention properties of the whey constituents.

b. More information is required about the proper combination of liquid and air nozzle pressures for better atomization of the liquid, or the creation of more product surface for rapid drying. Too much atomization may yield too many fine particles that are difficult to collect in the cyclone or give a product that is difficult to reconstitute.

c. A minimal air velocity is required in the duct to convey the powder to the cyclone. Since the majority of this air must come from the drying chamber, there is a limit to how much the retention in the drying chamber can be increased to build up the humidity in the air stream and lower the outlet temperature.

d. Some of the air required for pneumatic conveying may be obtained by opening the blast gate on the secondary inlet. When the secondary inlet is opened, the damper graduations will no longer indicate the volume

of air being drawn through the drying chamber, and, hence, another criterion must be devised for controlling the operation of the damper and/or the blast gate on the secondary inlet.

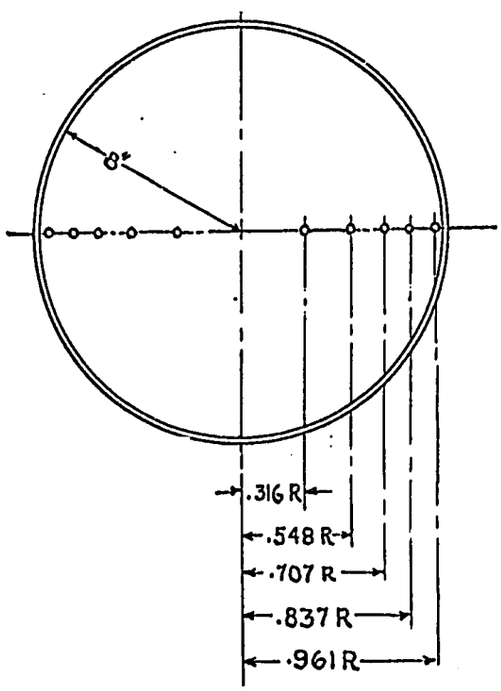
e. In order to increase the retention time of the atomized product in the dryer, the height of the dryer must be increased or a smaller duct to the cyclone installed on the dryer to maintain suitable air velocities for pneumatic conveying.

f. Because of structural limitations, it is doubtful if wide ranges in outlet temperatures can be achieved, although a satisfactory dried product may be obtained by operating in a narrow range of conditions.

Measurement of Air Flow Through the Spray Dryer

The experience gained in drying soy whey showed the need for information on air velocities in the dryer. This information was obtained by determining air velocities in the 16-in. dia. discharge duct from the fan using a hot wire anemometer (Hastings Precision Air Meter, Model B-22, Serial No. 26, Probe No. 1). Readings were made at 2-in. intervals across the diameter of the duct at a point 6 feet from the nearest elbow. The velocities varied, being highest around the center of the duct. To obtain the average air volume, each point of reading was considered to be the center of an annulus and the volume of air for that annulus was calculated from the velocity and area.

The volumes were then averaged to obtain a value representative of the air mass discharged by the fan. Later this procedure was simplified by using the procedure recommended by the National Association of Fan Manufacturers where the points of observation are spaced along the radius so that the cross sectional area is divided into 5 equivalent areas, as shown in Fig. 6. No 'egg-crate' straightener was used in the duct upstream from the point of measurement.



Traverse Points
Across 16" dia. duct
5/16 in.
1 5/16
2 3/8
3 5/8
5 1/2
10 1/2
12 3/8
13 5/8
14 11/16
15 11/16

Fig.6. Locations in discharge duct Used for Air Velocity Measurements

The amount of air drawn through the dryer was varied by varying the damper openings in the duct immediately upstream from the fan and the blast-gate in the secondary air inlet at the base of the drying chamber. In Fig. 7, the volumes of air

discharged by the fan have been plotted against the degree of damper opening. The sigmoid relationship shows that a relatively

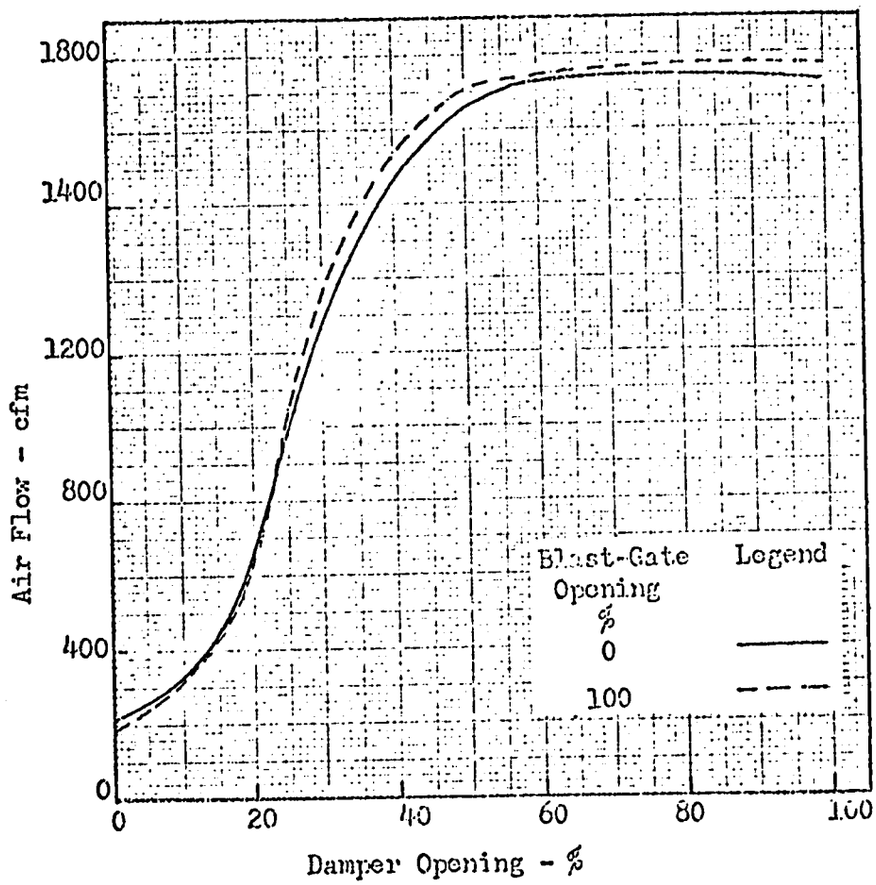


Fig.7. Control of Air Flow By Damper Movement

slight movement of the damper in the range of 400 to 1500 cfm can result in a major change in air movement through the dryer. This emphasizes the need for a more sensitive basis for controlling the damper setting.

The small increase in air flow when the secondary air inlet was opened suggested that the majority of the air discharged by the fan entered the dryer through the furnace or

that there were substantial air leaks at duct joints or between sections of the drying chamber. A number of leaks were found in the system when the inlet to the drying chamber was blocked off. Static pressure measurements made in the duct before the fan were lower than the rated suction pressure of the fan when operated at 1950 rpm. After tightening many joints on the dryer, the fan suction approached the rated value. There was also an increase of 100 cfm in the amount of air discharged by the fan when the blast gate was opened.

The Use of Static Pressure As an Index of Air Flow in the Spray Dryer

The following pressure taps are available on the dryer for measuring static pressures with U type manometers:

	Location	Pressure Measured
a.	After the cyclone	fan suction pressure
b.	Across the cyclone	pressure drop across cyclone
c.	Before the cyclone	suction before cyclone
d.	In the drying chamber	suction pressure

The suitability of these locations for monitoring the air flow through the dryer was evaluated by comparing the manometer readings with the volume of air discharged from the dryer when the damper and blast gate were opened to varying degrees. Static pressure readings taken at the 4 locations are plotted in Fig. 8 against the volumes of air.

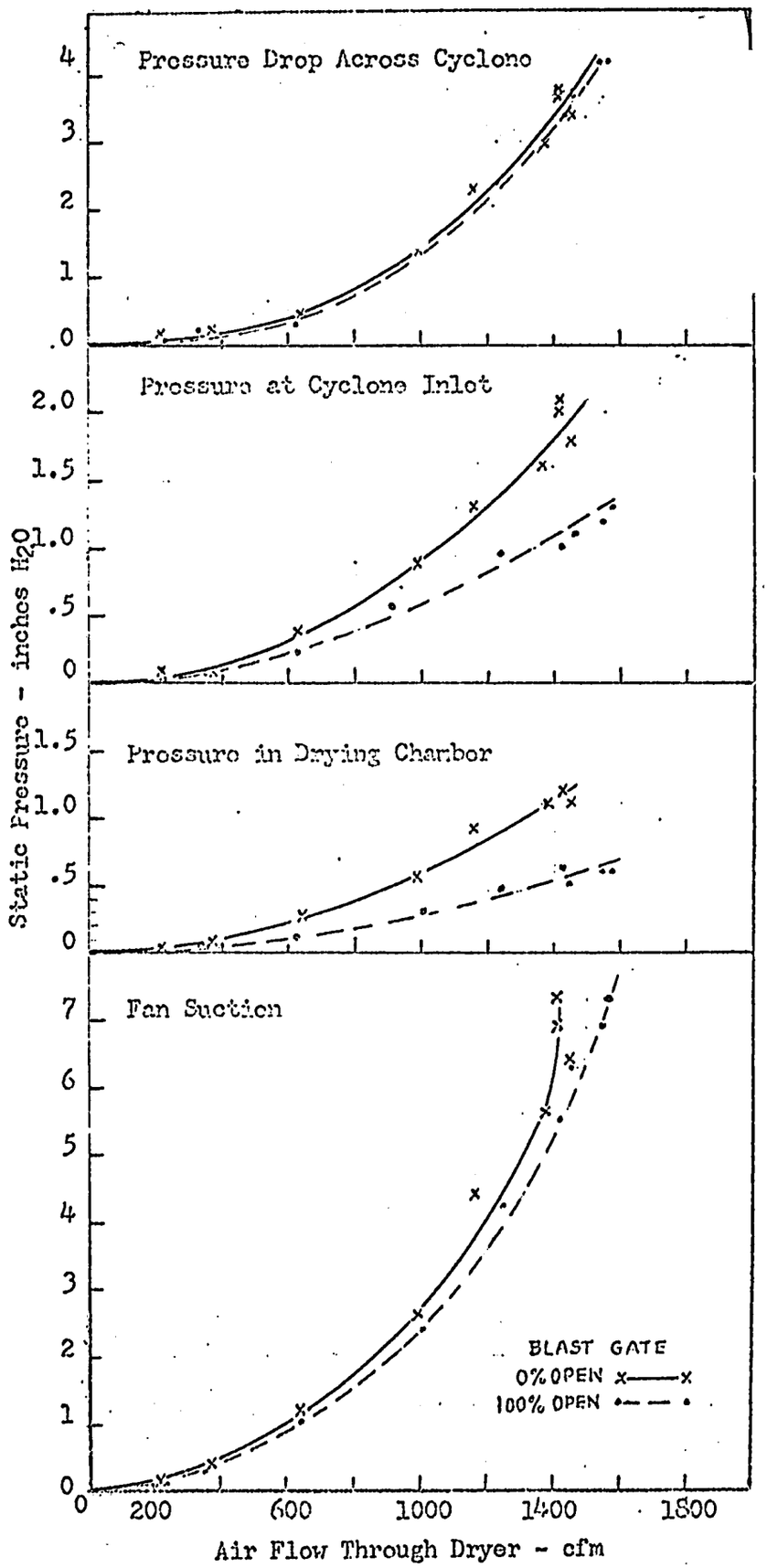


Fig.8. Static Pressure Measurements

The greatest range in manometer readings was obtained after the cyclone and across the cyclone due to the high resistance imposed on the system by the cyclone. However, this resistance obscured the effect of opening the blast gate. Of the two remaining pressure taps, the cyclone inlet appeared to be more suitable because the air temperature is recorded at this location and at elevated temperatures corrections must be made in static pressure readings due to the lower air density.

The cyclone inlet pressures have been replotted on a larger scale in Fig. 9 to aid in selecting the cyclone inlet pressure corresponding to the desired air flow in the dryer. Having selected the cyclone inlet pressure, the damper is then adjusted to give this manometer reading. On this graph only two blast-gate positions, either closed or fully opened, have been plotted because these are the two conditions under which the dryer is most likely to be operated. If intermediate amounts of cooling air are to be admitted to the dryer, an interpolation must be made for the desired cyclone inlet pressure. As a guide in selecting intermediate openings of the blast-gate, the height of the gate has been plotted in Fig. 10 against open cross-sectional area of the secondary inlet duct. For ready reference, the corresponding air velocities in the drying chamber and duct to the cyclone have been plotted along the abscissa of Fig. 9. These velocities are based on the relative duct sizes listed in Table 3.

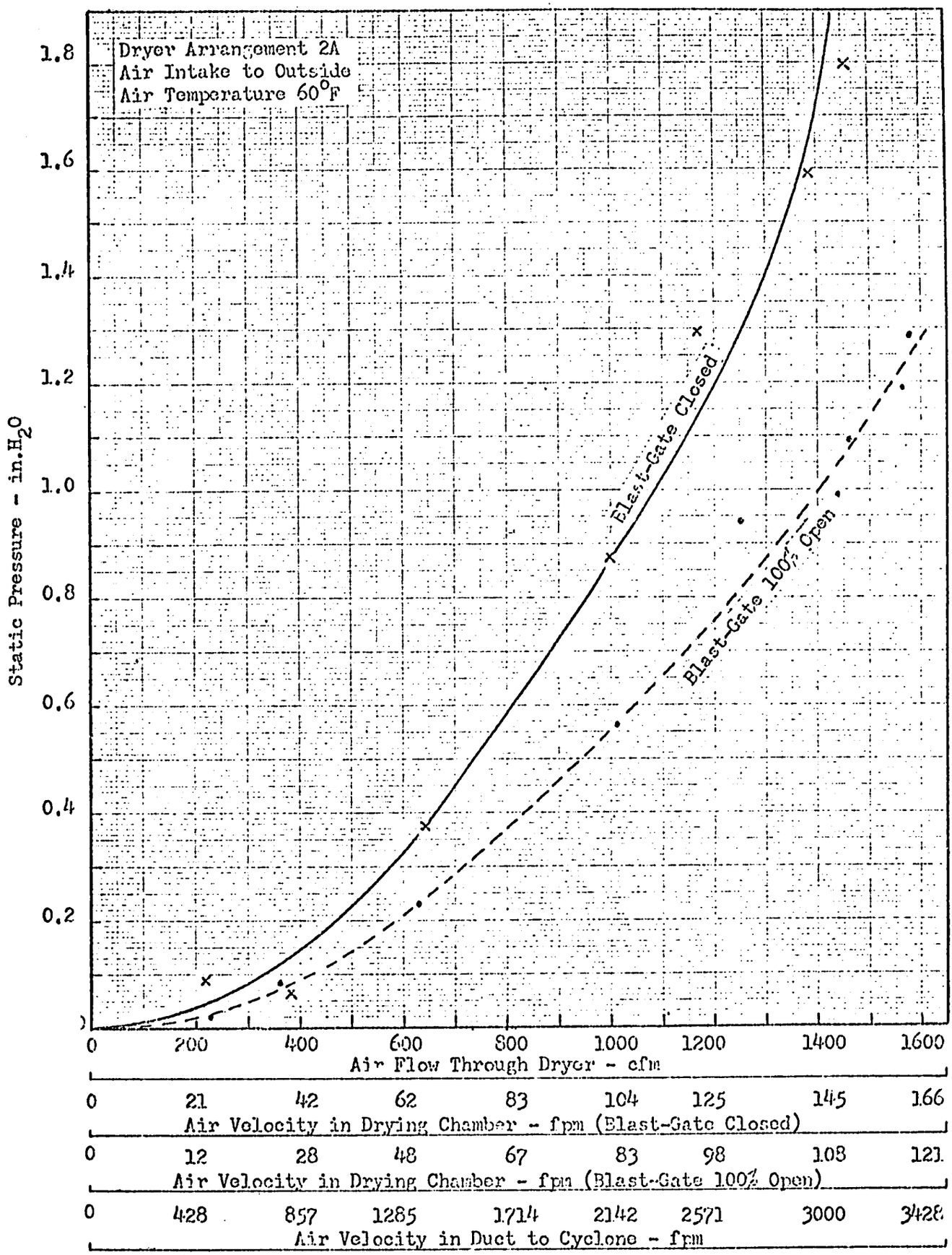


Fig.9. Cyclone Inlet Pressure and Air Flow Through Dryer

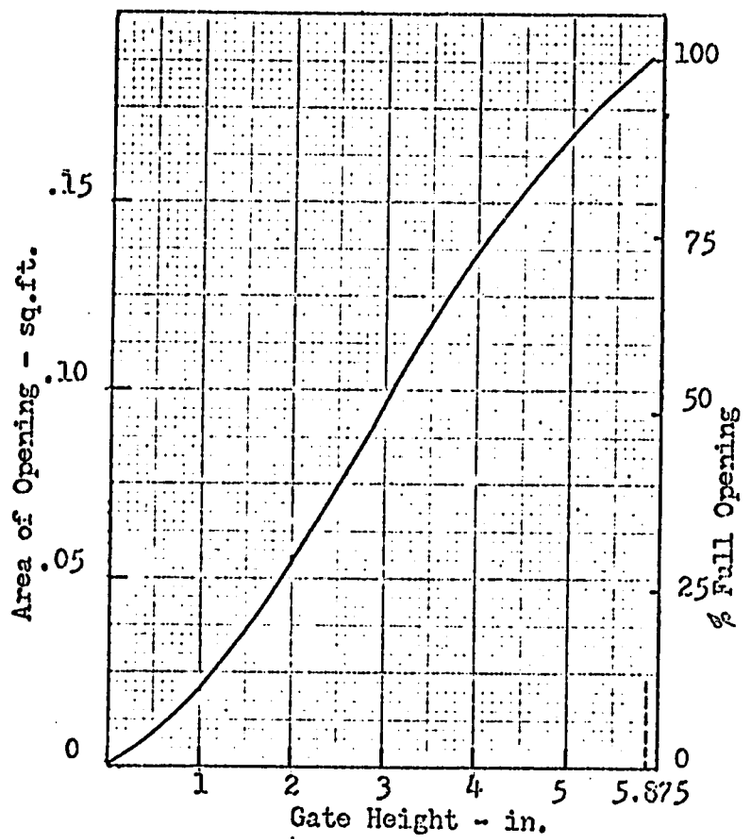


Fig.10. Calibration of Blast-Gate Opening

Table 3

Cross-Sectional Areas of Spray Dryer Ducts

Duct	Duct Dia. in.	Duct Area sq.ft.	Area Ratios			
Drying Chamber	42	9.621	1.00	0.145	0.082	0.0485
Discharge Duct	16	1.396	6.89	1.00	0.555	0.324
Fresh Air Intake	12	0.7854	12.25	1.78	1.00	0.594
Duct to Cyclone	9¼	0.4668	20.61	2.99	1.68	1.00
Blast Gate Duct	5-7/8	0.1883	51.09	7.41	4.17	2.48

Correction of Cyclone Inlet Pressures for Elevated Outlet Temperatures

The density of air decreases with temperature so that at elevated temperatures less suction pressure is required to effect an equivalent flow of air. Since the cyclone inlet pressures shown in Fig. 8 are for air at 60°F, the manometer reading will be lower when the dryer is operating with normal outlet temperatures of 150°F to 300°F. If the damper is adjusted while the dryer is operating with room air, no correction is needed after the furnace has been lit. However, if the air velocity is to be changed after the dryer has reached operating temperature, the cyclone inlet pressure must be corrected as follows:

$$SP_2 = SP_1 \times \frac{T_1 + 460}{T_2 + 460}$$

where SP_2 = corrected cyclone inlet pressure, in. H_2O

SP_1 = cyclone inlet pressure at 60°F

T_1 = 60°F

T_2 = new outlet temperature °F

Corrected cyclone inlet pressures may also be obtained by interpolation in Fig. 11.

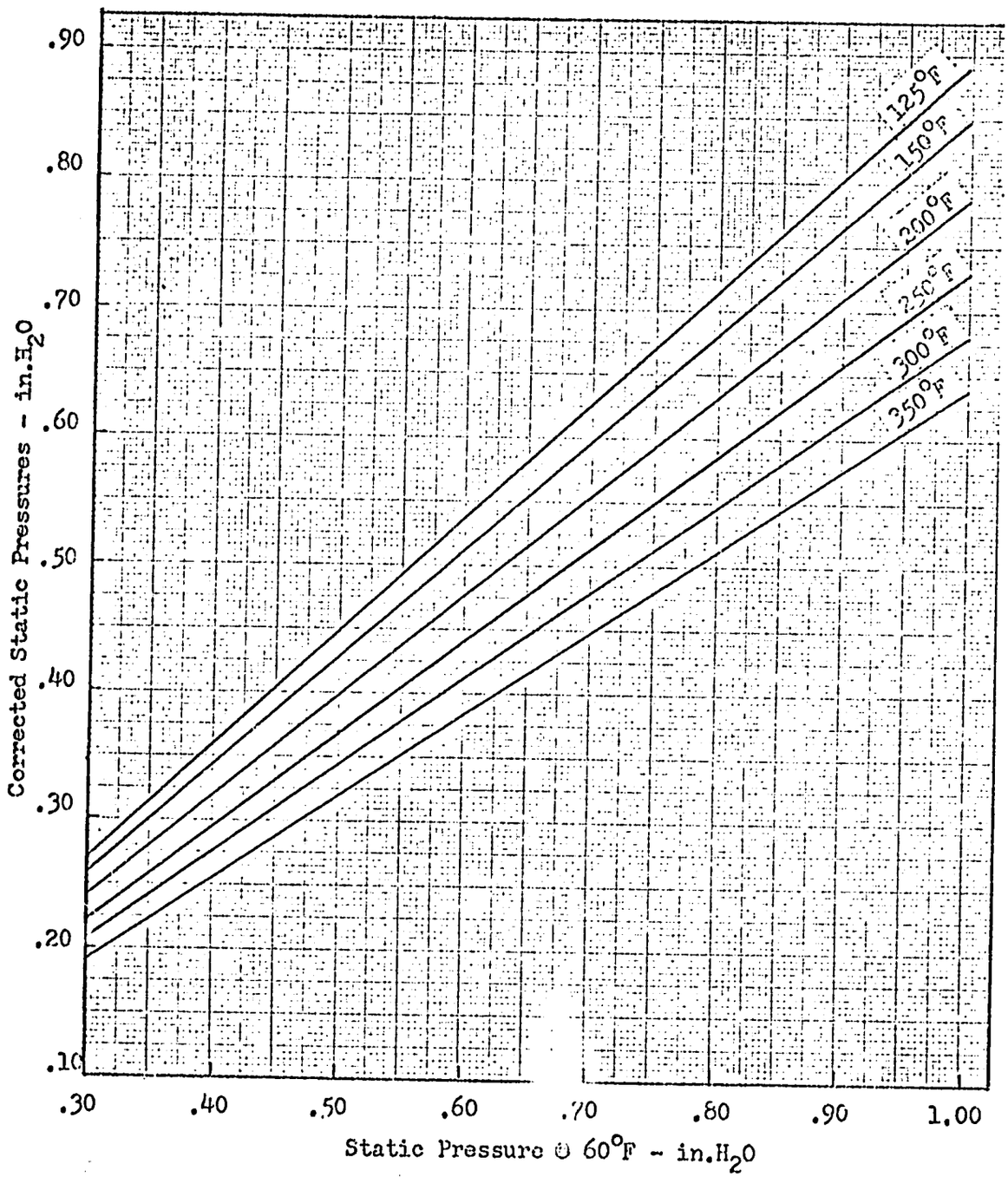


Fig. 11 Corrections for Cyclone Inlet Pressure

Calculated Minimal Air Velocity Required to Convey Dried Product to Cyclone

According to Madison, (Fan Engineering, Buffalo Forge Co., Buffalo, N. Y., 5th ed., 1944) different air velocities are required to convey materials in vertical or horizontal pipes. A higher velocity is required in horizontal pipes to overcome the tendency for the heavier particles to settle. In the Model 2A arrangement of the spray dryer, the dried product is conveyed from the drying chamber to the cyclone in both a horizontal and a vertical pipe. For such an application, Madison recommends the following equation for computing the necessary air velocity:

$$V = 1030 \sqrt[3]{W} \sqrt{d} + 582.5 \sqrt{W}$$

where V = air velocity, ft/min.

W = bulk density of product, lbs/cu.ft.

d = dia. of particle, inches

given - W = 0.31 g/cc or 0.31 x 62.43 = 19.6 lbs/cu.ft.

d = 10 microns or 10 x 0.00003937 = .0003937 in.

V = 2329 ft/min.

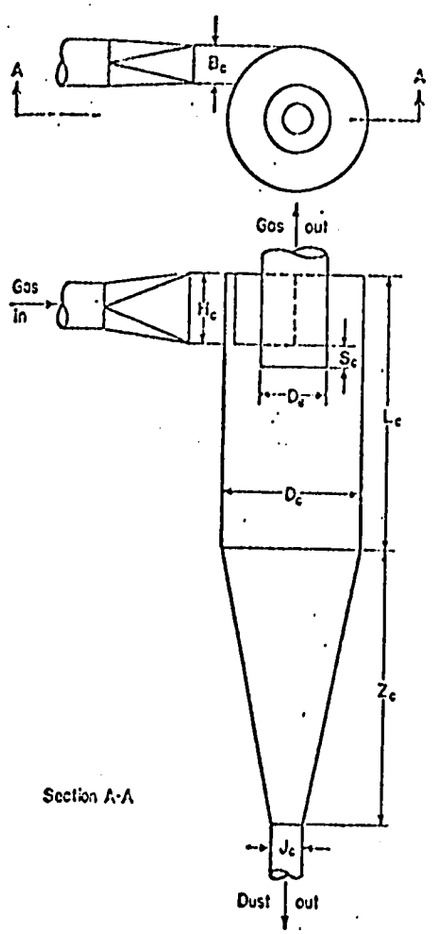
To attain a cyclone duct velocity of 2400 ft/min. when the blast gate is 100% open and dryer outlet temperature is 70°F, the damper according to Fig. 9 should be adjusted to give a cyclone inlet pressure of -0.7"H_2O. This duct velocity

would be equivalent to an air velocity of 93 fpm in the drying chamber, or a residence time of 9.7 seconds. According to work done at the Universities of Wisconsin and Michigan State, this residence time should be adequate under normal operating conditions to dry droplets ranging in size from 85 to 100 microns.

Cyclone Efficiency and Collection of Dried Product

A centrifugal dust collector is used on the spray dryer for separating the dried product from the air stream after it is conveyed pneumatically from the base of the dryer. The air and powder enter a cylinder tangentially and centrifugal force in the vortex throws the particles to the outer edge of the cylinder where they are led down a cone into a collection drum. This method of particle collection is generally considered suitable when the particles range in size from 5 to 200 microns.

Among the factors that affect the operation of a cyclone are air velocity and density, particle size and density, and the geometry of the unit. The dimensions of the present cyclone are given in Fig. 12 along with the geometrical proportions of a typical cyclone described by Lucas (Chemical Engineers' Handbook, R. H. Perry, Ed., McGraw-Hill Book Co., New York, N. Y. 4th Ed., 1963, p. 20-69). Since the proportions of the present cyclone and that cited by Lucas are identical, the following equation may be used in calculating the theoretical efficiency of the cyclone.



Cyclone Component		Size Ratio	Size (ft)
D_c			= 2.0
B_c	=	$D_c/4$	= 0.5
D_e	=	$D_c/2$	= 1.0
H_c	=	$D_c/2$	= 1.0
L_c	=	$2D_c$	= 4.0
S_c	=	$D_c/4$	= 0.5
Z_c	=	$2D_c$	= 4.0
J_c	=	$D_c/4$	= 0.5

Fig.12. Dimensions of Cyclone Separator

$$D_{\rho c} = \sqrt{\frac{9\mu B_c}{2\pi N_1 V_c(\rho s-\rho)}}$$

where $D_{\rho c}$ = size of particle, 50% collected

B_c = width of tangential entry to cyclone, feet

Ne = no. of turns made by air in cyclone

ρs = absolute density of particle, lbs/cu.ft.

ρ = air density, lbs/cu.ft.

μ = air viscosity, lbs/(ft)(sec)

Vc = air velocity at cyclone inlet, ft/sec.

given B_c = 0.5 ft.

Ne = assumed 5 for dimensions of present cyclone

ρ_s = 1.25 g/cc or 78 lbs/cu.ft.

ρ = air temp. of 150°F and 20% saturation = 0.068 lbs/cu.ft.

μ = viscosity of air @ 150°F = 0.02 cp

= $0.02 \times 0.000672 = 13.4 \times 10^{-6}$ lbs/(ft)(sec)

Vc = 2400 ÷ 60 = 40 ft/sec.

$$D_{\rho c} = \sqrt{\frac{9 \times 13.4 \times 10^{-6} \times 0.5}{2 \times 3.14 \times 5 \times 40 \times (78 - .068)}}$$

= 7.9 micron

The ratio of average product particle size to the average size of particle entrapped by the cyclone is

$$\frac{D_\rho}{D_{\rho c}} = \frac{10}{7.9} = 1.27$$

where D_ρ = 10 microns

$D_{\rho c}$ = 7.9 microns

From the graph (Fig. 13) cited by Lucas, a particle size ratio of 1.27 would be equivalent to a collection efficiency of 65%. To increase the collection efficiency to 90%, the

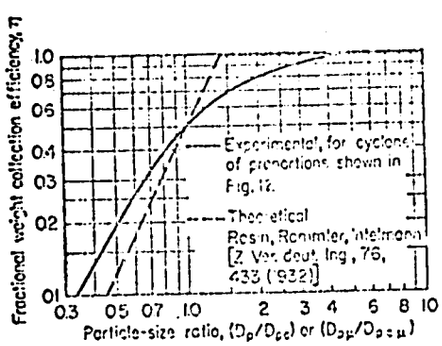


Fig.13. Cyclone Efficiency and Particle Size

particle size ratio would have to be 3 and the average particle of product should be 24 microns or larger.

There are several ways in which the collection efficiency of the cyclone might be increased. The air flow through the dryer might be increased and thereby improve the efficiency of the cyclone since its entrainment action is increased as

the square root of the entering air velocity. However, this approach might be self-defeating since the finer dispersion of the feed required for rapid evaporation during the shorter retention period in the drying chamber would probably lead to finer product particles. In the preliminary tests of the present study, the concentration of soy solids in the feed was around 8% which is low compared to many spray drying operations where the solids contents range from 20 to 40%. More solids in the feed liquid would increase the viscosity and make the formation of larger droplets during atomization. These larger droplets, having relatively less water to be evaporated, might be dried without increasing the retention time in the dryer. The use of the higher solids feed would require a concentration step before drying and the taking of precautions to avoid gelation prior to atomization.