

AIChE Equipment Testing Procedure

SPRAY DRYERS

A Guide to Performance Evaluation

Second Edition

Prepared by the

Equipment Testing Procedure Committee

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100 Purpose and Scope

101 Purpose

101.1 Purpose

The purpose of this procedure is to suggest a method and provide guidance for conducting and interpreting performance tests on spray dryers.

101.2 Summary

The text discusses the reasons for spray drying. These reasons are usually to produce a product with certain desired properties or with better efficiency than other methods. Full-sized spray dryers are usually tested to determine performance. Pilot dryers are tested to evaluate the properties of the product that can be produced and to choose suitable operating conditions. A systematic test program such as a factorial experiment plan may be carried out to determine the best conditions to achieve the desired results. A definitive test may be done on a spray dryer that has already been optimized for performance.

The text discusses how to plan the test in light of these objectives. It gives guidance on the variables affecting product properties and dryer performance, to decide which variables to evaluate. However, spray drying is a complex process. Multiple interacting variables have to be considered in the plan. In addition to using this procedure, it may be wise to consider obtaining the guidance of a person experienced in spray drying. Art is involved as well as science, especially in evaluating a new material or optimizing conditions for a plant spray dryer. Although this procedure will help to obtain data useful for design, it is not intended to explain how to design a spray dryer. Also, since the subject is complex, detailed study of this procedure and of other literature may be required in order to reach the objectives.

Typical spray dryer installations are briefly described. Checklists are given to aid in planning measurements and listing steps needed for a test. Safety must be considered in any test planning. Some of the important measurement methods are briefly described. Equations and calculation methods are given to carry out heat and material balances that can be used to check accuracy of test results.

Balances are given in three levels of detail (methods). The simplest method compares the heat lost by the drying air stream to the heat required to evaporate the water in the feed. The second method uses psychrometric charts to account for the energy and moisture in humid air and to make a graphical heat balance. The third method uses equations to consider all inputs to the heat and material balances. These methods are demonstrated by examples given in the Appendix. A sample data sheet is also provided.

In this procedure air is the drying gas and water is the liquid to be evaporated. Other noncondensable gases and liquids may be used. These usually present special safety requirements not covered in this procedure. The material and heat balances given can be adapted for the other systems.

101.3 Scope of Spray Drying

Spray drying is rarely cost competitive with two-step dewatering and solids-drying processes. The equipment is costly, and the addition of bag collectors for solids recovery from large volumes of exit gas may double the cost of a spray-dryer installation. These higher costs are usually justified on the basis of some improvement in product quality, such as particle form, size, product flavor, color, or heat stability. The major and most successful applications of spray dryers are for solutions, slurries, and pastes which (1) cannot be dewatered mechanically, (2) are heat-sensitive and cannot be exposed to high-temperature atmospheres for long periods, (3) contain ultra fine particles which will agglomerate and fuse unless they are dried in a dilute gas suspension, or (4) require the product to be in a powder form to fit the needs of its applications. In spite of these limitations, spray drying is widely used in industry because of the benefits it provides to many products.

101.4 Reasons for Testing Spray Dryers

The four types of tests usually performed on spray dryers are Exploratory, Performance, Acceptance and Troubleshooting. Exploratory tests are intended to determine whether a satisfactory product can be produced in a spray dryer, and under what conditions. The results may even be used to obtain data to design a spray dryer. Performance tests determine production capacity and/or thermal efficiency for an existing spray dryer while delivering an acceptable product. Acceptance tests determine whether a new spray dryer meets agreed-upon performance criteria. Performance tests that look into details of operation can be useful for troubleshooting drying problems.

Sections 300, 301, and 301.1 point out the need to pick the correct type of test (exploratory, performance, or acceptance), and how to develop a plan for each type of test. The test plan should support the business plan for the plant, i.e., whether to increase production, or to expand the range of products. Section 305 explains test plan preparation.

101.4.1 Commercial-Size Dryers

Typical reasons for conducting tests on commercial-size dryers are:

101.4.1.1 Performance Test

To check the capacity and performance capability of the dryer

- Determine the performance of a dryer under typical operating conditions.
- Determine the maximum dryer capacity under existing operating conditions.
- Determine the desirable operating range for routine control of the dryer.
- Determine the optimum operating conditions for product quality, cost effectiveness, fuel conservation, and minimum environmental impact.
- Compare the performance of a new dryer with design data.

Section 302.1 discusses types of tests to measure capacity. Section 302.2 discusses the importance of heat and material balances to validate test measurements and points out the importance of steady-state operation. See

also Section 501. Section 303.5 discusses the interaction of capacity and rate effects with product properties, an interaction that makes for complexity in planning and carrying out spray dryer tests. Therefore, it is necessary to define the required properties for your application before conducting the performance test. Also, the required operating conditions to achieve the desired properties should already have been determined by extensive exploratory testing before conducting a performance test.

101.4.1.2 Troubleshooting

It may help to run a dryer test when problems occur during production of a particular material. The detailed work done during the test may help to elucidate the cause of problems. Measurements will include operating conditions, calculations will include heat and material balances, and observations will include characteristics of the product, its behavior in the dryer, and behavior of peripheral equipment. The actual test work may be similar to that of a performance test, but the different objectives should be specified before the test. Securing the participation of outside experts may help in such a test.

Several sections of this procedure give information that may help during troubleshooting tests. They are:

301.4 Dryer Controls and Instrumentation

301.5 and 302.1.2 Peripheral Equipment

302.2 Heat and Material Balance

303 Variables Affecting Product Properties, especially 303.2 Atomization

400 Methods of Measurement and Sampling

101.4.1.3 Acceptance Test

Typically a dryer is tested during commissioning to assure that design rates can be met per contract. This usually involves not only confirming evaporation rate but also product rate, quality, and yield. This procedure is not intended to be used for guarantee testing. Instead, a plan for such a test should be developed by negotiation between buyer and seller. The test requirements may be similar to those for performance testing given above.

101.4.1.4 Exploratory Tests.

To define or test dryer for new products or design data

- Determine whether suitable product characteristics can be attained by spray drying.
- Gather data for design of new dryers of different capacity for similar products.
- Study specific dryer variables as they relate to product characteristics, e.g., particle size, particle shape, bulk density, dustiness, and heat sensitivity properties such as, taste, and odor.

Section 303 discusses how the dryer operating variables may be adjusted to achieve desired product properties. Table 303.6 lists variables and their effect on performance and on product properties. Section 304 gives a further list of variables that may affect the results, Section 502.1 gives some priorities in dealing with these variables. Section 301.7 suggests a systematic way to deal with multiple variables in the experiment plan.

101.4.2 Laboratory- or Pilot-Sized Dryers

Tests in commercial-size dryers will be costly. Often **exploratory tests** can be done in a smaller dryer, such as at the facilities of an equipment manufacturer or a contractor. The small size of these dryers allows rapid changeover of test conditions, and easy cleaning between tests. Also, a pilot dryer test is unencumbered by any need to produce salable material, or to meet a production schedule, and may be operated by research personnel rather than plant personnel.

101.4.3 Scale-Up Considerations

Some test conditions available in commercial dryers cannot be achieved in a pilot dryer, because pilot dryers may not have the geometry to successfully dry all products. An evaluation must be made to take into consideration the limitations of a small dryer, particularly the limited residence time and the small diameter. The spray droplets may hit the wall and stick before they evaporate if the drying temperature is low. Especially, it may not be feasible to use a disc atomizer, which tends to throw the droplets toward the wall. Therefore pneumatic spray nozzles are normally used in pilot dryers, whereas disc atomizers are often used in commercial dryers because of their greater throughput. They may produce a different particle size distribution than nozzles. Furthermore, to achieve a dry product in a pilot dryer it may be necessary to operate at a higher temperature than desired, causing damage to some properties such as taste, odor, and color. Still, the test may be useful if it provides samples of product that indicate other properties such as form, density, and flowability, and thus gives clues for further testing on a larger scale.

Although a heat balance can be made on a pilot dryer, the results may not be applicable to a scaled-up dryer. Different surface-to-volume ratio of commercial equipment will result in different heat balance and energy efficiency conditions. The heater itself may be quite different. Thermal insulation and surroundings of

the dryer may differ. Some of these effects can be corrected for by engineering calculations. However, measurement of thermal efficiency in a pilot dryer can give only a rough guide to efficiency in larger-scale production, but heat balance and thermal efficiency measurements will be important in large-scale dryer testing.

Some variables that were not thought of during pilot testing may arise during testing on commercial-scale dryers, such as different feed mixing techniques used by different plant operators. The product collection equipment may be different, but this should not affect the dryer.

102 Design vs. Operational Variables

A program of dryer testing can lead to optimum operating conditions for the dryer tested. In addition to the obvious effect on capacity, design can affect product properties. For example, chamber shape can affect residence time distribution, which in turn affects exposure of a product sensitive to heat. Thus the importance and limitations of dryer design should be recognized in an evaluation made prior to the actual test.

103 Liability

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200 Definitions and Descriptions of Terms

201 Dryer Design

201.1 Dryer Chamber

A spray dryer consists of a stationary vessel or chamber. It can have several shapes (Fig 201) and includes an atomizer to disperse the feed into the gas stream. The gas inlet to the dryer can be located at the top, bottom, or side, depending on the configuration. There is usually some method of gas distribution -- perforated plates, louvers, or vane rings -- within the chamber. The gas outlet will usually be at the opposite end of the chamber from which feed is introduced. If the gas outlet is the only outlet of the vessel, the spray dryer product is carried in the outlet drying gas. The vessel may be equipped for separation of the product by gravity, in which case, the chamber will have two outlets.

201.2 Airflow Patterns

Airflow patterns depend on chamber design and define gross airflow (as distinguished from localized eddies and backflow). (See Fig. 201) Parallel flow spray dryers usually tall and narrow to minimize back mixing of gas, and to expose sensitive dry product to only the cooler exit air, as in Figure 202.

Spray Dryers

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Counter-current flow dryers are used to expose the product to hot air. While this design removes tightly bound residual water more efficiently, and it also results in less expansion of the product, it is not feasible for sensitive materials.

Atomization and evaporation create complex localized flow patterns around the atomizer. These patterns usually contain some circular flow components. In mixed flow dryers, a portion of the air is supplied tangentially. Also, cooling air may be introduced at the exit, to protect a sensitive product.

201.3 Product Flow

Depending on the dryer design, product flow can be co-current or counter-current to gas flow. The dryer can be designed to either aid or counter particle separation by gravity or centrifugal forces. In this way, the designer can alter the residence time distribution of the larger and smaller particles, to aid in drying the larger particles or exposing particles longer to drying conditions.

201.4 Atomizer

The atomizer may be a high-speed rotating disc, a two-fluid (pneumatic) nozzle, or a single-fluid (pressure) nozzle. The function of the atomizer is to break the feed material into many droplets to increase the surface area and to form the droplets that will result in the desired particle size and shape for the final product. See 303.2.

201.5 Heating Methods

The gas stream may be heated directly or indirectly by any convenient means before entering the dryer cylinder. This gas stream provides the thermal energy needed to:

1. Heat the material to be dried.
2. Heat and evaporate the liquid and heat the vapor to the exhaust temperature.
3. Compensate for conduction, convection, and radiation heat losses from the chamber.
4. Provide the energy required for the heat of reaction, if applicable.
5. Provide the energy required for the heat of crystallization, if applicable
6. Avoid conditions where vapor might condense in the exit stream. See Section 604.2.3

201.6 Product Recovery

After leaving the drying chamber, all gases and vapor from drying usually pass through product/dust recovery equipment before being released to atmosphere. Cyclonic separators for product recovery, followed by dry fabric filters or wet scrubbers for dust collection, are the most common forms of separation equipment employed on spray dryers.

Figure 201. Typical Spray Dryer Configuration

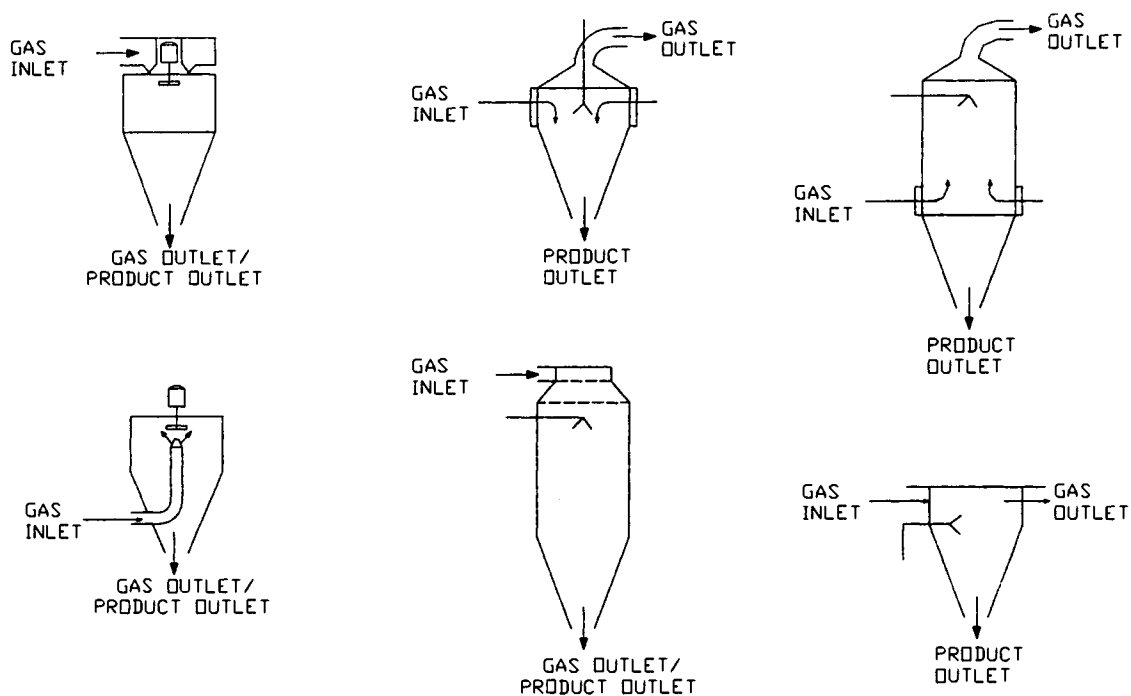
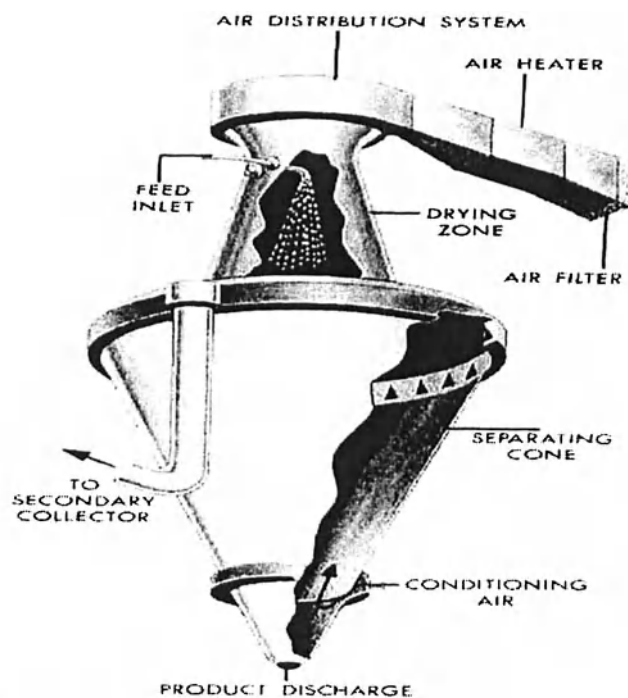


Figure 202. Exploded View of a Spray Dryer System



Operating diagram of a parallel-flow SWENSON spray dryer for special products

201.7 Airflow Motive Force

Fans induce the gas flow through the heater, drying chamber, and product/dust collection equipment. The most simple fan arrangement, which is used on dryers with low pressure drop heaters, is a single induced-draft exhaust fan located downstream of the dust collection system so the fan will operate on clean gas. This one fan, therefore, must have static pressure capability to accommodate the pressure-drop through the inlet gas filter, gas heater, gas inlet duct, and dust collector, which typically amounts to 3,750 to 12,500 Pa (15-50 inches of water).

Alternatively, when the air leakage into the dryer system seems excessive, the second forced-draft fan may be installed upstream of the heater inlet to overcome the inlet system pressure drop. By balancing the two fans in this manner, the pressure inside the spray-drying chamber can be adjusted to a level within 125 Pa (0.5 inches of water) of atmospheric pressure to minimize leakage to or from ambient air.

202 Description of Terms

202.1 Drying

Drying is an operation that separates a liquid from a solid or semisolid material by evaporation. Dehydration refers to the drying of vegetable and animal products to less than their natural moisture content and removal of water-of-crystallization from chemical compounds. Following is the terminology commonly employed for various drying and dehydration processes.

- Absolute Humidity is the amount of liquid (e.g., water) vapor in a given gas stream, expressed as weight of liquid per weight of dry gas (in kg/kg).
- Atomization is the formation of a spray by breaking up bulk liquid plus solids (dissolved or suspended) into many individual droplets. Its principal effect is to produce a high ratio of surface to mass in the liquid phase, which promotes drying and controls particle size of solid products.
- Constant-Rate Period is an initial period during which enough liquid reaches or remains on the surface of particles to maintain a constant rate of evaporation.
- Density is the mass per unit volume of material, kg/m^3 . It may be measured in several ways. Bulk density is measured by weighing a known volume in the as poured, or loose condition. A settled, tapped, or packed density is found by tapping the container. Particle density is that of particles without interstitial volume between them. Absolute density is that of material with no voids. Particle density is different from Absolute density because a particle may be a hollow sphere and thus the particle occupies a defined volume but has much less mass than a solid particle of the same dimension.
- Dew Point or saturation temperature is the temperature at which a given mixture of liquid (e.g., water) vapor and gas (air) is saturated. At the saturation temperature, the liquid exerts a vapor pressure equal to the partial pressure of the liquid vapor in the

given mixture. Below this temperature, liquid will condense. This can result in mist or condensation on cold surfaces or product.

- Diffusion-Dominated Drying is drying during the falling-rate period, when diffusion of moisture from within the particle limits the drying rate, rather than heat transfer from the gas to the surface of the particle.
- Direct Drying occurs when the heating medium, usually hot combustion products, comes in direct contact with the particles. It is said to be adiabatic because when the dryer is insulated there is no gain or loss of energy by the system.
- Direct-Heat Dryer is one of a class of drying equipment in which heat is transferred to the atomized droplets being dried by direct contact with the heating medium. The heating medium is usually a hot gas.
- Dry Basis expresses the moisture content of a wet material as a fraction of the weight of dry material. The advantage of using this basis is that the difference between the moisture content before and after drying is the moisture change per unit weight of dry material.
- Dryer Efficiency is the fraction of the thermal energy supplied that is used to heat and vaporize the liquid and to heat the vapor to the dryer exhaust temperature.
- Dust Loading is the amount of powder in a gas stream, kg/m^3 (mg/m^3).
- Enthalpy is the heat content of a material, kJ/kg . For a mixture, it is the weighted sum of the individual enthalpies. Enthalpy is measured above a base temperature, 273 K (0 EC).
- Evaporative Efficiency of the gas stream flowing through a direct-heat dryer compares the amount of evaporation actually obtained to that which could be obtained if the gas stream were saturated adiabatically before leaving the dryer.
- Falling-rate Period is a drying period during which the drying rate per unit of material surface continually decreases, generally after surface moisture has been removed. The liquid or vapor has to diffuse from within the particle.
- Heat of Vaporization is the change in enthalpy involved in the transition from liquid to vapor, expressed as kJ/kg (kcal/kg).
- Humid Heat is the combined sensible heat of the air stream and the heat of vaporization of its water vapor content. (See Section 602.3.2)
- Indirect-heat Dryer is one of a class of drying equipment in which the heating medium is physically separated from the material being dried by a barrier. The heater heats the inlet gas primarily by conduction and radiation through the barrier, and the hot gas heats the feed by conduction.
- Internal Diffusion occurs in a material during drying when the liquid evaporation rate appears to be controlled by diffusion of liquid or vapor flow to the particle surface.

As the particle dries the diffusion path lengths and causes reduced mass transfer. This results in the falling rate period.

- Latent Heat is the energy involved in a phase change (e.g., liquid to gas) that does not result in a temperature change expressed as kJ/kg (kcal/kg).
- Moisture Content of a material is the moisture quantity per unit weight of dry or wet solid. The basis should be specified. See Dry Basis, above.
- Moisture Gradient refers to the moisture profile in a material at a given moment during a drying process. The nature of the moisture gradient depends on the mechanism of moisture flow inside the material, *i.e.* internal diffusion. For fine particle products, it cannot be measured, but it can be calculated from the moisture content and the diffusivity of water in the solid.
- Percent Saturation of a gas containing a condensable vapor is the ratio of the partial pressure of the condensable vapor in the gas to the vapor pressure of the pure condensable material as a liquid at the same temperature, expressed as a percentage. For water in air this is also called percent relative humidity.
- Residence Time Distribution of the particles is spread over the mean residence time of the gas because of mixing in the chamber, and settling.
- Residence Time – Mean residence time of the gas is the ratio of the chamber volume to the volumetric flow rate. It may differ from the residence time of the solids.
- Sensible Heat is the energy involved in changing the temperature of a substance expressed as kJ/kg °K (kcal/kg °K).
- Swirl Chamber is used in pressure nozzles that produce a hollow cone spray pattern. The fluid enters the chamber tangentially and acquires centrifugal motion, which flings it outward as it exits the orifice. Vanes can also achieve this effect.
- Thermal Efficiency of a dryer is defined (*Reference 808.1, p 111*) as the ratio: Heat used in evaporation to Heat input.
- Wet Basis expresses the moisture content of a wet material as the weight of moisture per unit weight of dry material plus the contained moisture.
- Wet Bulb Temperature is the dynamic equilibrium temperature attained by a liquid surface when the rate of heat transfer provided to the surface by convection from the gas phase equals the latent heat taken up by the evaporation or mass transfer away from the surface.

300 Test Planning

301 Preliminary Objectives

The cost of performing a plant test goes far beyond the time and material expended during the actual test run. Careful planning and preparation are essential to maximize the economic and technical benefits of a test. A poorly run test may result in the loss of a business opportunity.

301.1 Test Objectives

301.1.1 *Inter-related Objectives*

Usually the most important objectives are to determine capacity, energy efficiency, and product properties. These objectives are inter-related. Section 303 includes a discussion of how the operating parameters may be varied to achieve desired properties.

301.1.2 *Specific Objectives*

Specific test objectives should be stated in writing. This phase of test planning should include techniques for determining whether or not the objectives are being met while the test is in progress.

301.1.3 *Capacity vs. Design*

A new dryer can be designed to achieve practically any desired production rate while delivering the desired product qualities. The design is based upon an evaporation rate or capacity at specified operating conditions derived from a required product rate at specific inlet and outlet concentrations of moisture (a design material balance).

In contrast, the production rate of an existing dryer will be limited by its design. For example, the manufacturer sets the inlet airflow rate. In dealing with an existing dryer, one must usually be willing to accept a production rate achievable under conditions that give the desired product qualities. The objective of testing an existing (full size) dryer will usually be to determine these conditions, and secondarily to determine achievable production rate under these conditions.

301.2 Organizational Resources

The test objectives help determine which organizational resources should be involved in the test. Plant tests frequently involve people from many disciplines such as plant maintenance, analytical services, design organization representatives, and equipment supplier representatives.

301.3 Schedule

It is (obviously) best to schedule a plant test for a time when the plant is expected to have time available on equipment. However, many other variables must be considered for a successful plant test such as availability of plant feed stocks and raw materials, conditions of upstream and downstream units, the time it will take to complete the required preparations, personnel availability, availability of analytical services, and the anticipated

ambient conditions. If the plant test must be conducted under extremely unfavorable conditions, alternative plans may be necessary. The length of test will depend on the test objectives, the number of conditions tested, and the required time to run at each test condition.

301.4 Dryer Controls and Instrumentation

The test participants should understand the spray dryer system control scheme so they can anticipate the equipment's response to deliberate or consequential disturbances. Equipment diagrams should be available showing the locations for temperature, pressure, flow rate, and humidity measurements and sample points. Accuracy provided by the dryer instrumentation is an important factor for a successful test. It may be necessary to recalibrate critical instruments and tune controllers prior to starting the test. It may also be necessary to make preparations for, and carry out all piping, instrument and equipment changes where necessary to obtain the operating conditions, samples, and data required. Be certain of the information that the instrument is providing (i.e. is the flow rate temperature or pressure compensated, what are the units of measure). Record external environmental conditions during the tests, i.e., barometric pressure, air temperature, and air humidity. Annual averages for these conditions for the site should be available to aid in the proper interpretation of the results and prediction of full-scale production. Convenient laboratory facilities should be made available to check the moisture content of the feed and product and microscopic and screen evaluation of particle size and shape.

301.5 Peripheral Equipment

The potential limitations of peripheral equipment such as pump, preheater, fans, valves, cyclones, and bag houses should be considered. Assure that a good supply of the desired feed is available.

301.6 Pretest Calculations

Pretest calculations of the test conditions can be useful to check against the capacity of fans, heaters, dryer, and product recovery. Also check the requirements for separately storing the test product grades from each test, since they may be nonstandard and variable material or quality. Review the environmental limitations on emissions and operating conditions for their effect on the test conditions. For orientation, it may be well to study the examples in Section 800.

301.7 Test Plan

Although the factors affecting spray dryer performance can be very complicated, there are a few variables that can be adjusted to help control final product characteristics. General trends are described below. Exceptions can arise, and other factors can affect, hide, or hinder the desired or expected results. Actual product tests are often needed to confirm and evaluate the ability to control and produce desired characteristics in a given product.

301.7.1 Handling Multiple Variables

So many variables affect spray dryer performance that a partial factorial experiment plan may be required to sort out the effect of these variables. A Factorial Experiment Plan is a plan for carrying out experiments laid out in a multidimensional matrix, usually at upper and lower conditions for each variable.

The matrix is symmetrical so that all variables are equally represented. In a Partial Factorial Experiment Plan only a fraction of the possible combinations of variables are included, but all are represented at some high and low values. See *Reference 808.7, Section 808, and Reference 808.3, pp 3-87 to 3-88.*

Initially, sufficient knowledge may not be available to choose these conditions. Under these conditions a preliminary Evolutionary Test Plan may be best. Start with any set of conditions chosen either from literature sources (such as Table 301 and Table 302 or *Reference 808.3, pp 12-81 to 12-90*) or recommendations from equipment manufacturer or others, or simply choose conditions that are convenient. Conduct a series of tests, varying first the variables expected to have the most effect on the desired properties. See Section 303 to determine these. For heat sensitive material, see Sections 303.3 and 502.

TABLE 301. Performance Data of Spray Dryers

Reference 808.6, p 275

Kind of Stock	Moisture Content		Spray Device	Flow Pattern	Air Temperature	
	In (%)	Out (%)			In (°C)	Out (°C)
Skim Milk, $d = 60\mu m$	48-55	4	Wheel or Nozzle 170 to 200 bar	Parallel	250	95-100
	50-60	4		Parallel	250	95-100
Whole Milk	50-80	2.5	Wheel or Nozzle 100 to 140 bar	Parallel	170-200	
Eggs, whole	74-76	2-4	Wheel or Nozzle	Parallel	140-200	50-80
Eggs, Yolk	50-55	2-4	Wheel or Nozzle	Parallel	140-200	50-80
Egg. Whites	87-90	7-9	Wheel or Nozzle	Parallel	140-200	50-80
Coffee, Instant, 300 μm	75-85	3-3.5	Nozzle	Parallel	270	110
Tea, Instant	60	2	Nozzle, 27 bar	Parallel	190-250	
Tomatoes	65-75	3-3.5	Wheel	Parallel	140-150	
Food Yeast	76-78	8	Wheel	Parallel	300-350	100
Tannin	50-55	4	Wheel	Parallel	250	90
PVC Emulsion, 90% >90 μm <60 μm	40-70	0.01-0.1	Wheel or Nozzle or Pneumatic	Parallel	165-300	
Melamine-urethane-formaldehyde resins	30-50	0	Wheel, 140-150 m/sec	Parallel	200-275	65-75
Heavy duty detergents	35-50	6-13	Nozzle, 30-60 bar	Counter	350-400	90-110
Kaolin	35-40	1	Wheel	Parallel	600	120

TABLE 302. Performance of a Dryer 18 ft Diameter by 18 ft High with a Spray Wheel and Airflow of 11,000 cfm at the Outlet

Reference: 808.6, p 275

Material	Air Temp (°K)		% Water In Feed	Evaporation Rate (kg/s)
	In	Out		
Blood, Animal	440	345	65	5.9
Yeast	500	335	86	8.2
Zinc Sulfate	600	380	55	10.0
Lignin	475	365	63	6.9
Aluminum Hydroxide	590	325	93	19.4
Silica Gel	590	350	95	16.9
Magnesium Carbonate	590	320	92	18.2
Tanning Extract	440	340	46	5.2
Coffee Extract	420	355	70	3.8
Detergent A	505	395	50	5.0
Detergent B	510	390	63	6.2
Detergent C	505	395	40	2.6
Manganese Sulfate	500	415	50	5.5
Aluminum Sulfate	415	350	70	1.7
Urea resin A	535	355	60	3.8
Urea Resin B	505	360	70	1.9
Sodium Sulfide	500	340	50	2.0
Pigment	515	335	73	13.2

301.7.2 Safety

Any equipment testing must conform to the latest requirements of applicable safety standards. These include, but are not limited to plant, industry, local, and state and federal regulations. It is recommended that all testing be conducted under the supervision of personnel fully experienced in plant and equipment operating practices. A safety review should be conducted prior to operating any dryer outside of the original design parameters.

Most spray drying systems are heated by natural gas or propane burner systems. Only qualified personnel familiar with the related safety regulations should adjust or modify the burner safety control systems on these heaters.

Explosions are a particular hazard involving dispersions of organic powder in air. A range of explosive concentrations and temperatures exists for most combustible powders in air; these properties can be found in the material's MSDS. A spray dryer may contain an air ignition source. Explosions may also occur in peripheral powder handling situations. The operators should be aware of this possibility and guard against it. For example, see Section 402.1. Certain dusts also expose workers to touch and/or inhalation hazards.

A combustible powder should not be dried in a dryer that has not been designed for the hazards of that particular material. Older spray dryers were often not built to current standards for materials that are dust explosion hazards. This is also true for flammable solvents.

301.8 Environmental

The test procedure must conform to the latest requirements of all applicable environmental standards, which include plant, industry, local, state and federal regulations. Environmental conditions that apply to the equipment in normal operation should also apply during testing.

301.9 Cleaning and Inspection

Before carrying out any test, open the dryer chamber and inspect the internals for damage, misalignment of parts such as nozzles, and for presence of material from previous tests on walls or nozzles. A light dusting of material may be removed by brushing, but caked materials must be washed off. Inspection may reveal problems with operating conditions of the previous test and help guide the next test.

301.10 "Dry Run"

A useful procedure is that of conducting a "dry run" before the official test. The pretest should include a walk-thru at the equipment following all of the actions of the operators, technicians, analyses, data collection, and data calculations. This will enable identification of shortcomings in data collection, sampling points, sample handling, analytical and sequencing of conditions. Check the blower(s) and feed pump(s) for lubrication and proper rotation. Calibrate all instruments, including air and liquid feed flow instruments.

302 Types of Test

The types of test that are usually run are summarized in Section 101.2. These fall into three general categories; Capacity, Product Properties, and Acceptance Test. All are discussed below.

302.1 Dryer System Capacity

Tests can be performed on new or old dryers to determine how the dryer is operating, whether it can be adjusted to achieve more capacity, or what capacity may be feasible for new operating conditions to achieve desired properties of new products. Some large spray dryers may have capacity for evaporation rates up to 6,800 kg/hr (15,000 lb/hr) or more, but powder production rate depends on many variables.

The dryer system capacity may be controlled by the limitations of the drying chamber itself, or by limitations of peripheral equipment such as the feed system, the atomizer, fan capacities, energy input, product recovery equipment, and environmental controls. Comparison of mass and energy balances with equipment capacities will help analyze which part of the system is likely to restrict capacity. (Also, see Section 502.1.)

302.1.1 *Dryer Chamber Limitations*

There is a limit to how much capacity can be increased by changing peripheral equipment, such as increasing heat input and fan size for a given dryer. The design of the drying chamber itself limits capacity because of the interaction of the equipment with the product properties. Increasing the severity of drying conditions will eventually affect product properties. Product properties include

required moisture content, flow properties and other quality measures. Details of these product property interactions are discussed in Section 303.

302.1.2 *Peripheral Equipment Limitations*

Initial design of the dryer should have properly fit or balanced all components to provide good drying conditions. In some cases design or maladjustment of peripherals may limit the performance. However, a specific application may deviate from assumptions made in the initial design. Therefore, it may be important to separately test the peripheral dryer components and evaluate their design. If the chamber design will support increased capacity, it may be desirable to investigate whether changes to the feed system, fan capacities, energy input, product recovery, and environmental controls will result in increased capacity.

Analysis of peripherals could include determining and confirming:

- The energy rating for the air heater. Can it reach its original design?
- The airflow rating for the system fans. How much can they be varied without causing problems, such as unsatisfactory chamber residence time or drying time?
- Duct size restrictions, transport velocity, dust collector or scrubber performance limitations. Will they cause airflow limitations?
- Feed pump flow rate and pressure- range and limits. Do they fit the test ranges and atomizer requirements?
- Atomization limits: Nozzle number and size, , rotary atomizer limits (volume or horsepower). Are they compatible with the test conditions?

In addition, confirming the capacity and performance of each component can help find and determine if losses are preventing intrinsic capacities from being reached (i.e. air leaks, poor insulation, poor component adjustment or maintenance.)

302.2 Heat And Material Balance

Another objective of testing may be to perform a heat and material balance to assure that the dryer is performing satisfactorily. In most cases, one can do a reasonable check on performance just by measuring production and heat input. However, instructions for a detailed heat and material balance are also included in Sections 603 & 800s. For this part of the test, it is important to determine that dryer operation is steady, and that the feed and product are adequately sampled and characterized.

302.2.1 *Heat Balances*

The major heat load Q for the dryer is the evaporation requirement, determined by the required production rate. In theory ($Q = L C_p \Delta T$) the same heat load Q can be provided by less process gas L at higher temperature drops (ΔT), or more process gas L at lower temperature drops (ΔT). The dryer is designed to provide this capacity at operating conditions ($L, \Delta T$) to give good product. The design

includes the component requirements: heater, fan, atomization technique, and chamber design and size. (See Computation, Section 600.)

302.2.2 *Economic Optimum Production Rate (Thermal Efficiency)*

Optimum conditions for thermal efficiency use the highest ΔT , i.e., the highest inlet gas temperature and lowest outlet temperature that will produce good product. Increasing inlet gas temperature increases evaporative capacity of the dryer, but also is likely to affect product properties, such as bulk density due to formation of more hollow particles, and may increase thermal degradation. Therefore, trial-and-error testing is required to determine this optimum. Section 303 discusses the effect of operating conditions on properties as a guide for testing.

302.2.3 *Steady State Requirements*

The performance capability of a spray dryer can be demonstrated only under conditions of steady-state flow of material and gas. Also, the feed material moisture content and temperature, the gas temperature and humidities into and out of the dryer, and the product moisture content and temperature must remain essentially constant during the test period.

302.2.3.1 Major Measurements

During the test, measurements must be taken of gas and material temperatures, moisture contents and flow rates, total heat input to the dryer, and heat losses from the drying chamber. It is necessary to record the quantity, temperature, and moisture content of material going to product collection equipment separately from the chamber product. This is necessary because the temperature of material conveyed to the product recovery equipment can be higher than the temperature of the product from the dryer, but it will not be higher than the gas temperature. There also may be a difference in residence time of the hot gas. Without an accounting of material division, a material balance on moisture content and an accurate accounting of heat consumed as sensible heat in the material is not possible.

302.2.3.2 Product Recovery Equipment

Apart from the need to close heat and material balances around the dryer, it is not essential to carry out a performance test on product recovery equipment at the same time as the dryer performance test.

302.2.3.3 Consistency Test

Most measurements made on commercial-sized dryers are susceptible to human, instrument, and analytical errors. In addition, small but uncontrollable variations usually occur in material flow, gas flow, temperature and moisture contents during the performance test. Therefore, the heat and material balance results must be checked to be verify that they are consistent among themselves. The balances to be obtained must be as follows: (See Section 600 and 800)