AIChE Equipment Testing Procedure

SPRAY DRYERS

A Guide to Performance Evaluation

Prepared by the
Equipment Testing Procedures Committee

American Institute of Chemical Engineers
345 East 47 Street, New York, NY 10017

TABLE OF CONTENTS

ISBN 0-8169-0462-6

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
EQUIPMENT TESTING PROCEDURES COMMITTEE

Chairman: R. L. Neary
Monsanto Company

Vice Chairman: S. D. Fegan
Lawrence Pump and Engine Co.

Past Chairman: R. E. McHarg
UOP (Retired)

SPRAY DRYERS

PROCEDURE SUBCOMMITTEE

Chairperson: J. J. Wettstein
Recon Systems, Inc.

Members

R. W. Bayliss
Davison Chemical Division
W. R. Grace & Co.

P. Y. McCormick
Drying Unincorporated

S. S. Grossel
Hoffmann-La Roche, Inc.

David Lee, Consultant

G. W. Baldwin
Union Carbide Corporation

100.0 PURPOSE, SCOPE, & LIABILITY

101.0 Purpose

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

101.2 Reasons for conducting performance tests on commercial-size dryers may be to:

1. Compare the performance of a new dryer with stated design data.

2. Determine the performance of the dryer under typical operating conditions.

3. Determine the maximum dryer capacity under existing operating conditions.

4. Study alternative operating conditions for increased dryer capacity.

5. Gather data for design of new dryers of different capacities or dryers for similar products.

6. Study specific dryer characteristics as they relate to product characteristics, e.g., residence time, temperature profiles.

7. Determine a desirable operating range for routine control of the dryer.

8. Determine the optimum operating conditions for product quality, cost effectiveness, fuel conservation, and minimum environmental impact.

101.3 Although this procedure might be used as a guide for designing tests to demonstrate dryer capacity under conditions of manufacturer's performance guarantee, the procedure is not intended for this purpose, nor is this procedure adequate to serve as a basis for a performance guarantee. It may, however, be used as a guide for preparing such a guarantee.

For example, this procedure does not set limits for acceptable deviations between pilot plant test results or manufacturer's predictions and commercial results; this procedure does not address material handling questions, nor feed properties and uniformity other than those of feed rate and moisture content; and this procedure does not set standards for fabrication quality and mechanical performance. Moreover, for any specific product, there may be particular temperature or moisture measurements, sampling techniques, and quality requirements other than dryness that should be included in performance specifications. This procedure is not intended to cover product quality in any aspect except moisture content. The issue of particle size distribution and morphology is discussed by Marshall, see Section 804.0.

102.0 Scope

102.1 This procedure applies to spray dryers in which a pumpable liquid is atomized into a hot gas stream, water or other liquid is flashed off, and the resulting powder is conveyed either with the drying gas (cocurrent) or by gravity against the drying gas (counter current). The gas stream is the sole external source of thermal energy for material heating and liquid vaporization, and is also the carrier gas for removing evolved vapors from the dryer shell.

102.2 This procedure may be adapted for several configurations of spray dryers, including cocurrent or counter current, turbulent, mixed, or parallel flow.

103.0 Liability

103.1 AIChE and members of the various committees involved make no representation, warranties, or guarantees expressed or implied as to the application or fitness of the testing procedures suggested herein for any specific purpose or use. Company affiliations are shown for information only and do not imply procedure approval by the company listed.

200.0 DEFINITIONS AND DESCRIPTION OF TERMS

201.0 Dryer Installation

201.1 A spray dryer consists of a stationary cylindrical vessel in the vertical position. The gas inlet to the dryer may be either at the top or the bottom, depending upon the configuration. There is some method of gas distribution--perforated plates, louvers, or vane rings--within the chamber. The gas outlet will normally be at the opposite end of the chamber from which feed is introduced. It may be the only outlet of the vessel, in which case the spray dryer product would be carried in the outlet drying gas. The vessel may be equipped for chamber product separation with two outlets, in which case, the product would be separated from the gas stream before it leaves the chamber.

201.2 Feed material is introduced into the top of the dryer, with some method of atomization. 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 for the final product. Once the material leaves the atomizer, it falls by gravity through the spray dryer until it reaches the bottom of the tower where it exits with the gas stream, or through the product outlet in the case of chamber separation.

201.3 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. Maintain the exit gas stream at a sufficiently high temperature so that vapor does not condense in the system.

201.4 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, are the most common forms of separation equipment employed on spray dryers.

201.5 Fans are used to 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 must, therefore, have static pressure

capability to accommodate the pressure drop through the entire system. Alternatively, when the pressure drop through the inlet gas filter, gas heater, and gas inlet duct exceeds 125 Pa (0.5 inches of water), a second forced-draft fan may be installed upstream of the filter or heater to overcome the inlet system pressure drop. By balancing the two fans in this manner, the pressure inside the spray drying chamber can be minimized at a level close to atmospheric to minimize inleakage of ambient air.

202.0 Description of Terms

202.1 Drying is an operation in which a volatile liquid is separated from a solid or semisolid material by vaporization. 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.

202.1.1 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 (expressed as kg/kg).

202.1.2 Atomization is the formation of a spray by breaking up bulk liquid into many individual droplets. Its principal effect is to produce a high ratio of surface to mass in the liquid phase.

202.1.3 Bound moisture is liquid held by a material that exerts a vapor pressure less than that of the pure liquid at the same temperature. Liquid may be bound by solution in cell or fiber walls as a homogeneous solution throughout the material or bound by chemical or physical adsorption on solid surfaces. The degree of bound moisture that can be removed depends on the specific conditions of humidity and temperature in the external surroundings.

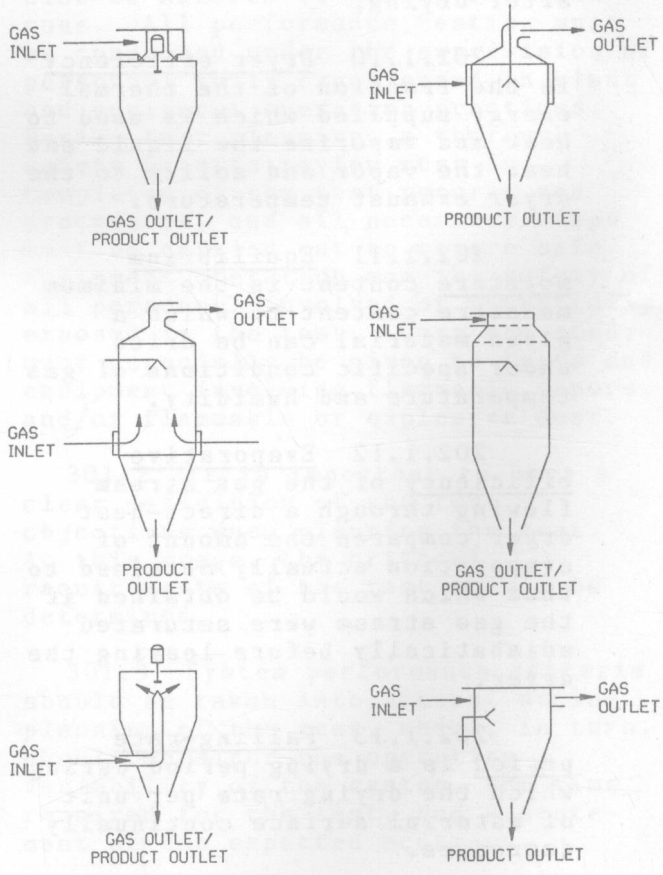
202.1.4 Capillary flow is flow of liquid through the interstices and over the surfaces of a solid caused by liquid surface tension and liquid-solid molecular attraction.

202.1.5 Constant-rate period is the drying period during which the rate of liquid removal per unit of material surface is constant.

202.1.6 Critical moisture content is the moisture content at which the constant-rate period ends and the falling-rate period begins.

202.1.7 Dew point, or saturation temperature is the temperature at which a given

Typical Spray Dryer Configurations



mixture of liquid (e.g., water) vapor and air is saturated, i.e., the temperature at which the liquid exerts a vapor pressure equal to the partial pressure of the liquid vapor in the given mixture.

202.1.8 Direct-heat dryer is one of a class of drying equipment in which heat is transferred to the material being dried by direct contact with the heating medium. The heating medium is usually a hot gas and the heat transfer mechanism is convection.

202.1.9 Dry basis expresses the moisture content of a wet material as the weight of moisture per unit weight of dry material. The advantage of using this basis is that the moisture change per unit weight of dry material is obtained simply by the difference between the moisture content before and after drying.

202.1.10 Dryer efficiency is the fraction of the thermal energy supplied which is used to heat and vaporize the liquid and heat the vapor and solids to the dryer exhaust temperature.

202.1.11 Equilibrium moisture content is the minimum moisture content to which a given material can be dried under specific conditions of gas temperature and humidity.

202.1.12 Evaporative efficiency of the gas stream flowing through a direct-heat dryer compares the amount of evaporation actually obtained to that which would be obtained if the gas stream were saturated adiabatically before leaving the dryer.

202.1.13 Falling-rate period is a drying period during which the drying rate per unit of material surface continually decreases.

202.1.14 Fiber saturation point is the bound moisture content of a cellular material, such as wood, at which the cell walls are completely saturated, whereas the cavities are liquid free. It is the equilibrium moisture content occurring when the humidity of the surrounding atmosphere approaches saturation.

202.1.15 Free moisture content is the liquid content that is removable at a given temperature and humidity. Free moisture may include both bound and unbound moisture, and is equal to the total average moisture content of the material minus the equilibrium moisture content for the prevailing conditions of drying.

202.1.16 Funicular state is the condition that occurs while drying a porous body when capillary action causes air to be sucked into the pores.

202.1.17 Heat of vaporization is the change in enthalpy involved in the transition from liquid to vapor, expressed as kJ/kg.

202.1.18 Indirect-heat dryer is one of a class of drying equipment in which heat is transferred primarily by conduction and radiation, and the heating medium is physically separated from the material being dried by a barrier.

202.1.19 Internal diffusion occurs in a material during drying when liquid or vapor flow appears to obey the fundamental laws of diffusion.

202.1.20 Latent heat is the energy involved in a phase change (e.g., liquid to gas) which does not result in a temperature change expressed as kJ/kg.

202.1.21 Moisture content of a material is the moisture quantity per unit weight of dry or wet solid.

202.1.22 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.

202.1.23 Pendular state is the state of liquid in a porous body when a continuous film of liquid no longer exists around and between discrete particles, so that flow by capillarity cannot occur. This state succeeds the funicular state.

202.1.24 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 vapor at the same temperature, expressed as a percentage. For water in air this is also called percent relative humidity.

202.1.25 Sensible heat is the energy involved in changing the temperature of a given substance expressed as kJ/kgK.

202.1.26 Unaccomplished moisture change refers to the ratio of the free moisture present at any time to that initially present.

202.1.27 Unbound moisture in a hygroscopic material is the moisture in excess of the equilibrium moisture content corresponding to saturation humidity in the surrounding atmosphere. All water in a non-hygroscopic material is unbound moisture.

202.1.28 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.

202.1.29 Wet-bulb temperature is the dynamic equilibrium temperature attained by a liquid surface when the rate of heat transfer to the surface by convection equals the rate of mass transfer away from the surface.

300.0 TEST PLANNING

301.0 Planning Considerations

301.1 Safety and environmental requirements must be considered in the planning of the test. Testing must conform to the latest requirements of all applicable safety and environmental standards and procedures, which include plant, industry, local, state, and federal regulations. Environmental standards that apply to the equipment and process during normal operation must also be adhered to during all test runs. All performance testing must be conducted under the supervision of personnel fully experienced in plant and equipment operating practices. During test planning, a thorough safety hazards review must be completed of the test program and procedures, and all necessary steps must be carried out to ensure safe equipment operation and the safety of all personnel involved or potentially exposed in the test. Care and study must especially be given to tests and equipment involving flammable vapors and/or flammable or explosive dust.

301.2 It is important to have a clear definition of the test objectives when planning the test. At this stage, the critical requirements of the test should be determined.

301.3 System performance criteria should be taken into account during planning of the test, which, in turn, should consider the operating variability of the system, the time required for the test, and a statement of the expected accuracy.

302.0 Dryer Material and Heat Balances

302.1 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 temperatures 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 During the test, measurements must be made 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. The reason is that the temperature of material conveyed to the product recovery equipment may 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 material moisture contents because of differences in residence time with 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.

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

302.4 Because most measurements made on commercial-sized spray dryers are susceptible to human, instrument, and analytical errors and because small but uncontrollable variations usually occur in material flow, gas flow, temperature and moisture contents during the performance test, a check should be made that heat and material balance results are consistent among themselves. The balances to be obtained must be as follows:

302.4.1 Moisture

(feed moisture content) - (product moisture content) - (dust moisture content) = (evaporation)

(evaporation) + (moisture from direct-fired fuel combustion) = (gas stream humidity gain)

302.4.2 Product

(dry material flow in) = (dry material flow out)

302.4.3 Gas

(dry gas flow in) = (dry gas flow out)

302.4.4 Energy

(heat gained by the gas through the heater) = (heat provided by fuel burner or other heat source)

(heat lost by gas through the dryer) = (material sensible heat gain) + (vapor sensible heat gain) + (heat of evaporation) + (dryer heat losses) + (heat of reaction/crystallization).

302.5 In order to complete these balances, all of the following data should be obtained (either directly by measurement or indirectly by calculation) during the test. Data units cited are S.I.; any consistent system may be employed.

302.5.1 Ambient air temperature (K)

302.5.2 Spray dryer inlet gas temperature (K)

302.5.3 Spray dryer outlet gas temperature (K)

302.5.4 Product collection equipment outlet gas temperature (K)

302.5.5 Exhaust fan outlet temperature (K)

302.5.6 Supply fan outlet temperature (K)

302.5.7 Feed temperature (K)

302.5.8 Spray dryer product temperature (K)

302.5.9 Product collection equipment product temperature (K)

302.5.10 Chamber, duct, and product collection equipment surface temperatures (K)

302.5.11 Ambient absolute humidity (kg/kg)

302.5.12 Fuel consumption (kg/s)

302.5.13 Fuel heating value (kJ/kg)

302.5.14 Fuel carbon and hydrogen contents (kg/kg)

302.5.15 (Alternative steam or electricity use) (kg/s or kw)

302.5.16 (Alternative steam latent heat value) (kJ/kg)

302.5.17 Exhaust fan absolute humidity (kg/kg)

302.5.18 Exhaust fan flow (m^3/s)

302.5.19 Exhaust fan speed (s^{-1})

302.5.20 Exhaust fan static pressure (Pa)

302.5.21 Exhaust fan power consumption (kw)

302.5.22 Supply fan absolute humidity (kg/kg)

302.5.23 Supply fan flow (m^3/s)

302.5.24 Supply fan speed (s^{-1})

302.5.25 Supply fan static pressure (Pa)

302.5.26 Supply fan power consumption (kw)

302.5.27 Product collection equipment pressure drop (Pa)

302.5.28 Dry feed rate (kg/s)

302.5.29 Feed moisture content, dry basis (kg/kg)

302.5.30 Feed density (kg/m^3)

302.5.31 Chamber product rate (kg/s)

302.5.32 Product/dust collection rate (kg/s)

302.5.33 Chamber product moisture content, dry basis (kg/kg)

302.5.34 Product/dust collection moisture content, dry basis (kg/kg)

302.5.35 Product bulk density (kg/m^3)

302.5.36 (Heat of reaction or crystallization) (kJ/kg)

302.6 The measured fuel consumption of a direct-fired, direct-heat dryer also can be compared to the calculated fuel consumption by Orsat analysis of the exit gas. If this method is used, a complete fuel analysis should be obtained and the effects of air

leakage considered.

302.7 Product collection cyclone pressure-drop characteristics usually can be obtained from the manufacturer; pressure drop should be expressed in terms of a number of gas velocity pressure heads based on the inlet gas velocity and density. With this information, the pressure drop can be used as an additional measurement of gas flow to compare to other flow measurements.

302.8 Fan manufacturer's performance data and fan curves showing volume flow versus static pressure versus power consumed at the operating fan speed must be available for the performance test. In the United States, published fan data are usually based on air at 294K (70°F), and these data often must be corrected for actual fan gas density. On the other hand, most manufacturers will provide fan curves corrected for specific applications if asked to do so.

302.9 Inlet gas (air) flow measurements on dryers provided with direct-combustion air heaters must include measurement of both primary air supplied for fuel combustion and the dilution air supplied for dryer inlet gas temperature control.

302.10 Inlet gas (air) flow to dryers provided with steam-coil air heaters also can be estimated by measuring the static pressure drop of the gas flowing through the heaters. Most steam-coil manufacturers provide pressure drop data for their specific coils based on gas velocity, gas density, number of coil rows deep, and fin density. Coil pressure drop measurements sometimes may be substituted for a direct measurement of inlet gas flow, but such a measurement is recommended mainly as a way to confirm a direct gas flow measurement and, perhaps, uncover other measurement errors.

303.0 Test Preparation

303.1 During the test planning period, the following preparations should be completed.

1. All burner, fan, heater, steam coil, and product collection equipment performance data are obtained from the manufacturers.

2. Fuel analyses and fuel heating values are determined.

3. All test instruments are installed on the dryer or are available at the test site for temporary use.

4. All instrument connections and taps are provided on the dryer installation, and safe access to all measurement points is provided.

5. All test instruments have been tested and are in working order.

6. Test data sheets are prepared; test personnel are trained in the safe and proper use of all instruments and in the test procedures; and all laboratory analytical procedures for feed and product evaluations have been tested and proven, e.g., moisture determinations.

7. A mechanical inspection of the equipment has been completed.

400.0 INSTRUMENTS AND METHODS OF MEASUREMENT

401.0 Gas Temperature and Humidity

401.1 Exposed-junction thermocouples connected to continuous indicator-recorders are preferred for rapid response and accuracy. Sheathed and thermowell-enclosed thermocouples, and gas-filled temperature sensors also are

acceptable provided time-constants are known. Dial thermometers are a poor third choice, and then, only if scale division is sufficiently narrow to provide sensitivity. The use of glass thermometers for field tests on commercial dryers is an unsafe practice.

401.2 Gas temperature instruments should be installed in gas streams having velocities in excess of 10 m/s, to minimize radiation effects. If a temperature sensor is installed in the line of sight of a burner flame or near a high temperature steam-coil gas heater, a radiation shield may be necessary between the high temperature source and the sensor. Whenever such a heat source is 50 K hotter than the gas stream, possible measurement errors due to radiation and convention should be evaluated and the necessary compensations made.

401.3 A thermocouple temperature is a point measurement and, in any gas conveying duct, the gas velocity and gas temperature may not be uniform across the full duct section. Before the performance test, all duct sections planned for thermocouple or other sensor locations should be thoroughly explored for temperature and velocity variations. This work should be done under drying operating conditions similar to the proposed test conditions. A proper duct section profile should reveal the best location for a single point measurement or reveal whether repeated profiles of the duct section also will be necessary to obtain accurate data during the actual performance test.

401.4 The degree of accuracy sought for gas dry-bulb temperature measurements is $\pm$ 0.50% of the absolute gas temperature reading, K.

401.5 Atmospheric humidity can be determined by comparing dry-bulb and wet-bulb temperatures obtained using a sling psychrometer or by use of an accurate aluminum-oxide hygrometer.

401.6 Dryer exit humidity should be measured downstream from all dry-type dust collection equipment, so as to sample the cleanest gas possible. Vapor condensation on measuring devices must be avoided. Wet-bulb temperatures up to about 350 K can be measured by a "wet-bulb" thermocouple in clean gas. If the gas contains dust or exceeds 350 K in wet-bulb temperature, a gas sample method that cleans and cools the gas for dew point measurement will be needed. In this situation, standard sampling equipment is available and a manufacturer of gas moisture monitoring instruments should be consulted.

401.7 The degree of accuracy sought for gas wet-bulb or dew point temperature measurements is $\pm$0.50% of the absolute gas temperature reading, K.

402.0 Gas Flow

402.1 Very few commercial-sized continuous direct-heat spray dryers have permanently installed flow measurement nozzles, orifices, or venturi meters; therefore, for a performance test, it usually is necessary to employ portable pitot tubes or hot-wire anemometers.

> **NOTE:** Hot-wire anemometers must not be used in the presence of flammable or explosive vapors or dusts.

402.2 Inlet gas (air) flow at ambient temperature can be measured by:

402.2.1 Making a velocity profile across the total face area of an inlet gas duct or inlet gas filter using a hot-wire anemometer.

402.2.2 Making a velocity profile across a convenient and reasonably straight, uniform section of inlet duct using either a pitot tube or a hot-wire

anemometer.

402.3 These gas flow measurements can be confirmed by comparing the fuel burned in the combustion gas heater to the gas temperature rise through the heater. For steam-coil systems the pressure drop across the coil can be measured and compared to the coil manufacturer's published data showing air velocity versus pressure drop. The steam condensate rate from the steam coils can be compared to the gas temperature rise across the coils. When measuring steam condensate flow from steam coils, a weight allowance must be added to account for condensate flash loss which occurs when condensate is released from a pressurized condensate system into an atmospheric-pressure condensate collector. Both electric and steam heaters, and fuel burners should yield an efficiency of about 95%; the 5% loss is due to heater radiation losses and incomplete combustion.

402.5 When making gas flow calculations based on the temperature rise attributable to fuel combustion, the lower heating value of the fuel must be used. The higher heating value, which is often cited by the supplier as the fuel's heating value, includes the latent heat of condensation of the water produced by the combustion of hydrogen in the fuel. This latent heat is not usable or recoverable in the dryer.

402.5 When a gas inlet system also has a supply fan, an additional check of air flow can be obtained by measuring fan speed, static pressure, and power consumed and comparing these to the fan manufacturer's data showing fan volume versus static pressure versus power.

402.6 Agreement within $\pm$5% between any two independent methods of inlet gas flow measurement is good agreement; $\pm$10% is acceptable. The latter is the maximum measurement deviation that should be accepted without explanation as experimental error on a commercial-sized dryer.

402.7 The dryer's exit gas flow also can be measured by making a pitot tube profile of a clean duct section. A hot-wire anemometer can be used if the duct gas temperature is below the maximum allowable by the anemometer specifications and flammable or explosive dusts are not present. If it is necessary to measure flow in a dusty gas stream, the Type "S" (Stauscheibe) pitot tube may be preferred over a regular pitot tube because the Type "S" is less susceptible to plugging and gives a higher differential pressure reading for any given velocity.

402.8 Powder collection equipment (cyclone, bag collector, scrubber) pressure drop measurements, compared to manufacturer's data, are usable to confirm exit gas flow measurements.

402.9 Measurement of the speed, static pressure, and power consumed by an exhaust fan, compared to the fan manufacturer's data, provides a second confirmation of measured gas flow. In the exit gas from a dryer, note that the presence of a large fraction of water vapor and possibly carbon dioxide significantly affect the gas density; gas composition as well as temperature must be known to determine gas density for use with fan curves and tables.

402.10 When a wet scrubber is used for recovery of dust, and gas flow measurement is made downstream from the scrubber, the humidity change that occurs in the scrubber must be accounted for in order to determine the scrubber's inlet gas flow. Again, the large fraction of water vapor in the scrubber exit gas significantly reduces the average gas density compared to dry air.

402.11 Agreement between the dryer's exit gas flow measurement and that indicated by cyclone pressure drop or fan performance is good if within +10%; a deviation of $\pm$ 15% is the maximum acceptable without explanation.

403.0 Material Temperature and Moisture Content

403.1 Probably the best way to measure the temperature of particulate solids is to place a representative sample in a closed, insulated container with an exposed-junction thermocouple immersed in the material to equilibrate in temperature with the material. If the material has either a low bulk density or a low thermal conductivity, occasional shaking of the container and immersed thermocouple may be necessary to heat the thermocouple to the material temperature.

403.2 Thermocouples immersed in flowing streams of particulate solids usually yield unreliable data; the indicated temperature is likely to be closer to that of the entrained gas than to the temperature of the solids.

403.3 Infrared absorption instruments may yield acceptable material temperature data provided the field of view can be limited to the material. Accuracy of material temperature measurements should be $\pm$1.0% of the absolute temperature measurement, K.

403.4 During the performance test, material moisture samples should be taken at frequent intervals, stored in gas-tight and pre-dried containers, and evaluated by the most accurate laboratory moisture test available for the material. On-line, continuous moisture meters may be acceptable for routine dryer control, but the purpose of a dryer performance test is usually to test drying capacity and doubt regarding moisture data should be minimized. Variations in moisture measurements that can be considered acceptable depend on material properties and the accuracy of the moisture test employed.

403.5 Moisture samples of cyclone or bag collector product should be collected and analyzed separately from dryer product; the same sampling precautions and analytical procedures should be followed.

403.6 Material flow to dust recovery also must be measured by collecting the recovered dust for a measured time period and weighing the increment collected.

404.0 Radiation and Convection Heat Losses

404.1 For estimating purposes, the heat loss from the exposed surfaces of a well-insulated spray dryer may be assumed to be about 5% of the dryer process heat sink, i.e., sensible heat taken up by the solid, liquid and vapor plus the latent heat of vaporization.

404.2 Performance tests conducted on dryers installed outside, regardless of insulation quality, should be made on dry, windless days to minimize heat losses and errors in heat balance calculations that might be attributable to large heat losses.

404.3 On dry, windless days, the surface temperature of an uninsulated gas duct within which the gas velocity is 10-30 m/s, may be assumed to be the average of the gas and ambient temperatures. The same assumption may be applied to uninsulated cyclone or bag collectors; however, assumptions should never be employed in place of surface temperature measurements when it is possible to make these arrangements.

404.4 The best accounting of radiation and convection heat losses is realized by making surface temperature measurements on all uninsulated surfaces and, as well as possible, on all insulated surfaces. Then the radiation and convection heat losses from these surfaces to the environment in dry, still air can be calculated using the data on pipe and duct heat losses, which are included in most engineering

handbooks and texts dealing with heat transfer.

405.0 Miscellaneous Measurements

405.1 A spray dryer should always have at least one permanently installed static pressure indicator, which should be mounted either on the suction side of the process fan or on the direct-combustion gas heater if this heat source is used. In the case of fuel-fired heaters, instrument type and location must always conform to combustion equipment safety standards; these, however, are not included within the scope of this procedure. During the performance test, other static pressure measurements can be made using temporarily-mounted water manometers or gauges, if this practice conforms to plant and product safety standards.

405.2 Care must be taken to ensure that static pressure instruments are installed in places remote from areas of high gas turbulence and points of gas flow direction change, such as in duct elbows and transitions. Static pressure data should be obtained from points of reasonably uniform gas velocity so that gas velocity can be measured at the same points and, if desired, velocity head and total pressure can be calculated.

405.3 Provisions for safely measuring electric power consumption by the fan motors and electric gas heaters should be arranged before the performance test by installation of indicating or recording wattmeters on the motor and heater controls by qualified electricians. The use of portable instruments designed for electric system troubleshooting is not recommended during the performance test except by a skilled electrician. If variable-speed drives are used, manufacturer's drive input power versus efficiency data must be available.

500.0 TEST PROCEDURE

501.0 Procedure

501.1 Performance tests often fail, or yield inconclusive results, because of a desire to run full capacity equipment demonstrations too soon after a new plant start-up; e.g., before operators are fully trained and familiar with the equipment, before start-up troubleshooting on all equipment upstream or downstream from the dryer is complete, or before representative quality feed material can be produced at a rate great enough to supply the dryer. It is not unusual for a year to elapse between an initial plant start-up and the time operators, equipment, and material are all ready for a valid full-capacity dryer demonstration. Where a performance demonstration may be required, start-up delay should be considered when making arrangements regarding test timing.

501.2 When it appears that all facilities are ready for a performance test, a preliminary trial during which the dryer is operated for a period of time at a rate as close as possible to the test rate should be made in order to identify any major equipment deficiencies that, until corrected, could obviate the performance test. For example, if it is found that the gas heater does not attain the needed gas temperature or the capacity of the exhaust fan is inadequate at the design fan speed, there is no purpose in proceeding with a test until corrections are made.

501.3 When all preparations are complete, the dryer feed rate should be gradually increased to that specified for the test. Dryer operation at this feed rate should continue until all gas and material temperatures approach steady-state conditions. At the end of this first period, the relevant temperature, pressure, and flow measurements specified in 302.5 should be recorded. Uninterrupted operation

should continue for a second period of at least one hour. Then, a second set of temperature, pressure, and flow data should be recorded. If this second set of data is essentially identical to the first, the test is complete. If not, a third period of operation under steady-state conditions and essentially equal in length to the second period should be completed and followed by another set of measurements. This procedure should continue until two successive series of data, separated in time by at least one hour, are essentially identical.

501.4 Humidity measurements and material moisture samples should be taken at the same intervals as other data. If the dryer is believed to be operating on a borderline condition close to a maximum moisture specification, material samples should be taken at more frequent intervals.

600.0 COMPUTATION OF RESULTS

601.0 Material Balance

m(1) = dry solids feed rate, kg/s

m(2) = dry solids chamber product rate, kg/s

m(3) = dry solids rate from dust collection equipment, kg/s

X(1) = feed moisture, dry basis, kg/kg

X(2) = chamber product moisture, dry basis, kg/kg

X(3) = dust collector product moisture, dry basis kg/kg

E(1) = evaporation rate, kg/s

Dry Solids Balance

$$m(1) = m(2) + m(3) \quad (1)$$

Moisture Balance

$$m(1) * X(1) = m(2) * X(2) + m(3) * X(3) + E(1) \quad (2)$$

Y(3) = air humidity at dryer inlet, kg/kg

Y(4) = air humidity at dryer outlet, kg/kg

T(3) = air temperature at dryer inlet, ^{o}C

T(4) = air temperature at dryer outlet, ^{o}C

V(3) = volumetric air flow at dryer inlet, m^3/s

V(4) = volumetric air flow at dryer outlet, m^3/s

M(3) = dry air mass flow to dryer, kg/s

M(4) = dry air mass flow from dryer, kg/s

M(leak) = mass flow of dry air from leaks, kg/s

Y(a) = ambient air humidity, kg/kg

Vh(3) = humid volume of inlet air, m^3/kg

Vh(4) = humid volume of outlet air, m^3/kg

Dry Air Mass Flow

$$Vh(3) = (0.00283 + 0.00456 * Y(3)) * (T(3) + 273) \quad (3)$$

$$M(3) = V(3)/Vh(3) \quad (4)$$

$$Vh(4) = (0.00283 + 0.00456 * Y(4)) * (T(4) + 273) \quad (5)$$

$$M(4) = V(4)/Vh(4) \quad (6)$$

Air Leaks

$$M(leak) = M(4) - M(3) \quad (7)$$

Moisture Gain By Drying Gas

$$M(gain) = M(4) * Y(4) - M(3) * Y(3) - M(leak) * Y(a) \quad (8)$$

Evaporation

$$E(1) = m(1) * X(1) - m(2) * X(2) - m(3) * X(3) \quad (9)$$

NOTE: Moisture gain by the drying gas should agree within ±10% of evaporation.

602.0 Heater Calculations

Vh(a) = ambient air humid volume, m^3/kg

Y(a) = ambient humidity, kg/kg

T(a) = ambient temperature, °C

V(1) = primary air volumetric flow, m^3/s

V(2) = combustion air volumetric flow, m^3/s

M(1) = primary air dry mass flow, kg/s

M(2) = combustion air dry mass flow, kg/s

Ambient humid volume

$$Vh(a) = (0.00283 + 0.00456 * Y(a)) * (T(a) + 273) \quad (10)$$

Dry air mass flow

$$M(1) = V(1)/Vh(1) = V(1)/Vh(a) \quad (11)$$

$$M(2) = V(2)/Vh(2) = V(2)/Vh(a) \quad (12)$$

Dry Air Mass Balance

$$M(1) + M(2) \tilde{} M(3) \quad (13)$$

NOTE: M(3) is not exactly equal to M(1) + M(2) for direct fired heaters. Differences result from neglecting combustion products and air leaks. Differences are normally small unless large air leaks are present or inlet temperatures are very high. A complete fuel analysis should be used to check this mass balance if the difference is more than 5%.

Heater Duty and Fuel Consumption

Q(1) = heat required to heat air to heater outlet temperature, kJ/s

Cs(3) = average humid heat across heater, kJ/kg °C

T(3) = heater outlet temperature, °C

FHV = fuel heating value, kJ/kg

M(f) = fuel consumption, direct fired heater, kg/s

M(s) = steam consumption, indirect heater, kg/s

Q(e) = power required for electric heater, kW

Lambda(stm) = latent heat of steam for indirect heater, kJ/kg

Humid Heat

$$Cs(3) = 1.0 + (1.88 * Y(3) \quad (14)$$

NOTE: Use heater outlet humidity for direct fired heaters.

Heat Required to Heat Inlet Air

$$Q(1) = M(3) * Cs(3) * (T(3) - T(a)) \quad (15)$$

Calculated Fuel Consumption

Direct fired heater

$$M(f) = Q(1)/(0.95 * FHV) \quad (16)$$

Indirect heater

$$M(s) = Q(1)/(0.95$$