AIChE Equipment Testing Procedure

# SPRAY DRYERS

A Guide to Performance Evaluation

Second Edition

Prepared by the

Equipment Testing Procedure Committee

Copyright 2003

American Institute of Chemical Engineers 3 Park Avenue, New York, NY 10016-5991 This Page Intentionally Left Blank

AIChE Equipment Testing Procedure

# SPRAY DRYERS

A Guide to Performance Evaluation

Second Edition

Prepared by the

Equipment Testing Procedure Committee

Copyright 2003

American Institute of Chemical Engineers 3 Park Avenue, New York, NY 10016-5991 © 2003 by the American Institute of Chemical Engineers 3 Park Avenue, New York, NY 10016-5991 <u>www.aiche.org</u> ISBN 0-8169-0925-3 Pub. E-32

Cover and Layout by Beth Shery Sisk

All rights reserved. No part of the publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, or otherwise, without the prior permission of the American Institute of Chemical Engineers

Approved for publication by AIChE's Chemical Engineering Technology Operating Council in Spring 2003. Second edition approved for publication by AIChE's Board of Directors in 2003.

It is sincerely hoped that the information presented in this document will lead to even more impressive performance by the chemical processing and related industries. However, the American Institute of Chemical Engineers, its employees and consultants, its officers and directors, Equipment Testing Procedures Committee members, their employers, and their employers' officers and directors disclaim making or giving any warranties or representations, express or implied, including with respect to fitness, intended purpose, use or merchantability and/or correctness or accuracy of the content of the information presented in this document. Company affiliations are shown for information only and do not imply approval of the procedures by the companies listed. As between (1) the American Institute of Chemical Engineers, its employees and consultants, its officers and directors, Equipment Testing Procedure Committee members, their employers, and their employers' officers and directors, and (2) the user of this document, the user accepts any legal liability or responsibility whatsoever of the consequence of its use or misuse.

### AMERICAN INSTITUTE OF CHEMICAL ENGINEERS EQUIPMENT TESTING PROCEDURE COMMITTEE

*Chair:* Dr. P.C. Gopalratnam, P.E. DuPont Apparel & Textile Sciences

Vice Chair: Richard P. O'Connor R.P. O'Connor and Associates

## **SPRAY DRYERS** Procedure Revision Subcommittee

Chairman: Dr. Richard H. Snow, P.E., Chicago Chem Consultants Corp. General Committee Liaison: Joseph F. Hasbrouck, P.E., Hasbrouck Engineering, P.C.

Members:

| Robert E. Barnes | Engelhard Corporation                         |
|------------------|---|
| Miguel Castro    | Hughes Petroleum                              |
| Edward M. Cook   | Energy Saving Consultants                     |
| Mark Roisum      | Nyro, Inc.                                    |
| Paul Schmidtchen | Martin Marietta Magnesia<br>Specialties, Inc. |

Members Participating in First Edition

J.J. Wettstein G.W. Baldwin R.W. Byliss S.S. Grossel David Lee P.Y. McCormick

First Edition approved by AIChE Council in 1988 for publication.

### AMERICAN INSTITUTE OF CHEMICAL ENGINEERS EQUIPMENT TESTING PROCEDURE COMMITTEE

GENERAL COMMITTEE (2003)

Dr. P.C. Gopalratnam, P.E., *Chairman* DuPont Apparel & Textile Sciences

Richard P. O'Connor, Vice Chairman Thomas H. Yohe, Past Chairman Prabir K. Basu, Council Liaison Stephen R. Smith, Staff Liaison Beth Shery Sisk, Staff Liaison

#### GENERAL COMMITTEE MEMBERS

Prashant Agrawal S. Dennis Fegan Joseph F. Hasbrouck, P.E. Dr. John G. Kunesh Robert E. McHarg Anthony L. Pezone Rebecca M.W. Starkweather

#### **Table of Contents**

| 100         | Purpose and Scope1                    |
|-------------|---------------------------------------|
| 101         | Purpose1                              |
| 101.1       | Purpose1                              |
| 101.2       | Summary1                              |
| 101.3       | Scope of Spray Drying2                |
| 101.4       | Reasons for Testing Spray Dryers2     |
| 102         | Design vs. Operational Variables5     |
| 103         | Liability                             |
| 200         | Definitions and Descriptions of       |
|             | Terms                                 |
| 201         | Dryer Design5                         |
| 201.1       | Dryer Chamber5                        |
| 201.2       | Airflow Patterns5                     |
| 201.3       | Product Flow6                         |
| 201.4       | Atomizer6                             |
| 201.5       | Heating Methods                       |
| 201.6       | Product Recovery                      |
| 201.7       | Airflow Motive Force                  |
| 202         | Description of Terms 8                |
| 202 1       | Drving 8                              |
| 300         | Test Planning 11                      |
| 301         | Preliminary Objectives 11             |
| 301.1       | Test Objectives 11                    |
| 301.2       | Organizational Resources 11           |
| 301.2       | Schedule 11                           |
| 301.5       | Dryer Controls and Instrumentation 12 |
| 301.5       | Peripheral Equipment 12               |
| 301.6       | Pretest Calculations 12               |
| 301.7       | Test Plan 12                          |
| 301.8       | Fnvironmental 15                      |
| 301.9       | Cleaning and Inspection 15            |
| 301.10      | "Dry Run" 15                          |
| 302         | Types of Test 15                      |
| 302 1       | Dryer System Canacity 15              |
| 302.1       | Heat and Material Balance 16          |
| 302.2       | Product Properties 10                 |
| 302.5       | Acceptance Test 10                    |
| 302.4       | Variables Affecting Product           |
| 505         | Properties 10                         |
| 303 1       | Residual Moisture Content 19          |
| 303.2       | Atomization 20                        |
| 303.2       | Heat Sensitivity 23                   |
| 303.4       | Physical Properties 23                |
| 303.5       | Prediction of Canacity and Rate       |
| 505.5       | Effects 26                            |
| 303.6       | Summary 26                            |
| 303.0       | Data Requirements Product             |
| JU <b>4</b> | Droperties 27                         |
| 304 1       | Data Requirements 27                  |
| 204.1       | A tomizer Data 20                     |
| 204.2       | Complete Heat and Matarial            |
| 504.5       | Delenses                              |
|             | Datatices                             |

| 304.4Peripheral Equipment Limitations29304.5Product Quality Measurements29305.1Objective of Tests29305.2Operating Variables30305.3Test Data Sheet30305.4Measurement Methods30305.5Test Plan30305.6Planning Check List30400Methods of Measurement and<br>Sampling30401Gas Temperature and Humidity30401.1Selection of Temperature Sensors31401.2Installation of Temperature Sensors31401.3Duct Temperature and Velocity<br>Profiles31401.4Accuracy of Dry Bulb Temperatures31401.5Atmospheric Humidity31401.6Dryer Exit Humidity31401.7Accuracy of Gas Wet Bulb<br>Temperature31402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32403.3Exit Gas Measurement34403.4Product Temperature Measurement34404Dust Flow Measurements34405Radiation and Convection Heat<br>Losses35405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35405.4Readiation Capacity37502.5Procedure36500Test Procedure36501Plant-Scale Test36 <td< th=""><th>204.4</th><th></th><th>^</th></td<>  | 204.4 |                                       | ^      |
|--|-------|---------------------------------------|--------|
| 304.5   Product Quality Measurements   | 304.4 | Peripheral Equipment Limitations 2    | 9      |
| 304.6   Particle Properties   29     305   Test Preparation   29     305.1   Objective of Tests   29     305.2   Operating Variables   30     305.3   Test Data Sheet   30     305.4   Measurement Methods   30     305.5   Test Plan   30     305.6   Planning Check List   30     400   Methods of Measurement and   Sampling     401   Gas Temperature and Humidity   30     401   Sate Temperature and Velocity   Profiles     9   Profiles   31     401.4   Accuracy of Dry Bulb Temperatures     31   401.5   Atmospheric Humidity   31     401.5   Atmospheric Humidity   31   401.7   Accuracy of Gas Wet Bulb     Temperature   31   401.7   Accuracy of Gas Wet Bulb   32     402.1   Installed Flow Meters   32   402.1   Installed Flow Meters   32     402.2   Inlet Gas   32   402.2   Inlet Gas   33     403   Material Temperature Measurement.34   403.1  | 304.5 | Product Quality Measurements2         | 9      |
| 305Test Preparation29305.1Objective of Tests29305.2Operating Variables30305.3Test Data Sheet30305.4Measurement Methods30305.5Test Plan30305.6Planning Check List30400Methods of Measurement and<br>Sampling30401Gas Temperature and Humidity30401.1Selection of Temperature Sensors31401.2Installation of Temperature Sensors31401.3Duct Temperature and Velocity<br>Profiles31401.4Accuracy of Dry Bulb Temperatures31401.5Atmospheric Humidity31401.6Dryre Exit Humidity31401.7Accuracy of Gas Wet Bulb<br>Temperature32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and Moisture<br>Content34404Dust Flow Measurements34405Radiation and Convection Heat<br>Losses35405.1Estimated Heat Loss35405.2Measuring Heat Loss35406Miscellaneous Measurements36406.1Static Pressure36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Production Capacity38 <td>304.6</td> <td>Particle Properties</td> <td>9</td>  | 304.6 | Particle Properties                   | 9      |
| 305.1   Objective of Tests.   29     305.2   Operating Variables.   30     305.3   Test Data Sheet.   30     305.4   Measurement Methods.   30     305.5   Test Plan   30     305.6   Planning Check List.   30     400   Methods of Measurement and Sampling.   30     401   Gas Temperature and Humidity.   30     401.1   Selection of Temperature Sensors.   30     401.2   Installation of Temperature Sensors.   31     401.3   Duct Temperature and Velocity   Profiles.   31     401.4   Accuracy of Dry Bulb Temperatures   31     401.5   Atmospheric Humidity.   31     401.6   Dryer Exit Humidity.   31     401.7   Accuracy of Gas Wet Bulb   Temperature   32     402.1   Installed Flow Meters.   32   32     402.2   Inlet Gas.   32   33     403   Material Temperature and Moisture   33     404   Dust Flow Measurement.   34     405   Radiation and Convection Heat   35 <   | 305   | Test Preparation20                    | 9      |
| 305.2Operating Variables $30$ $305.3$ Test Data Sheet $30$ $305.4$ Measurement Methods $30$ $305.5$ Test Plan $30$ $305.6$ Planning Check List $30$ $400$ Methods of Measurement andSampling $30$ $401$ Gas Temperature and Humidity $30$ $401.1$ Selection of Temperature Sensors $30$ $401.2$ Installation of Temperature Sensors $31$ $401.3$ Duct Temperature and VelocityProfiles $31$ $401.4$ Accuracy of Dry Bulb Temperatures $31$ $401.5$ Atmospheric Humidity $31$ $401.6$ Dryer Exit Humidity $31$ $401.6$ Dryer Exit Humidity $31$ $401.7$ Accuracy of Gas Wet BulbTemperature $7$ Temperature $32$ $402.1$ $402.1$ Installed Flow Meters $32$ $402.2$ Inlet Gas $32$ $402.3$ Exit Gas Measurement $34$ $403.1$ Product Temperature Measurement $34$ $403.2$ Product Temperature Measurements $34$ $403.1$ Product Temperature Measurements $34$ $405$ Radiation and Convection HeatLosses $35$ $405.1$ Estimated Heat Loss $35$ $405.2$ Measuring Heat Loss $35$ $406.1$ Static Pressure $36$ $406.1$ Static Pressure Sensors $36$ $406.2$ Location of Pressure Sensors $36$ $406.3$ <td< td=""><td>305.1</td><td>Objective of Tests</td><td>9</td></td<> | 305.1 | Objective of Tests                    | 9      |
| 305.3   Test Data Sheet.   30     305.4   Measurement Methods.   30     305.5   Test Plan   30     305.6   Planning Check List.   30     400   Methods of Measurement and<br>Sampling.   30     401   Gas Temperature and Humidity.   30     401.1   Selection of Temperature Sensors30     401.2   Installation of Temperature Sensors30     401.3   Duct Temperature and Velocity<br>Profiles.   31     401.4   Accuracy of Dry Bulb Temperatures   31     401.5   Atmospheric Humidity.   31     401.6   Dryer Exit Humidity.   31     401.7   Accuracy of Gas Wet Bulb   32     402.1   Installed Flow Meters.   32     402.2   Inlet Gas.   32     402.3   Exit Gas Measurement   | 305.2 | Operating Variables                   | 0      |
| 305.4   Measurement Methods.   30     305.5   Test Plan   30     305.6   Planning Check List.   30     400   Methods of Measurement and<br>Sampling.   30     401   Gas Temperature and Humidity.   30     401.1   Selection of Temperature Sensors.   30     401.2   Installation of Temperature Sensors.   31     401.3   Duct Temperature and Velocity<br>Profiles.   31     401.4   Accuracy of Dry Bulb Temperatures   31     401.5   Atmospheric Humidity.   31     401.6   Dryer Exit Humidity.   31     401.7   Accuracy of Gas Wet Bulb   1     Temperature   32   402.   1     402   Gas Flow.   32     403   Material Temperature and Moisture   32     404.2   Installed Flow Meters   33     403   Material Temperature Measurement.   34     404   Dust Flow Measurements   34     405   Radiation and Convection Heat   Losses     Losses   35   405.1   Estimated Heat Loss   35   | 305.3 | Test Data Sheet                       | 0      |
| 305.5Test Plan $30$ $305.6$ Planning Check List $30$ $400$ Methods of Measurement and<br>Sampling $30$ $401$ Gas Temperature and Humidity $30$ $401.1$ Selection of Temperature Sensors $31$ $401.2$ Installation of Temperature Sensors $31$ $401.3$ Duct Temperature and Velocity<br>Profiles $31$ $401.4$ Accuracy of Dry Bulb Temperatures $11.4$ Accuracy of Gas Wet Bulb<br>Temperature $31$ $401.5$ Atmospheric Humidity $31$ $401.6$ Dryer Exit Humidity $31$ $401.7$ Accuracy of Gas Wet Bulb<br>Temperature $32$ $402.1$ Installed Flow Meters $32$ $402.2$ Inlet Gas $32$ $402.3$ Exit Gas Measurement $33$ $403$ Material Temperature and Moisture<br>Content $34$ $403.1$ Product Moisture Content $34$ $404$ Dust Flow Measurements $34$ $405$ Radiation and Convection Heat<br>Losses $35$ $405.1$ Estimated Heat Loss $35$ $406.1$ Static Pressure $36$ $406.1$ Static Pressure Sensors $36$ $406.1$ Static Pressure Sensors $36$ $500$ Test Procedure $36$ $501$ Plant-Scale Test $36$ $503.1$ Water Run $38$ $503.1$ Water Run $38$ $503.1$ Vater Run $38$ $504.2$ Croyer Operability $38$ $504.2$ Ru  | 305.4 | Measurement Methods                   | 0      |
| 305.6   Planning Check List  | 305.5 | Test Plan                             | 0      |
| 400   Methods of Measurement and<br>Sampling   30     401   Gas Temperature and Humidity   30     401.1   Selection of Temperature Sensors   30     401.2   Installation of Temperature Sensors   31     401.3   Duct Temperature and Velocity   profiles   31     401.4   Accuracy of Dry Bulb Temperatures   31     401.5   Atmospheric Humidity   31     401.6   Dryer Exit Humidity   31     401.7   Accuracy of Gas Wet Bulb   Temperature     7   Accuracy of Gas Wet Bulb   32     402   Gas Flow   32     402.1   Installed Flow Meters   32     402.2   Inlet Gas   32     403.1   Product Temperature Measurement   33     403   Material Temperature Measurements   34     403.2   Product Moisture Content   34     403.2   Product Moisture Content   34     403.2   Product Moisture Content   34     405   Radiation and Convection Heat   Losses     Losses   35   405.3   Outdoor Equipment   35  | 305.6 | Planning Check List                   | 0      |
| Sampling30401Gas Temperature and Humidity30401.1Selection of Temperature Sensors30401.2Installation of Temperature Sensors31401.3Duct Temperature and VelocityProfilesProfiles31401.4Accuracy of Dry Bulb Temperatures   | 400   | Methods of Measurement and            |        |
| 401   Gas Temperature and Humidity   |       | Sampling                              | 0      |
| 401.1   Selection of Temperature Sensors30     401.2   Installation of Temperature Sensors 31     401.3   Duct Temperature and Velocity     Profiles   31     401.4   Accuracy of Dry Bulb Temperatures  | 401   | Gas Temperature and Humidity          | 0      |
| 401.2   Installation of Temperature Sensors 31     401.3   Duct Temperature and Velocity     Profiles  | 401.1 | Selection of Temperature Sensors 30   | 0      |
| 401.2   Instantion of Penperature and Velocity     Profiles  | 401.2 | Installation of Temperature Sensors 3 | 1      |
| 401.3   Duct Temperature and versetry     Profiles   | 401.2 | Duct Temperature and Velocity         | •      |
| 401.4   Accuracy of Dry Bulb Temperatures     31     401.5   Atmospheric Humidity     31     401.6   Dryer Exit Humidity     31     401.7   Accuracy of Gas Wet Bulb     Temperature   31     402   Gas Flow     402.1   Installed Flow Meters     402.2   Inlet Gas     402.3   Exit Gas Measurement     403   Material Temperature and Moisture     Content   34     403.1   Product Temperature Measurement     403.2   Product Moisture Content     404   Dust Flow Measurements     405   Radiation and Convection Heat     Losses   35     405.1   Estimated Heat Loss     405.2   Measuring Heat Loss     405.3   Outdoor Equipment     406   Miscellaneous Measurements     406.3   Electric Power Measurements     406.3   Electric Power Measurements     406.3   Electric Power Measurements     406.3   Electric Power Measurements     501   Plant-Scale Test     502   | 401.5 | Profiles 3                            | 1      |
| 401.4   Accuracy of Dry Builty Temperatures     31     401.5   Atmospheric Humidity     401.6   Dryer Exit Humidity     401.7   Accuracy of Gas Wet Bulb     Temperature   31     402   Gas Flow     402.1   Installed Flow Meters     402.2   Inlet Gas     402.3   Exit Gas Measurement     403   Material Temperature and Moisture     Content   34     403.1   Product Temperature Measurement     403.2   Product Moisture Content     404   Dust Flow Measurements     405   Radiation and Convection Heat     Losses   35     405.1   Estimated Heat Loss     405.2   Measuring Heat Loss     405.3   Outdoor Equipment     406   Miscellaneous Measurements     406   Static Pressure     406.3   Electric Power Measurements     406.3   Electric Power Measurements     406.3   Electric Power Measurements     501   Plant-Scale Test   36     502   Exploratory Experiments   37 <   | 401.4 | A course of Dry Dulk Torrestores      | I      |
| 401.5Atmospheric Humidity31401.6Dryer Exit Humidity31401.7Accuracy of Gas Wet Bulb1Temperature31402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection HeatLossesLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss35405.3Outdoor Equipment36406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-Scale Dryer39   | 401.4 | Accuracy of Dry Build Temperatures    |        |
| 401.5   Atmospheric Humidity   31     401.6   Dryer Exit Humidity   31     401.7   Accuracy of Gas Wet Bulb   Temperature   31     402   Gas Flow   32     402.1   Installed Flow Meters   32     402.2   Inlet Gas   32     402.3   Exit Gas Measurement   33     403   Material Temperature and Moisture   34     403.1   Product Temperature Measurement   34     403.2   Product Moisture Content   34     403.1   Product Moisture Content   34     404   Dust Flow Measurements   34     405   Radiation and Convection Heat   Losses     Losses   35   405.1   Estimated Heat Loss   35     405.2   Measuring Heat Loss   35   406   Miscellaneous Measurements   36     406.1   Static Pressure   36   406.2   Location of Pressure Sensors   36     406.3   Electric Power Measurements   36   36   30   37     501   Plant-Scale Test   36   36   36   37  |       |                                       | 1      |
| 401.6Dryer Exit Humidity31401.7Accuracy of Gas Wet BulbTemperature31402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection Heat1000000000000000000000000000000000000   | 401.5 | Atmospheric Humidity                  | 1      |
| 401.7Accuracy of Gas Wet Bulb<br>Temperature402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and Moisture<br>Content34403.1Product Temperature Measurement34403.2Product Moisture Content34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection Heat<br>Losses35405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment36406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>   | 401.6 | Dryer Exit Humidity                   | 1      |
| Temperature31402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement34403.2Product Moisture Content34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection HeatLossesLosses3535405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment36406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39   | 401.7 | Accuracy of Gas Wet Bulb              |        |
| 402Gas Flow32402.1Installed Flow Meters32402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement403.2Product Moisture Content404Dust Flow Measurements405Radiation and Convection HeatLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss405.3Outdoor Equipment406Miscellaneous Measurements406Miscellaneous Measurements406.1Static Pressure406.2Location of Pressure Sensors406.3Electric Power Measurements500Test Procedure501Plant-Scale Test502Exploratory Experiments503Preliminary Trial503Preliminary Trial503.1Water Run504Definitive Test504.1Test Start-Up504.2Running a Definitive Test in a Plant-<br>Scale Drver504Sole Drver504Sole Drver504Sole Drver504Sole Drver504Sole Drver505Sole Drver506Sole Drver507Sole Drver508Sole Drver509Sol4.2504Sole Drver504Sole Drver505Sole Drver506Sole Drver  |       | Temperature                           | 1      |
| 402.1Installed Flow Meters32402.2Inlet Gas32403Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement403.2Product Moisture Content404Dust Flow Measurements405Radiation and Convection HeatLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss405.3Outdoor Equipment406Miscellaneous Measurements406.1Static Pressure406.2Location of Pressure Sensors406.3Electric Power Measurements500Test Procedure501Plant-Scale Test502Exploratory Experiments503Preliminary Trial503.1Water Run503.2Dryer Operability504Definitive Test504.1Test Start-Up504.2Running a Definitive Test in a Plant-Scale Dryer504.2Running a Definitive Test in a Plant-Scale Dryer   | 402   | Gas Flow                              | 2      |
| 402.2Inlet Gas32402.3Exit Gas Measurement33403Material Temperature and MoistureContent34403.1Product Temperature Measurement34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection HeatLossesLosses35405.1Estimated Heat Loss405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Drver39  | 402.1 | Installed Flow Meters                 | 2      |
| 402.3Exit Gas Measurement.33403Material Temperature and Moisture<br>Content34403.1Product Temperature Measurement.34403.2Product Moisture Content.34404Dust Flow Measurements34405Radiation and Convection Heat<br>Losses35405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39   | 402.2 | Inlet Gas                             | 2      |
| 403Material Temperature and Moisture<br>Content34403.1Product Temperature Measurement.34403.2Product Moisture Content34404Dust Flow Measurements34405Radiation and Convection Heat<br>Losses35405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Drver39  | 402.3 | Exit Gas Measurement                  | 3      |
| Content34403.1Product Temperature Measurement. 34403.2Product Moisture Content404Dust Flow Measurements405Radiation and Convection HeatLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss405.3Outdoor Equipment406Miscellaneous Measurements406Static Pressure406.1Static Pressure Sensors406.2Location of Pressure Sensors406.3Electric Power Measurements500Test Procedure501Plant-Scale Test502Exploratory Experiments503Preliminary Trial503.1Water Run504Definitive Test504.1Test Start-Up504.2Running a Definitive Test in a Plant-Scale Drver   | 403   | Material Temperature and Moisture     |        |
| 403.1Product Temperature Measurement. 34403.2Product Moisture Content  |       | Content                               | 4      |
| 403.2Product Moisture Content  | 403.1 | Product Temperature Measurement, 34   | 1      |
| 404Dust Flow Measurements34405Radiation and Convection Heat35405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Drver39   | 403.2 | Product Moisture Content 34           | 1      |
| 405Radiation and Convection Heat405Radiation and Convection HeatLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss405.3Outdoor Equipment406Miscellaneous Measurements406Static Pressure406.1Static Pressure406.2Location of Pressure Sensors406.3Electric Power Measurements406.3Electric Power Measurements500Test Procedure501Plant-Scale Test502Exploratory Experiments503Preliminary Trial503.1Water Run504Definitive Test504.1Test Start-Up504.2Running a Definitive Test in a Plant-<br>Scale Drver  | 404   | Dust Flow Measurements 34             | 1      |
| 405Radiation and Convection HeatLosses35405.1Estimated Heat Loss405.2Measuring Heat Loss405.3Outdoor Equipment406Miscellaneous Measurements406Static Pressure406.1Static Pressure406.2Location of Pressure Sensors406.3Electric Power Measurements406.3Electric Power Measurements500Test Procedure501Plant-Scale Test502Exploratory Experiments503Preliminary Trial503.1Water Run504Definitive Test504.1Test Start-Up504.2Running a Definitive Test in a Plant-<br>Scale Drver  | 405   | Padiation and Convection Heat         | •      |
| 405.1Estimated Heat Loss35405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Drver39  | 405   | Losser 34                             | 5      |
| 405.1Estimated freat Loss33405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39   | 405 1 | Estimated Heat Loss 26                | ,      |
| 405.2Measuring Heat Loss35405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 405.1 | Magnuring Heat Loss                   | )<br>= |
| 405.3Outdoor Equipment35406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 405.2 | Outdoor Fouriement                    | )<br>- |
| 406Miscellaneous Measurements36406.1Static Pressure36406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 405.3 | Outdoor Equipment                     | )<br>- |
| 406.1Static Pressure   | 406   | Miscellaneous Measurements            | )      |
| 406.2Location of Pressure Sensors36406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39   | 406.1 | Static Pressure                       | )      |
| 406.3Electric Power Measurements36500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 406.2 | Location of Pressure Sensors          | )      |
| 500Test Procedure36501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 406.3 | Electric Power Measurements           | 5      |
| 501Plant-Scale Test36502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39   | 500   | Test Procedure                        | 5      |
| 502Exploratory Experiments37502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 501   | Plant-Scale Test                      | 5      |
| 502.1Production Capacity37502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 502   | Exploratory Experiments               | 7      |
| 502.2Product Quality38503Preliminary Trial38503.1Water Run38503.2Dryer Operability38504Definitive Test39504.1Test Start-Up39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 502.1 | Production Capacity                   | 7      |
| 503Preliminary Trial.38503.1Water Run.38503.2Dryer Operability.38504Definitive Test39504.1Test Start-Up.39504.2Running a Definitive Test in a Plant-<br>Scale Dryer39  | 502.2 | Product Quality                       | 3      |
| 503.1Water Run   | 503   | Preliminary Trial                     | 3      |
| 503.2Dryer Operability   | 503.1 | Water Run                             | 3      |
| 504Definitive Test39504.1Test Start-Up   | 503.2 | Dryer Operability                     | 3      |
| 504.1   Test Start-Up  | 504   | Definitive Test                       | )      |
| 504.2 Running a Definitive Test in a Plant-<br>Scale Drver   | 504.1 | Test Start-Up                         | )      |
| Scale Drver  | 504 2 | Running a Definitive Test in a Plant- |        |
|  | 20112 | Scale Drver                           | )      |

\_\_\_\_\_