

# **STUDIES IN GAS - SOLID SYSTEMS**

THESIS SUBMITTED BY

**M. S. LYALL**

DEPARTMENT OF CHEMICAL ENGINEERING

IN FULFILMENT OF REQUIREMENTS OF THE DEGREE OF  
DOCTOR OF PHILOSOPHY

TO THE  
INDIAN INSTITUTE OF TECHNOLOGY, DELHI  
DECEMBER, 1986

CERTIFICATE

This is to certify that the thesis entitled "STUDIES IN GAS-SOLID SYSTEMS" submitted by me to the Indian Institute of Technology, Delhi, for the award of the degree of 'Doctor of Philosophy' is the record of bonafide research work carried out by me.

The thesis or any part thereof has not been submitted to any other University or Institution for the award of any degree or diploma.

*M. S. Lyall*

(M.S. LYALL)

*H. W. L.*  
24.12.86

*Chairman. BRC*

## ABSTRACT

Available literature on hydrodynamic aspects of a spouted bed dryer as well as the batch and the continuous drying in the same are reviewed. From a route different from the one available in the literature an expression is derived for the stable spouting pressure drop.

A mathematical model is developed to predict the complete batch drying dynamics. A computer program based on the same has been written and tested. With the help of this, the variation with time of the solids moisture content, the temperature and the outlet moisture concentration, are predicted.

A novel method is given to obtain the Arrhenius relationship for internal moisture diffusivity from simple batch spouted bed drying data. The method is shown to yield excellent results vis-a-vis the available diffusivity data of wheat and peas.

A number of experimental drying runs are performed in batch and continuous spouted bed modes with wheat, paddy, maize and peas. The predictions of the batch model compare well with the data of  $Q$ ,  $T$  and  $C$  as a function of time. A generalized correlation is developed to predict the specific drying rates of all the materials:

$$\phi_m = \frac{dQ}{dt} = k(50Q_0 + 0.118 T_0 - 12.5)10^{-5} \text{ kg/kgs} \quad (A)$$

where the single parameter  $k$  is shown to account for the difference in the type of grains studied. It is also proposed that

the k-value, representing the relative drying rate of any material with respect to wheat, remains independent of mode of drying (i.e. the k-values for spouted drying and tray drying are equal).

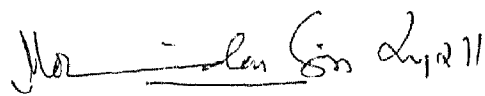
The complete dynamics of continuous drying predicted by the model of Viswanathan<sup>118</sup> is shown to compare favourably with the measured data. As predicted, the moisture content of initially dumped, solids,  $Q_d$ , is shown to play a critical role in determining the type of dynamics obtained. For example, for low  $Q_d$ , the solids temperature passes through a maximum which is not found in high  $Q_d$ .

A number of tray drying experiments have also been performed with 12 different grains. The k-values estimated from tray drying data for paddy, maize and peas, compare well with those estimated from spouted bed drying. Therefore, for any grain, the k-value may be obtained from tray drying and the same may be used in Eq. (A) presented above to design a spouted bed dryer.

### ACKNOWLEDGEMENT

The author wishes to acknowledge gratefully the facilities provided by the Head, Department of Chemical Engineering and the Co-operation and constant encouragement given by the faculty, staff and close friends during the tenure of this work.

The author is grateful to the Department of Non-conventional Energy Sources, Government of India, for providing financial assistance for the project through Sanction No. 1(15)/4/81-NES/367.

  
(M.S. Lyall)

CONTENTS

|           |                            | <u>Page</u> |
|-----------|----------------------------|-------------|
|           | List of Figures            | .. vi       |
|           | List of Tables             | .. viii     |
|           | Nomenclature               | .. x        |
| CHAPTER-1 | INTRODUCTION               | .. 1        |
| 1.1       | Importance of Drying       | .. 1        |
| 1.2       | Drying Systems             | .. 1        |
| 1.3       | Drying Plant               | .. 2        |
| 1.4       | Spouted Bed Dryer          | .. 5        |
| 1.5       | Thesis Contents in Brief   | .. 5        |
| CHAPTER-2 | LITERATURE SURVEY          | .. 8        |
| 2.1       | Importance of Drying       | .. 8        |
| 2.2       | Spouted-Bed Hydrodynamics  | .. 12       |
| 2.2.1     | Minimum Spouting Velocity  | .. 12       |
| 2.2.2     | Spouting Pressure Drop     | .. 14       |
| 2.2.3     | Maximum Pressure Drop      | .. 17       |
| 2.2.4     | Stability                  | .. 21       |
| 2.3       | Batch Drying               | .. 21       |
| 2.4       | Continuous Drying          | .. 23       |
| 2.4.1     | Steady State               | .. 23       |
| 2.4.2     | Bed Solids Temperature     | .. 24       |
| 2.4.3     | Dynamics                   | .. 25       |
| 2.5       | Diffusivity                | .. 26       |
| CHAPTER-3 | THEORETICAL                | .. 28       |
| 3.1       | Spouting Pressure Drop     | .. 28       |
| 3.2       | Batch Drying Dynamic Model | .. 30       |

Page

|           |                                   |    |     |
|-----------|-----------------------------------|----|-----|
| 3.2.1     | Assumptions                       | .. | 30  |
| 3.2.2     | Solids Moisture Content           | .. | 32  |
| 3.2.3     | Material Balance                  | .. | 33  |
| 3.2.4     | Bed Solids Temperature            | .. | 35  |
| 3.2.5     | Diffusivity Determination         | .. | 47  |
| 3.2.6     | Specific Overall Drying Rate      | .. | 49  |
| CHAPTER-4 | EXPERIMENTAL                      | .. | 51  |
| 4.1       | Set-Up                            | .. | 51  |
| 4.1.1     | Slotted Draft Tube                | .. | 56  |
| 4.2       | Solids Studied                    | .. | 59  |
| 4.2.1     | Solids Preparation                | .. | 59  |
| 4.3       | Procedure                         | .. | 62  |
| 4.4       | Measurements                      | .. | 63  |
| 4.4.1     | Measurements of Bed Hydrodynamics | .. | 71  |
| 4.4.2     | Temperature Correlation           | .. | 71  |
| 4.5       | Operating Conditions              | .. | 71  |
| 4.6       | Tray Drying Experiments           | .. | 81  |
| 4.7       | Adsorption Runs                   | .. | 88  |
| CHAPTER-5 | RESULTS AND DISCUSSION            | .. | 92  |
| 5.1       | Hydrodynamics                     | .. | 92  |
| 5.1.1     | Effect of Slotted Draft Tube      | .. | 95  |
| 5.2       | Batch Drying                      | .. | 97  |
| 5.2.1     | Dynamics                          | .. | 97  |
| 5.2.2     | Overall Drying Rate               | .. | 118 |
| 5.2.3     | Relative Drying Rate              | .. | 124 |
| 5.2.4     | Scale-Up                          | .. | 128 |

|             |                                                    | <u>Page</u> |
|-------------|----------------------------------------------------|-------------|
| 5.3         | Diffusivity                                        | .. 130      |
| 5.4         | Continuous Drying                                  | .. 134      |
| 5.4.1       | Dynamics                                           | .. 136      |
| 5.4.2       | Overall and Relative Drying Rates                  | .. 163      |
| 5.5         | Tray Drying                                        | .. 169      |
| 5.6         | Dynamics of Spouted Bed Adsorption                 | .. 175      |
| CHAPTER-6   | CONCLUSIONS                                        | .. 182      |
| APPENDIX-A: | Computer Program for Batch Drying<br>Dynamics      | .. 185      |
| APPENDIX-B: | Computer Program for Continuous<br>Drying Dynamics | .. 186      |
| REFERENCES  | ..                                                 | .. 188      |