International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol.4, No.4, pp 1633-1641, Oct-Dec 2012

Simulation Of Pneumatic Drying: Influence Of Particle Diameter And Solid Loading Ratio

K.S. Rajan

School of Chemical & Biotechnology,SASTRA University,Tirumalaisamudram Thanjavur, India – 613401.

Corres.author: ksrajan@chem.sastra.edu
Ph: 914362 304270

Abstract: Pneumatic drying has been simulated using a steady state, one-dimensional, two-fluid model that predicts the literature experimental data. The effect of particle diameter and solid loading ratio are studied on the profiles of gas pressure and solid moisture content. Dryer height required to achieve desired final moisture content for various solid loading ratios and particle diameters has also been presented. The study can be used to determine the optimum operating variables for any pneumatic drying duty.
Keywords: Pneumatic drying, solid loading ratio, particle diameter, simulation.

INTRODUCTION

Pneumatic drying or flash drying involves co-current flow of high temperature gas and fine wet solids through a duct, with short residence times and rapid drying. Pneumatic drying can be used to dry particles below the critical moisture contents as demonstrated in [1,2] while reporting the industrial data for drying of PVC, limestone and alumina. Laboratory drying data for alumina and iron have been presented in [3,4]. Many steady one-dimensional mathematical models for pneumatic drying are available in the literature [2,5-8]. While the models of Matsumoto [5] and Pelegrina and Crapiste [8] have been derived for drying of surface moisture, the models reported in [2,6,7,9] predicted drying behavior in the falling rate period. Levy and Borde [7] accounted for particle shrinkage, due to reduction in moisture content. Different mechanisms for drying in falling rate regime have been elaborated by Radford [2]. Skuratovsky et al. [10,11] developed two-dimensional models for vertical, pneumatic drying and the cross-sectional averaged profiles predicted were compared with literature data [1].

One-dimensional models have been used to predict the gas and solid velocity, temperature and moisture profiles in industrial dryers for drying PVC, limestone and alumina. The effect of ratio of dry-solid to gas mass flow rate on the temperature and moisture profiles along the dryer height has been simulated by Pelegrina and Crapiste [8] for drying of potato, and by Matsumoto [5] for wheat, corn and rape seed in the range of 0.011 to 0.045 and 0.1 to 0.5 respectively. During those simulations, the inlet moisture content of solid and gas humidity were maintained constant. However, Pelegrina and Crapiste [8] has reported that the initial solid moisture content affects drying rate profiles in the dryer and hence the final moisture content. Gas pressure drop, solid moisture content and the dryer height required are important in the optimal design of a pneumatic drying system, as they determine the power consumption and performance of dryer. Hence, in the present study the effect of solid loading ratio (ratio of wet-solid to gas mass flow rate) has been studied on gas pressure drop, solid moisture content and the dryer height required for desired final moisture content. The effect of particle diameter on the above three is also being reported. The simulations have been performed based on a simple one-dimensional model, for the removal of surface moisture only. Information on the pore structure of the solid to be dried is needed to model the removal of internal moisture and is not attempted here.

COMPUTATIONAL EXPERIMENTS

The model, complimentary equations and solution algorithm are available in our earlier work [12]. Computational experiments were performed to simulate the experimental data available in literature [1]. Upon validation of the model and solution procedure, simulation experiments were carried out over a range of solid loading ratios (0.1 – 2) and particle size (100-500 µm).

RESULTS AND DISCUSSION

Figure 1 shows the comparison between the simulated values of the gas temperature and the experimental values reported in [1]. The abscissa is the height of the dryer. It is clear from Fig. 1, that the model predicts the outlet gas temperature reasonably well. The figure 2 shows the comparison between the simulated values of solid moisture content and the experimental values in [1]. It is clear from Fig. 2, that the model predicts the moisture content very well for this condition. Since the reliability of the model to predict the experimental data has been demonstrated, the model can be utilized to study the effect of particle diameter and solid loading ratio on gas pressure and solid moisture content profiles.

.

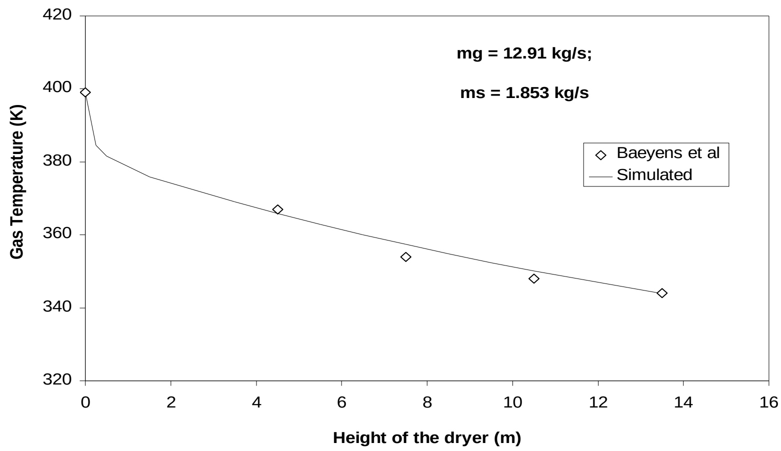

Fig. 1. Simulated gas temperature profile and comparison with the experimental data of Baeyens et al. for the drying of 180 mm PVC particles

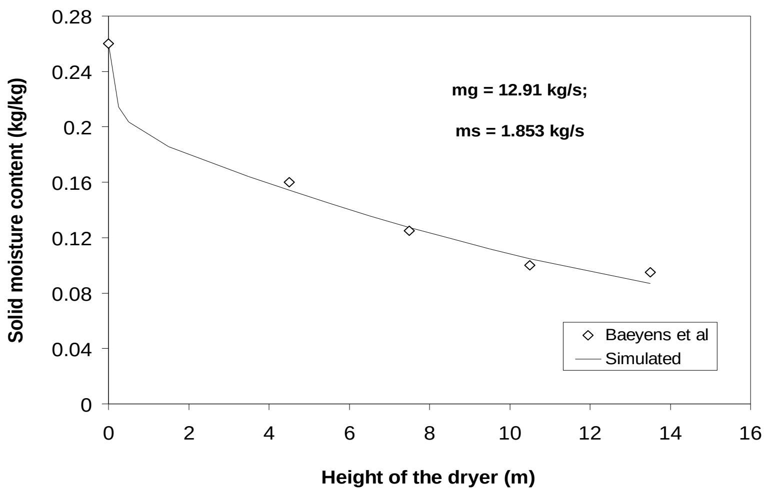

Fig. 2. Simulated gas temperature profile and comparison with the experimental data of Baeyens et al. for the drying of 180 mm PVC particles

EFFECT OF SOLID LOADING RATIO

Solid loading ratio (m) is known to influence the temperature and moisture profiles in pneumatic drying [8,10]. Review of reported industrial drying data indicates that the range of solid loading ratio lie between 0.1 and 1.1 for the drying of alumina and PVC particles [1,2]. Laboratory data for drying of iron and alumina have also been reported in the range of 0.4 – 1.3 in [3] and [4] respectively. Skuratovsky and his co-workers [10] performed simulation at solid loading ratios of 2 and 50, the later clearly indicating dense phase regime. Simulation of pneumatic drying at solid loading ratios in the range of 0.05 – 1 have not been reported.

In the present study, simulations were performed for drying of alumina particles of 180 m diameter, with an initial moisture content (X) of 0.26 kg/kg at a flow rate of 1.853 kg/s. The initial air temperature was taken as 126 °C. To study the effect of solid loading ratio, simulations were performed by varying gas flow rates for constant solid mass flow rate to get different solid loading ratios in the range of 0.1 to 2. The simulated profiles of gas pressure with height for different solid loading ratios are shown in Fig 3, from which rapid decrease in absolute pressure with height is noticed for higher ratios. With higher solid to gas mass flow ratios, the drag between the phases is more, due to higher solid concentration and higher relative velocity. This contributes to gas pressure drop and hence the pressure decreases steeply at higher solid to gas mass flow ratios. Also, it can be observed that in the initial portions of the duct decrease in pressure is rapid due to acceleration of particles from a very low velocity. This region lies within 0.5 – 1 m of the conveying duct. After the acceleration region, pressure change is linear with the height at all solid loading ratios. The pressure change in the fully developed region is also more with higher solid loading ratios due to higher drag as evident from Fig. 3.

Figure 4 shows the changes in pressure drop with solid loading ratio for alumina particles of 180 µm size at the gas inlet temperature of 126 °C and initial solid moisture content of 0.26 kg/kg. Pressure drops between the feed point and various heights along the duct are indicated in Fig. 4. It is clear from Fig.4 that the pressure drop decreases initially with solid loading ratio and reaches a minimum, before starting to increase. This trend is visible for pressure drops calculated between the feed point and at 2 m, 5 m and 10 m. Also, the minima in the pressure drop curves lie between the solid loading of 0.1 and 0.2. Total pressure drop from the feed till a height of 2 m shows a clear minimum, indicating the impact of solid loadig ratio in the acceleration region. This analysis can be utilized to determine the optimum solid loading ratio, which would lead to minimum pressure drop, provided the required heat duty is achieved.

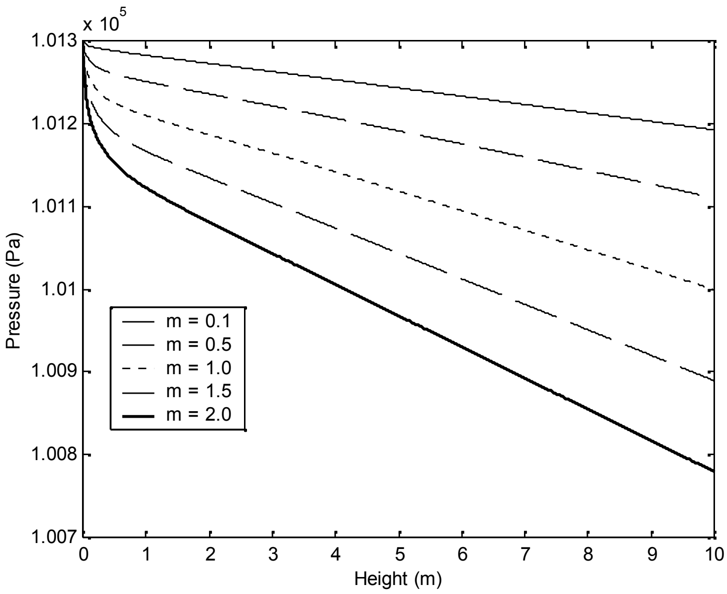

Fig. 3. Pressure profiles in the duct for various solid-gas mass flow ratios

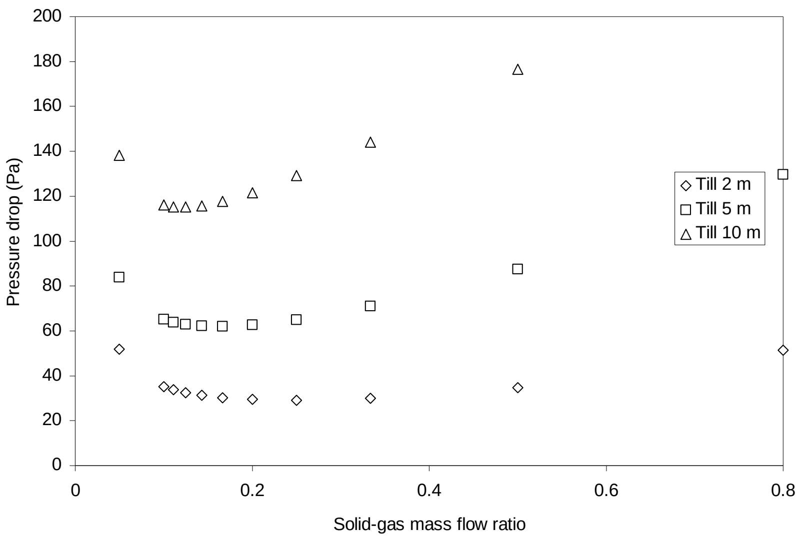

Fig. 4. Variation of pressure drop with solid-gas mass flow ratio

To study the effect of solid loading ratios on the performance of dryer, in terms of solid moisture contents, profiles of solid moisture contents with height for various solid loading ratios are illustrated in Fig. 5. It is clear from Fig.5 that the solid moisture content falls rapidly at loading ratio of 0.05, due to the availability of large quantity of air to lose heat and gain moisture. Also at a solid loading ratio of 0.25, the solid moisture content falls relatively very slowly, due to the presence of small quantity of air. For the ratios between 0.1 and 0.2, the moisture profiles intersect at some intermediate height in the dryer.

With lower solid loading ratios, solid moisture content falls rapidly in the acceleration region and hence the driving force for mass transfer decreases rapidly. Also under these conditions, the surface area per unit length of dryer, for mass transfer is less reducing the drying rate. Hence, after a certain height of the duct the rate of mass transfer becomes less, leading to slower decrease in moisture content. For higher solid loading ratios, decrease in moisture content in the initial portions of the duct is less, leading to larger driving force in the subsequent sections. The combination of larger driving force and higher solid concentrations enhance drying rate and hence, the decrease in moisture content is rapid for these solid loading ratios. As Fig.4 shows a minimum in pressure drop between solid loading ratios 0.1 and 0.2, the observations from Fig.5 can be utilized for optimizing the performance of the dryer. The plots for large difference in solid loading ratios are shown in Fig.6. It can be noticed from Fig. 6 that the moisture content profiles as different solid loading ratios do not intersect. This is due to large differences in solid loading ratios simulated. Hence, it can be inferred from Fig. 5 and Fig.6 that the profiles of solid moisture contents at different solid loading ratios would intersect, if the ratios chosen are closer to each other.

Since, solid loading ratio affects the drying rate and hence the moisture content profiles, its effect on the dryer height required for achieving final solid moisture contents of 0.175, 0.15 and 0.125 (all above critical moisture content) is shown in Fig. 7. It can be observed from Fig.7, at lower solid loading ratios, in the range from 0.05 to 0.1, the required dryer height increases sharply. The role of solid loading ratio in determining required dryer height is pronounced, for higher final moisture contents. This is due to its higher impact in the acceleration region or in the initial region, where the moisture content is reduced from a very high value to a relatively lower value. Above the solid loading ratio of 0.1 and the final moisture content greater than 0.15 kg/kg, the dryer height required decreases initially with solid loading ratio before increasing further. To achieve lower final moisture contents, larger dryer height will be required, leading to the possibility of intersection of the moisture content profiles of different solid loading ratios. From the above discussions, it is clear that the optimum solid to gas mass flow ratio for a specified solid feed rate and desired final solid moisture content can be decided on the basis of pressure drop and dryer height required.

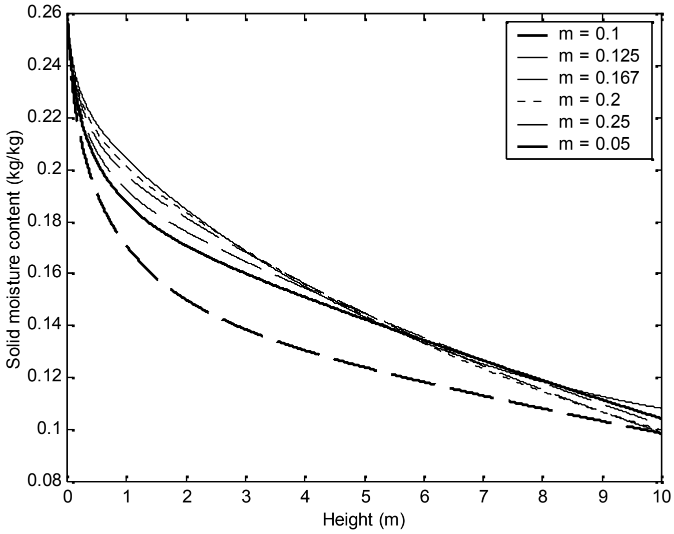

Fig. 5. Profile of solid moisture content for various solid-gas mass flow ratios

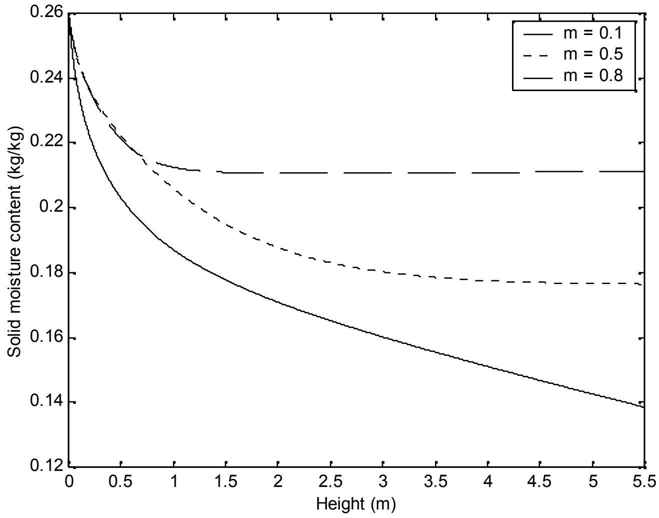

Fig. 6. Profile of solid moisture content for various higher solid-gas mass flow ratios

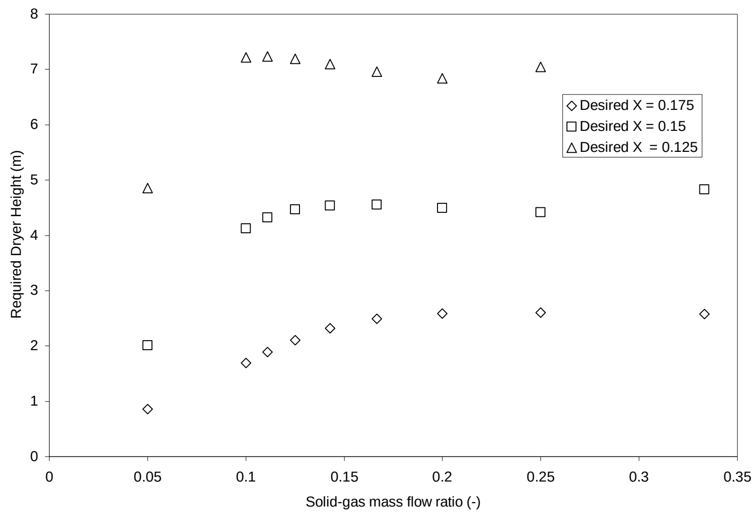

Fig. 7. Effect of solid-gas mass flow ratio on the required dryer height.

EFFECT OF PARTICLE SIZE

Figure 8 shows the effect of alumina particle size on the gas pressure profiles in the dryer, with the solid and gas mass flow rates being 1.853 and 12.91 kg/s respectively. The initial solid moisture content is 0.26 kg/kg and the initial gas temperature is 126 °C. The particle sizes simulated are 100, 140, 180, 250 and 500 µm, but Fig. 8 has been drawn only for the particles of 100, 180 and 500 µm. One may observe the rapid decrease in pressure with 100 µm particles, when compared with that of particles of 180 µm and 500 µm. Smaller particles have larger drag [13, 14] and hence the pressure drop is more. In the acceleration region, pressure decreases rapidly for all the particle sizes, after which the decrease in pressure in linear. Also the pressure profiles for different particle sizes tend to intersect and cross each other near a height of 9-10 m.

Figure 9 shows the perturbations in pressure drop with particle size, at different heights. Generally, at all the heights the pressure drop decreases with particle size. In the acceleration region, pressure profiles for different particle sizes differ appreciably. At a height of 10m, very little difference in pressure drop is observed, leading to the conclusion that the particle size influence on pressure drop is restricted to shorter ducts or in acceleration region.

Figure 10 shows the influence of particle size on the solid moisture content in the initial heights of the dryer, from which a rapid decrease in solid moisture content with height is noticed for 100 µm particles, and the rate of decrease of solid moisture content with height, decreases with increasing particle size. Figure 11 shows the moisture content profiles along the dryer height for all the particle sizes simulated. It can be observed from Fig. 11, that after a height of 1.5 m, the fall in moisture content is rapid with 500 µm particles, when compared to other particle sizes simulated, indicating higher drying rates with larger particles. This contradicts the variation of drying rate with particle size in the initial portions of the dryer and can be explained using the formulation described in our earlier work [12].

In nutshell, the gas-particle heat and mass transfer is a function of D_p^n, where n ranges from –0.5 to 1.0, depending on the value of particle Reynolds number. 'Dp' represents particle diameter. At short distances from the solid feed point, the slip velocity between the phases is more, as a result of which high particle Reynolds numbers are observed over a height of 0.5m from the bottom of the dryer. In this range of particle Reynolds number, the value of 'n' is negative. Hence increasing the particle size decreases the heat and mass transfer rate and hence lower drying rates and higher moisture contents are observed with large particles. After a certain height of the duct, the slip velocity is constant and lower than that in the acceleration region, and hence will be in low Reynolds number regime (n is positive). This results in enhanced heat and mass transfer rates with increase in particle size as shown in Fig. 11, for data after 1 m.

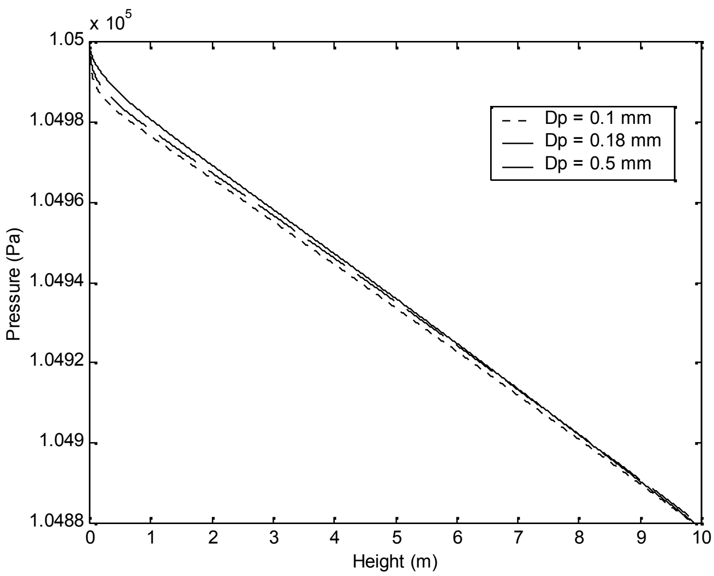

Fig. 8. Pressure profiles as a function of particle diameter

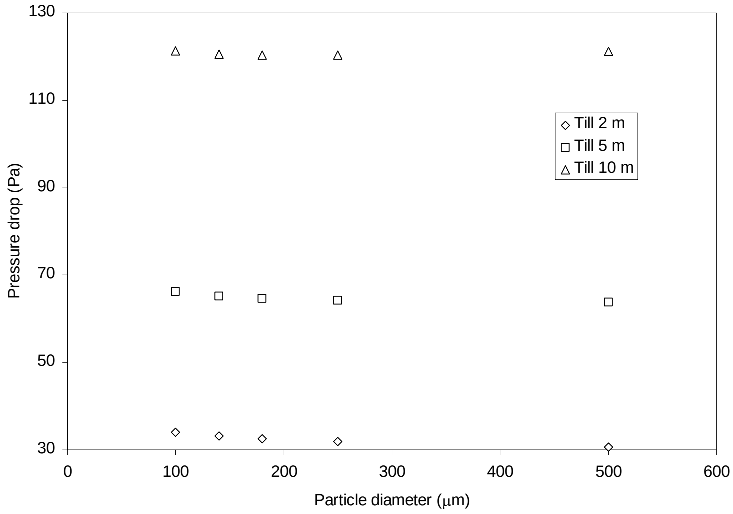

Fig. 9. Effect of particle diameter on pressure drop at different heights for a solid-gas mass flow ratio of 0.14

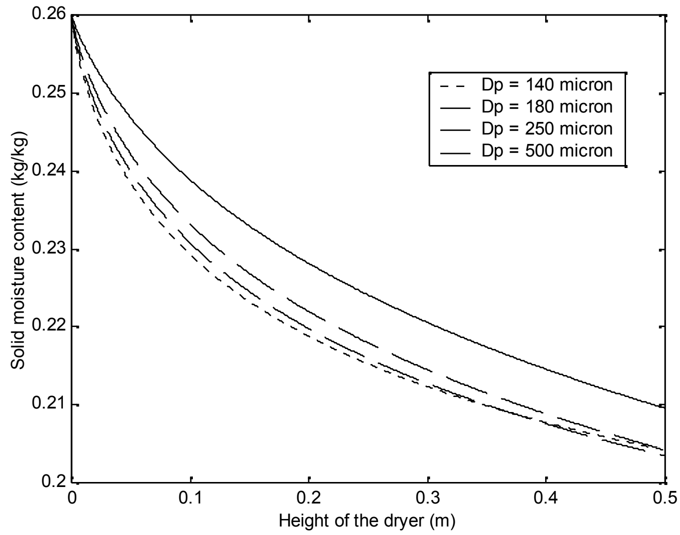

Fig.10. Profiles of solid moisture content along the dryer height for particles of different sizes

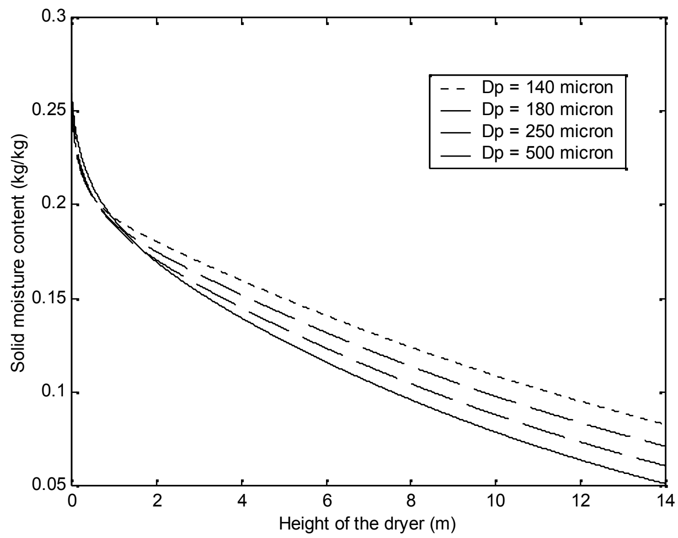

Fig.11. Effect of particle size on the solid moisture content, at various axial locations in the dryer.

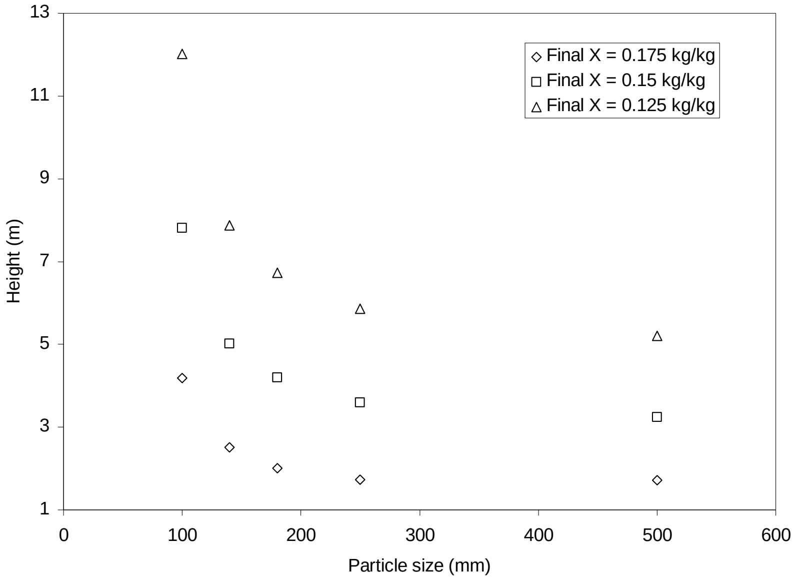

Fig.12. Height required for achieving desired solid moisture content as a function of particle diameter of PVC particles.

The effect of particle size on the height of dryer required to attain desired final solid moisture contents is evident from the Fig.12, where the dryer height are calculated for the final moisture contents of 0.175, 0.15 and 0.125. With increase in particle size, the height of the dryer required for achieving desired final moisture content decreases, while all other conditions remain same (Fig. 12). The effect is pronounced for particle sizes in the range of 100 to 250 µm, but increasing the particle size by 100% after 250 m shows very little difference in the height of the dryer required for all the desired final moisture content.

CONCLUSIONS

The following conclusions may be drawn from the present computational study on the influence of particle diameter and solid loading ratio on gas pressure and moisture content profiles in a pneumatic conveying dryer:

(i) There exists an optimum solids loading ratio at which the dryer height required for a fixed degree of drying is minimum. This depends on the particle size, initial & final moisture content.

(ii) The influence of particle size on height of the dryer required is predominant only at small particle sizes. Hence if particle size reduction is carried out to achieve higher drying rate, the size must be reduced to such a value that is influential in determining dryer height.

REFERENCES

1. Baeyens J, Van Gauwbergen D, Vinckier I. “Pnuematic drying: the use of large –scale experimental data in a design procedure”, Powder Technol., 1995; 83: 139-148.
2. Radford RD. “A model of particulate drying in pneumatic conveying systems”, Powder Technol., 1997; 93: 109-126.
3. Narimatsu CP, Ferreira MC, Freire JT. “Drying of porous alumina particles in a vertical pneumatic dryer”, in: Proceedings of Fourteenth International Drying Symposium, Sao Paulo, 2004; vol.A: 549-556.
4. Won N, Minyoung C. “Pneumatic Drying of iron ore particles in a vertical tube”, Drying Technol., 2004; 22: 877-891.
5. Matsumoto S, Pei CT. “A mathematical analysis of pneumatic drying of grains – I. Constant drying rate”, Int. J. Heat Mass Trans., 1984; 27: 843-849.
6. Levy A, Mason DJ, Hevroni DL, Borde I. “Drying of wet particles in a steady-state one-dimensional flow”, Powder Technol., 1998; 95: 15-23.

7. Levy A, Borde I. “Steady state one dimensional flow model for a pneumatic dryer”, Chem. Eng. Process., 1999; 38: 121-130.
8. Pelegrina AH, Crapiste GH. “Modelling the pneumatic drying of food particles”, J. Food Eng., 2001; 48: 301 – 310.
9. Matsumoto S, Pei CT. “A mathematical analysis of pneumatic drying of grains – II. Falling rate drying”, Int. J. Heat Mass Trans., 1984; 27: 851-855.
10. Skuratovsky I, Levy A, Borde I. “Two-Fluid, Two-Dimensional Model for Pneumatic Drying”, Drying Technol., 2003; 1: 1645 – 1668.
11. Skuratovsky I, Levy A, Borde I. Two-dimensional numerical simulations of the pneumatic drying in vertical pipes, Chem. Eng. Process., 2005; 44: 187-192.
12. Rajan KS, Srivastava SN, Pitchumani B. Simulation of a commercial flash dryer using finite difference technique, CDROM Proceedings of 18th National and 7th ISHMT-ASME Heat and Mass Transfer Conference, Guwahati, India, 2006; 1253-1260.
13. Rajan KS, Pitchumani B, Srivastava S.N, Mohanty B. “Two dimensional simulation of gas-solid heat transfer during pneumatic conveying”, Int J Heat Mass Transfer, 2007; 50 (5-6): 967-976.
14. Rajan KS, Srivastava S.N, Pitchumani B, Mohanty B. Simulation of gas-solid heat transfer during pneumatic conveying: Use of multiple gas inlets along the duct, Int Commun Heat Mass Transfer, 2006; 33(10): 1234-1242.

*****