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Changes in Moisture Content of Corn Starch during Pneumatic Conveying

ASBI B. ALI and J. LAMB[1]
Department of Food Technology
Universiti Pertanian Malaysia
43400 Serdang, Selangor Darul Ehsan, Malaysia.
[1]Procter Department of Food Science, University of Leeds, Leeds LS2 9JT, UK

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ABSTRAK

Pengangkutan pneumatik digunakan sebagai satu cara pengendalian bahan dalam kebanyakan operasi pemprosesan makanan. Kandungan air bagi pepejal pukal merupakan faktor yang terpenting yang mengawal sifat pengaliran bahan berbentuk butiran. Kertaskerja ini melaporkan kajian kesan pengangkutan pneumatik ke atas kandungan air serbuk kanji jagung. Perubahan kandungan air serbuk kanji jagung ketika mengalir dalam talian pengangkutan pneumatik didapati dapat dihuraikan oleh teori pengeringan. Hukum Fick yang kedua bagi resapan dalam sfera digunakan untuk menjelaskan data eksperimen dan pekali resapan bagi perubahan kandungan air kanji jagung dihitung dan didapati mempunyai nilai dalam julat 1.1×10^{-11} *hingga* 8.3×10^{-12} m^2/s.

ABSTRACT

Pneumatic conveying as a means of material handling is widely used in many food processing operations. Moisture content of bulk solids is the most important factor controlling the flow properties of granular materials. This paper reports an investigation on the effect of pneumatic conveying on the moisture content of corn starch powder. Changes in the moisture content of corn starches during flow in the pneumatic transport conveying lines were found to be adequately described by drying theories. Fick's second law for diffusion out of spheres was used to fit the experimental drying data and the diffusion coefficients for the change in moisture content of the corn starch were calculated to be in the range of 1.1×10^{-11} *to* 8.3×10^{-12} m^2/s.

INTRODUCTION

Pneumatic conveying as a means of material handling is widely used in many food processing operations such as in handling flour in a mill, bakery or confectionery. The method not only improves utilisation of manpower, machines and storage space, but can also cut down labour costs dramatically, by as much as 90% (Brennan *et al.* 1976).

Moisture content of bulk soilds is the most important factor controlling the flow properties of granular materials (Stoess 1970). The surface moisture leads to the appearance of cohesive forces between particles of solids and of adhesive forces between particles and the walls of the conveying duct. Both retard the flow of solids and under certain conditions may stop the flow entirely. The degree to which bulk solids are hygroscopic will affect the conveying rate as well as their suitability for pneumatic conveying.

This paper reports an investigation on the effect of pneumatic conveying on the changes in moisture content of a typical food powder, corn starch. Changes in the moisture content of the starch would certainly affect the flow patterns during pneumatic transport of starch in conveying lines such as those found in flour mills.

MATERIALS AND METHODS

Plant Design

Since food starch is fine and hygroscopic, either a vacuum or low-pressure type of pneumatic system could be adopted (Stoess 1970). However, because the objective of the experiment demanded that the conditions of the air used in conveying be controlled, a closed-circuit system was preferred.

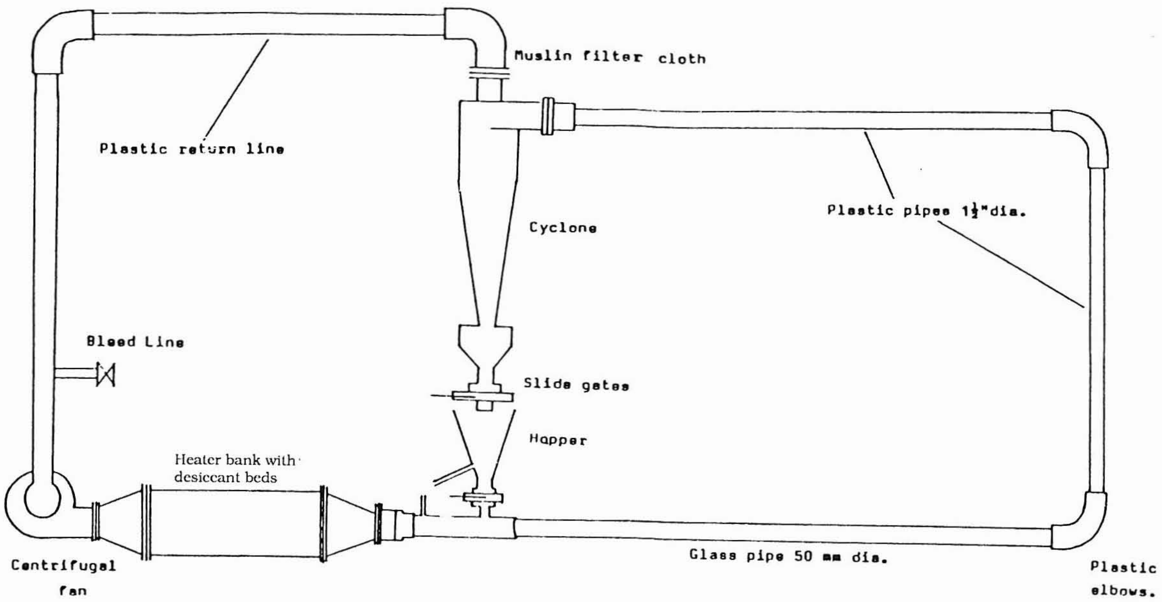


Fig 1. Experimental rig for pneumatic conveying of food starches

A bench-top recirculating pneumatic rig was designed and constructed as shown in *Figure 1.*

Calculations of the saltation velocity of starch in pneumatic conveying as well as the total pressure drop in the recirculating line were determined by the method of Kunii and Levenspiel (1969). As only a very low pressure drop was predicted (approximately 105 mm water), a centrifugal fan was selected for providing the motive power. A conical glass hopper of cone angle 70° acted as the powder feeder and a conveying glass tube covering a total distance of 3.0 m and of inner diameter 50 mm served as the main duct. The glass tube made it possible to view the flow patterns of the pneumatic transport during the experimental runs. Plastic pipes were assembled by slip-on connectors to complete the circuit.

The cyclone was constructed according to Stairmand's standard design based on the critical particle diameter for starch (Stairmand 1956). Since the collection efficiency of the cyclone was calculated to be about 95%, a filter cloth was attached to the top of the cyclone to prevent any entrainment of the smaller starch particles in the clean-gas exit.

For mass transfer studies another experimental set-up using the same centrifugal fan and pipe fittings was designed as shown in *Figure 2.* The starches were allowed to be fluidised in this apparatus and the Biot numbers for mass transfer

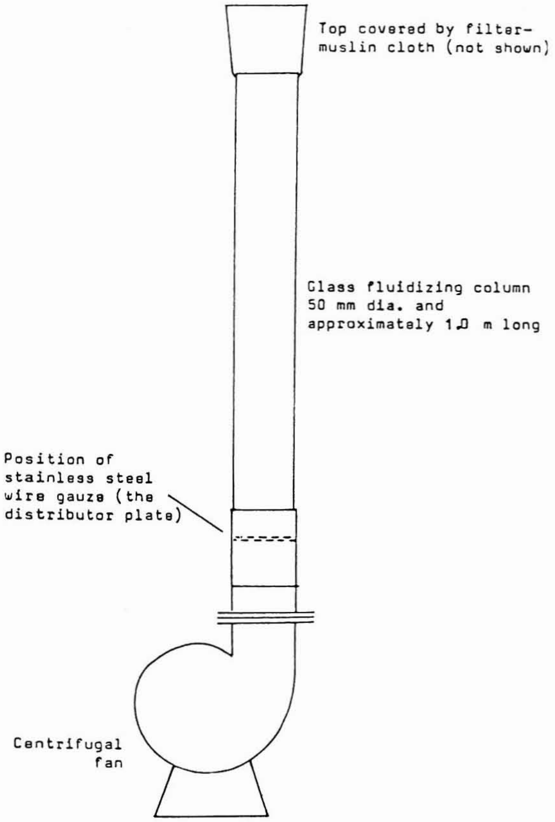


Fig 2. Fluidizing apparatus for determination of Biot numbers for mass transfer for flow-past through spheres

for flow-past through spheres were calculated according to the procedure of McCabe and Smith (1976).

Moisture Content and Equilibrium Moisture Isotherm

Corn starches were provided by RHM Foods Ltd. (Middlewich, England) and were kept in chambers of specific humidity and temperature for over 48 hours before use. The moisture content of the starches was determined by placing 10 g samples in an infra-red dryer. Duplicate measurements were carried out with an error of approximately ± 0.1%.

Atmospheres of different relative humidity were established by using saturated solutions of different salt slushes as described by Rockland (1960). Starch samples were equilibrated by placing them in each of these relative humidity flasks and their moisture contents were determined as soon as their weight showed no change.

Relative Humidity

The percentage relative humidity of the conveying air was determined with a laboratory hygrometer.

RESULTS

The moisture sorption isotherm for corn starch as determined experimentally was plotted as in *Figure 3.* The shape of the isotherm of corn starch was found to be typical for foodstuff (Labuza 1968). From the isotherm data, the equilibrium moisture content of the starches could be determined and used in the drying calculations. Based on the starch critical particle diameter (Stairmand 1956), the cyclone was designed to have a diameter of 14 cm.

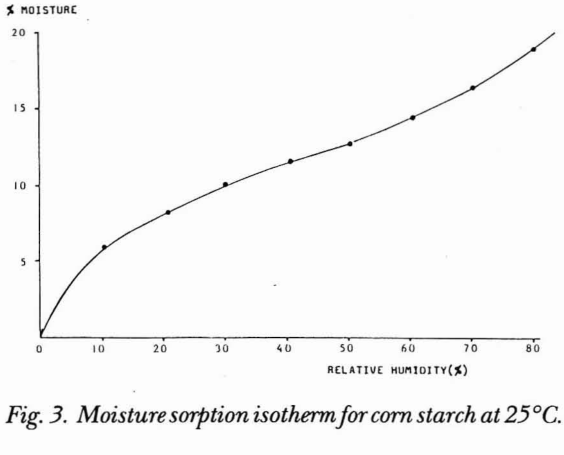


Fig. 3. Moisture sorption isotherm for corn starch at 25°C.

By careful adjustment of the flowrate when feeding the starch powder into the conveying line, the right amount of solids-to-air ratio obtained gave satisfactory pneumatic transport. The flow pattern of the starch was determined to be that of the dilute phase type (Stoess 1970) as was clearly seen in the visual section of the test rig, i.e the glass tube.

Several tests were carried out in which the moisture content of the starch was measured for every run performed. The drying curves for corn starch at different initial moisture contents and inflow of air of different relative humidity were plotted in *Figure 4.* The drying curves exhibited negligible constant-rate periods, which was in agreement with the findings of Cooley *et al.* (1954) who demonstrated similar drying profiles in their pneumatic drying of potato powder materials.

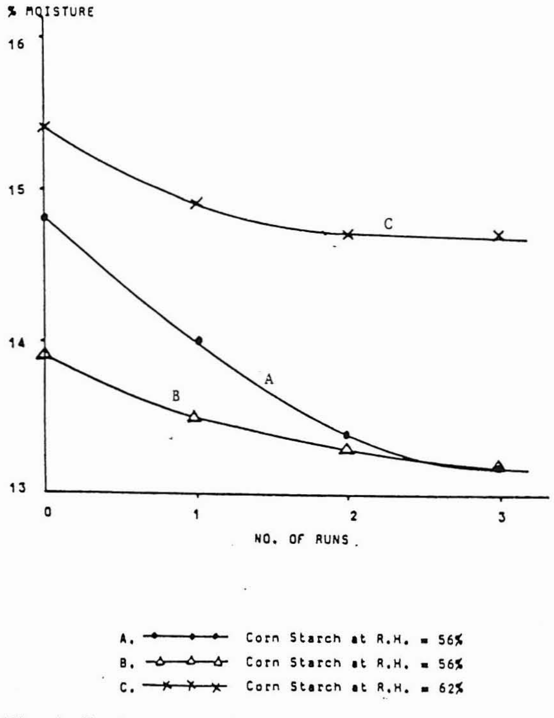


Fig. 4. Drying curves for corn starch during pneumatic conveying with different initial moisture content and relative humidity.

The absence of constant-rate periods under such drying conditions inferred that the resistance to mass tranfer was controlled by internal parameters, such as moisture transport from the centre of the solid particles to the surface. In order to ascertain this, a model for mass transfer for flow-past through spheres was adopted. Using the apparatus set-up as shown in *Figure 2,* the mass transfer coefficients calculated from this modelling exercise gave the equivalent Biot number for mass transfer in the range of 20 to 400 for diffusion coefficients of 1×10^{-8} to 1×10^{-12} m^2/s respectively (McCabe and Smith 1976). The change in the moisture content of starch powder during pneumatic transport was, therefore, controlled by internal resistance to mass transfer and in these conditions, Fick's second law of diffusion (moisture flux proportional to the moisture gradient) for diffusion-out of spheres may be used to fit the experimental drying data (Heldman and Singh 1981)

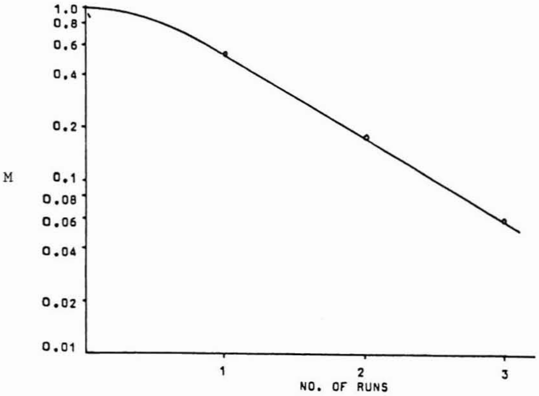
$$\mathbf{M} = \frac{m - m_e}{m_o - m_e} = \frac{6}{\Pi^2} \sum_{n=1} \frac{1}{n^2} \exp \frac{-n^2 \Pi^2 Dt}{r^2} \qquad (1)$$

This equation was used to indicate the accuracy with which the diffusion theory with constant diffusivity could predict the experimental drying behaviour. The plot of M (dimensionless moisture) versus time of drying on semilogarithmic coordinates should produce a straight line. This was done for the corn starch samples as shown in *Figure 5.* As can be seen, the change in the moisture content of the starch during pneumatic conveying appeared to obey Fick's law of diffusion satisfactorily.

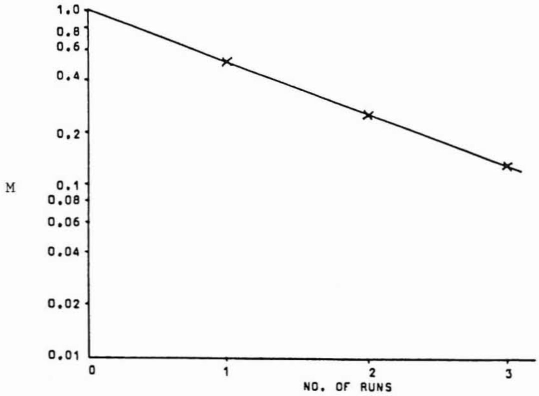
From the slopes of the lines in *Figure 5* and equation (1), the diffusion coefficients for the change in the moisture content of corn starches were calculated to be in the range of 1.1×10^{-11} to 8.3×10^{-12} m^2/s.

CONCLUSION

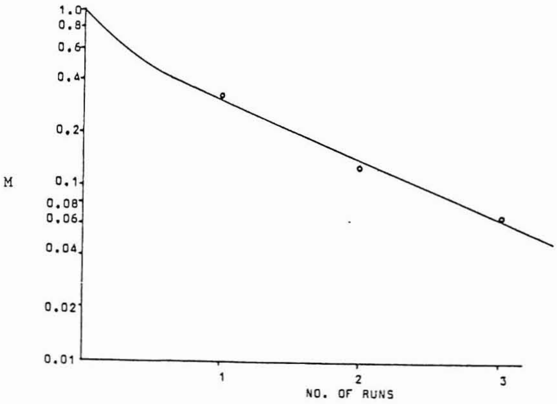
Pneumatic transport of starch powder could be identified with simple air drying process which is a simultaneous heat and mass transfer phenomenon. In this study, the effect of pneumatic conveying on the moisture content of corn starch powder was investigated with a pneumatic conveying rig designed on a bench-scale. The corn starch was conditioned to different moisture contents and ambient air was utilized as the conveying medium. The change in the moisture content of the corn starch exhibited negligible external resistance to mass transfer. A physical model based on mass transfer for flow-past though spheres was developed and was shown to be a valid approach to the problem. The drying effect of pneumatic transport on the corn strach conveyed was, therefore, successfully desribed by Fick's second law of diffusion.



Corn starch at initial m.c. = 14.8 %
and R.H. = 56% (Curve A)



Corn starch at initial m.c. = 13.9%
and R.H.= 56% (Curve B)



Corn Starch at initial m.c. = 15.4%
and R.H. = 62% (Curve C)

Fig. 5. Plots of dimensionless moisture against number of pneumatic conveying runs.

Nomenclature

D = diffusion coefficient
M = dimensionless moisture
m = average moisture content (dry basis)
m_o = initial moisture content
m_e = equilibrium moisture content (at the dry bulb temperature)
r = radius of the starch granule
t = residence time

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