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Diffusion of carbon dioxide through grain bulks

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Abstract

The diffusion coefficient of carbon dioxide (CO_2) through grain bulks was determined using a transient method with the following variables: (1) grain bulk (wheat, barley, and canola); (2) moisture content (m.c.) (dry, damp, and wet conditions); (3) temperature (5°C, 15°C, 25°C, and 40°C); (4) direction of gas flow (upwards, downwards, and horizontal); (5) porosity (two levels for each grain bulk); (6) grain kernel orientation (vertical and horizontal); (7) initial concentration in the gas chamber (20%, 40%, and 60%); and (8) dockage (0%, 4%, 8%, and 12%). The diffusion coefficients of CO_2 through wheat bulks ranged from 5.9×10^{-6} to $7.6 \times 10^{-6}\,m^2\,s^{-1}$, through barley bulks from 5.1×10^{-6} to $8.4 \times 10^{-6}\,m^2\,s^{-1}$, and through canola bulks from 3.7×10^{-6} to $5.3 \times 10^{-6}\,m^2\,s^{-1}$ for the test conditions studied.

Increasing the m.c. decreased diffusion coefficients. An increase in temperature generally increased the diffusion coefficient of CO_2. Diffusion in the downward direction resulted in higher diffusion coefficients. No significant difference in diffusion coefficients was observed between the upward and horizontal directions of flow. An increase in porosity resulted in higher diffusion coefficients. The upward diffusion coefficient of CO_2 was higher for vertical grain kernel orientation than for horizontal kernel orientation for wheat and barley but for canola, the difference between the two kernel orientations was not significant. There was no significant difference in diffusion coefficients for different initial gas concentrations. The diffusion coefficient increased linearly as the dockage was increased.

The amount of CO_2 absorbed by barley and canola increased with an increase in m.c. in polynomial fashion. There was no significant difference in the sorption of CO_2 by barley and canola when the temperature of the grain was changed from 15°C to 40°C.

Keywords: Diffusion; Carbon dioxide; Bulk grain; Wheat; Barley; Canola; Sorption

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1. Introduction

In Canada, harvested grain is stored on farms for up to 2 years. Insect incidence is reported frequently in farm storages on the Prairies (Sinha, 1972; Madrid et al., 1990). Along with preventive practices, farmers rely mostly on chemical control of stored-product pests. However, this can be potentially harmful to human health in the form of chemical residues. Most of the contact insecticides have been restricted from use on food materials. Among the alternatives and substitutes for the fumigants methyl bromide and phosphine is controlled atmosphere (CA) fumigation using carbon dioxide (CO_2) (Anonymous, 1993).

Controlled atmosphere use in storage involves gas movement through grain bulks. Its effectiveness and efficiency as a disinfestation technique in a grain bulk depends on whether the applied gas moves through the grain bulk in the given time and gives a complete kill of insects. Gas movement in a grain bulk is caused by one or more of the following factors: diffusion through the porous grain bulk due to concentration gradients; diffusion caused by temperature gradients within the grain bulk; convection currents set up by temperature differences within the grain bulk; bulk flow caused by pressure differences within the grain mass; diurnal variations in atmospheric pressure; and sorption and desorption of gases by the grain.

As diffusion is expected to be the major factor in gas movement through grain bulks, it is imperative to determine the diffusion coefficient of CO_2 through grain bulks. Few studies have been reported in the literature on the determination of the diffusion coefficient of CO_2 through grain bulks (Henderson and Oxley, 1944; Bailey, 1959; Haugh and Isaacs, 1967; Singh (Jayas) et al., 1984). The objective of these studies was primarily to identify grain spoilage based on CO_2 concentration. Factors such as dockage, grain temperature, grain kernel orientation, and concentration dependence of the diffusion coefficient, which are important from the standpoint of CA use in storage, were not considered in these studies. Also, most earlier studies used a steady-state method where the grain bulk was continuously flushed for 24 h. However, in a typical CA application, the diffusion processes will be mostly transient and are influenced strongly by the sorption of gas by grain during the initial 6 h of the introduction of the gas into the bulk. Therefore, a study was conducted to determine the diffusion coefficient of CO_2 through grain bulks for economically important crops in Canada; namely wheat, barley, and canola, and to determine sorption of CO_2 by barley and canola.

2. Objectives

The objectives of this study were:

(1) To determine the diffusion coefficients of CO_2 through wheat, barley, and canola bulks by measuring the CO_2 concentration along a grain column in a diffusion cell, and by solving the diffusion equation by the finite difference method;
(2) To determine the effects of grain moisture content (m.c.), grain temperature, direction of CO_2 flow, porosity, grain kernel orientation, initial CO_2 concentration, and dockage on the diffusion coefficient of CO_2 through grain bulks; and
(3) To determine the sorption of CO_2 in barley and canola. Data on sorption of CO_2 by grain are needed to determine the diffusion coefficient of CO_2 through grain bulks.