AVERAGE CONVECTIVE-PORE VELOCITY OF CARBON DIOXIDE GAS THROUGH GRAIN BULKS

BY

CURTIS LYLE BUNDUS

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Submitted to the Faculty of Graduate Studies
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ABSTRACT

Experiments were conducted to observe the movement of carbon dioxide gas through a variety of grain bulks subjected to controlled temperature differences. The carbon dioxide concentration, as it varied with time, was used in a finite difference, diffusion-convection model to determine an average convective-pore velocity of carbon dioxide (CO_2) across the interstitial pore area of grain bulks. The average convective-pore velocity increased as the temperature difference increased when the CO_2 was introduced into the grain bulk from the bottom surface ($P<0.05$). The average convective pore-velocity was not affected by the temperature difference when the CO_2 was introduced into the grain bulk from the top surface ($P>0.05$). The average convective-pore velocity was smaller for canola than for the cereal grains (barley and wheat) and lentils when the CO_2 was introduced into the grain bulk from the top and bottom surfaces ($P<0.05$). The lowest average convective-pore velocity was 4.30×10^{-6} m/s for canola at a temperature difference of 20°C when CO_2 was introduced into the grain bulk from the bottom surface. The largest average convective-pore velocity was 2.42×10^{-3} m/s for wheat at a temperature difference of 40°C when CO_2 was introduced into the grain bulk from the top surface. For wheat, at a temperature difference of 40°C and when CO_2 was introduced from the bottom surface the average convective-pore

velocity was 2.27×10^{-4} m/s.

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A	amplitude of the seasonal temperature variation, (°C or K)
CA	Controlled Atmosphere
CV	Coefficient of Variation
c	chemical species concentration in the pore volume, (kg/m^3)
c_m	moisture concentration of air near the potatoes, (kg/m^3)
c_{mo}	moisture concentration of the inlet air, (kg/m^3)
c_p	heat capacity at constant pressure, ($J \bullet kg^{-1} \bullet K^{-1}$)
div	divergence of the fluxes (convection and diffusion), (m^{-1})
$\mathbf{g}$	acceleration due to gravity in vector form: $g(0,0,-g)$, (m/s^2)
grad	gradient (m^{-1})
K	permeability, (m^2)
k_{th}	thermal conductivity of stagnant bed, ($W \bullet m^{-1} \bullet K^{-1}$)
L	height of cylindrical grain bin, (m)
L_D	length of the porous medium over which the pressure drop occurs, (m)
P	pressure, (Pa)
ΔP	pressure drop, (Pa)
Q	internal heat generation, (W/m^3)
Ra	Raleigh number
S	net rate of internal production of the chemical species mass per unit volume of pore fluid, ($kg \bullet m^{-3} \bullet s^{-1}$)
S_η	source term, ($kg \bullet m^{-3} \bullet s^{-1}$)
SD	Standard Deviation
T	temperature of fluid, (°C)
T_o	temperature of inlet air (°C or K)
T_p	average temperature of potatoes (°C or K)
t	time, (s)

v	one-dimensional velocity, (m/s)
$\mathbf{v}$	velocity vector of fluid in the porous medium, (m/s)
v_p	average (laminar) velocity of the pore fluid phase (m/s)
v_{nc}	natural convection velocity of moist air moving upward through a vertical cylinder of potatoes, (m/s)
wb	wet basis
y	length in the vertical direction, (m)
∇	gradient operator
∇^2	Laplace operator

Greek Letters

α	thermal diffusivity of mixture of air and grain, (m^2/s)
β	thermal coefficient of expansion, (K^{-1})
β_c	concentration expansion coefficient, (m^3/kg)
Γ	diffusion coefficient, (m^2/s)
Γ_η	diffusion coefficient for η, ($kg \bullet m^{-1} \bullet s^{-1}$)
η	dependant variable, (mass fraction of chemical species)
μ	dynamic viscosity, ($kg \bullet m^{-1} \bullet s^{-1}$)
ρ	density, (kg/m^3)
ρ_a	density of dry air, (kg/m^3)
ϕ	porosity of the porous medium
φ	dissipation function describing viscous fluid stresses (s^{-2})

Subscript

r	reference value of a property measured at a reference temperature which is usually the temperature in the porous medium
f	fluid properties
m	solid properties of the porous medium

1. INTRODUCTION

Techniques for controlling insect and mite infestations in grain stores are very important since the infestations can cause losses in grain quality. Several countries that export grain, such as Canada and Australia also have a legally defined zero tolerance for detectable insects in stored grain. In Canada, fumigation of the grain bulk with a pesticide such as phosphine has long been the accepted course of action to disinfest grain and thus preserve its quality. Fumigants and contact insecticides used on or near stored grain are becoming unacceptable because of increased insect resistance and the concern about danger to applicators and toxic residues left on the grain. There is a need to find alternative techniques to disinfest grain.

Modified or controlled atmosphere (CA) storage techniques are being developed as alternative methods for grain disinfestation. In such techniques, the grain bulk in a sealed or nearly sealed enclosure is purged with a gas such as nitrogen (N_2) or carbon dioxide (CO_2). Depending on the gas, either the oxygen (O_2) concentration of the interstitial air is decreased until it no longer supports insect life (<1% by volume) or until the concentration of CO_2 becomes lethal to the insect population. The lethality is a function of CO_2 concentrations, time, and temperature. A high concentration of CO_2 must be maintained for a long enough period to achieve

100% mortality. Achieving a uniform distribution of CO_2 throughout the grain store will not only ensure the required concentrations throughout the grain bulk but also help to minimize the amount of CO_2 required to achieve the goals of CA disinfestation.

The rate at which CO_2 gas is transported through a grain bulk is an important factor affecting the distribution of CA gases and is dependent upon many phenomena that affect gas transport which occurs in stored grain. The phenomena affecting transport include: natural convection, diffusion, sorption or desorption, and forced distribution (Banks 1990). These phenomena are influenced by many factors including external environmental factors, properties of the grain through which the gas is moving, and properties of the gases introduced into the storage. Interactions occur among these phenomena that are complex and not yet fully understood. Accurately predicting the rate that any particular gas is transported throughout a grain bulk is necessary for determining the time (a) for a gas to become uniformly distributed throughout a CA storage and (b) for an amount of gas to be maintained in the case of a non-sealed storage.

A mathematical model used for predicting the gas flow rates, due to natural transport phenomena, must incorporate the contributions made by each individual transport process involved. Alagusundaram et al. (1991) developed a three-dimensional diffusion model for CO_2 in grain bins. This model predicted lower concentrations of CO_2 than the concentrations measured in experimental bins. The non-inclusion of the movement of interstitial air due to convection currents within the grain bulk or leaks in the storage structure might have caused these deviations. Cofie-Agblor et al. (1993) showed how sorption and desorption affect the concentration of CO_2 in stored wheat. By measuring the level of CO_2 in a confined quantity of wheat, the influence of temperature and moisture content on the rate of sorption of CO_2 was investigated. An accurate model for prediction of gas distribution in grain bulks during controlled atmosphere storage should incorporate the effects of these phenomena.

The goal of this study was to increase the understanding of natural convection effects in grain bulks so that this transport process can be incorporated into a gas flow model for stored grain.

2. OBJECTIVES

More research is required to understand the nature of the movement of CO_2 resulting from natural convection during CA storage. The specific objectives of this study were:

1. to determine the convective-pore velocity of CO_2 through grain bulks; and

2. to determine the effects of bulk temperature differences, grain type, and location of introducing CO_2 into the grain bulk on the convective-pore velocity.

3. REVIEW OF THE LITERATURE

3.1 THE SCOPE OF REVIEW

The published literature was reviewed to explore the scope of the transport process of natural convection through a porous medium similar to a grain bulk. The basic principles of natural convection were examined first. These basic principles were then applied to the process of natural convection as it is thought to occur in stored grain bulks exposed to the climate of the Canadian Prairies. Next, the mathematical models that were developed to describe the process of natural convection in porous media were reviewed. Finally, the studies where experiments were performed to measure the velocity of interstitial gas resulting from the process of natural convection are discussed.

3.2 BASIC PRINCIPLES OF NATURAL CONVECTION

Convection is defined as the transport of mass and energy caused by potential gradients and bulk fluid motion. If the fluid motion is induced by body forces such as gravitational forces, the process is referred to as natural or free convection (Kays and Crawford 1987). The fluid flow in this process is caused by buoyancy forces that are generated by density gradients. Such density gradients arise from temperature or concentration gradients or both. For circulation to occur, a mass of less dense fluid must be directly or indirectly below a mass of fluid which is more dense. If such a situation exists it is called unstable and the flow that occurs is commonly referred to as convection currents. This situation occurs with air or other gases in grain storage structures experiencing temperature gradients.

3.2.1 Momentum and energy equations

The equations which completely describe the process of natural convection in a porous medium are the governing equations for continuity, momentum, and energy. For three-dimensional steady flow having constant properties, the generalized equations (Kays and Crawford 1987) are:

Continuity

$$\nabla \boldsymbol{v} = 0 \tag{1}$$

Momentum

$$\rho \frac{\partial \boldsymbol{v}}{\partial t} = -\nabla P + \rho \boldsymbol{g} - \mu \nabla^2 \boldsymbol{v} \tag{2}$$

Energy

$$(\rho c_p)_m \frac{\partial T}{\partial t} + (\rho c_p)_f \boldsymbol{v} \cdot \nabla T = k_{th} \nabla^2 T + \mu \varphi + \boldsymbol{v} \cdot \nabla P + Q \tag{3}$$

where: c_p = heat capacity at constant pressure ($J \bullet kg^{-1} \bullet K^{-1}$),

ρ = density (kg/m^3),

P = pressure (Pa),

T = temperature of fluid (°C),

$\mathbf{g}$ = acceleration due to gravity in vector form: $g(0,0,-g)$ (m/s^2),

Q = internal heat generation (W/m^3),

t = time (s),

k_{th} = thermal conductivity of stagnant bed ($W \bullet m^{-1} \bullet K^{-1}$),

$\mathbf{v}$ = velocity vector of fluid in the porous medium (m/s),

μ = dynamic viscosity ($kg \bullet m^{-1} \bullet s^{-1}$),

φ = dissipation function describing viscous fluid stresses, (s^{-2}),

∇ = gradient operator,

∇^2 = Laplace operator,

subscript f = fluid properties, and

subscript m = solid properties of the porous medium.

Beukema et al. (1983) gave a simplified version of these equations that is commonly used when modelling natural convection in porous media. In this version, inertia in the momentum equation is neglected and viscous heating by fluid flow is assumed negligible in the energy equation. The pressure gradient term on the right side of the energy equation is neglected since consideration is only given to low velocities. Beukema et al. (1983) made two other important assumptions which are commonly used.

First, the Boussinesq approximation is made which neglects all variable property effects except for density in the momentum equation where the density causes buoyancy forces. This variable density can be approximated by:

$$\rho=\rho_r[1-\beta(T-T_r)] \tag{4}$$

where: β = thermal coefficient of expansion (K^{-1}) and

subscript r = reference value of a property measured at a reference temperature which is usually the average temperature in the porous medium.

The second approximation is the use of Darcy's law for describing the pressure drop experienced by a fluid flowing through porous media.

$$\frac{\Delta P}{L_D}=-\frac{\mu}{K}v \tag{5}$$

where: ΔP = pressure drop (Pa),

L_D = length of the porous medium over which the pressure drop occurs (m),

K = permeability (m^2), and

v = one-dimensional velocity (m/s).

The viscous term in the momentum equation is replaced with the right-hand side of Eq. 5. Although this approximation is valid, better agreement with experimental data are observed when non-Darcian effects are taken into consideration in the momentum equation (Beji and Gobin 1992, Hsiao et al. 1992, Kladias and Prasad 1991).

Applying these simplifications the governing equations become:

Continuity

$$\nabla \boldsymbol{v} = 0 \tag{6}$$

Momentum

$$\rho_r \frac{\partial \boldsymbol{v}}{\partial t} = -\nabla P + \rho_r [1 - \beta (T - T_r)] \boldsymbol{g} - (\frac{\mu}{K}) \boldsymbol{v} \tag{7}$$

Energy

$$(\rho c_p)_m \frac{\partial T}{\partial t} + (\rho c_p)_f \boldsymbol{v} \cdot \nabla T = k_{th} \nabla^2 T + Q \tag{8}$$

The solution to these differential equations is not easily obtained analytically, therefore, numerical methods such as finite difference or finite element are commonly used to solve them. By applying the boundary conditions, mathematical models can be solved to study the effects of parameters on temperature distributions and fluid velocities in porous media. Singh and Thorpe (1993) present a methodology to solve numerically, the continuity, momentum, and energy equations that describe the behaviour of free convective processes occurring in peaked bulks of grain.

These particular governing equations illustrate that the velocity is affected by many parameters such as temperature, fluid density, dynamic viscosity, and permeability. To solve for the velocity, the pressure gradient must also be known which may not be easily measured in a grain bulk.

3.2.2 General transport equation

Another possible way to model natural convection of a gas through porous media is to solve a general transport differential-equation (Patankar 1980).

$$\frac{\partial}{\partial t}(\rho\eta) + div\ (\rho \boldsymbol{v}\eta) = div\ (\Gamma_\eta\, grad\eta) + S_\eta \qquad \textbf{(9)}$$

where: η = dependant variable (mass fraction of a chemical species),

Γ_η = diffusion coefficient for η ($kg \bullet m^{-1} \bullet s^{-1}$),

S_η = source term ($kg \bullet m^{-3} \bullet s^{-1}$),

grad = gradient (m^{-1}), and

div = divergence of the fluxes (convection and diffusion) (m^{-1}).

This equation can be used to describe many processes. In this case the units refer to the transport of a chemical species in a fluid.

This transport equation for unsteady, one-dimensional movement of a given chemical species through a porous medium becomes (Bear 1979, Ebach and White 1958, Fried and Combarnous 1971, Hensley and Schofield 1991):

$$\frac{\partial(\phi c)}{\partial t} + \frac{\partial(\phi c v_p)}{\partial y} = \frac{\partial}{\partial y}\left[\phi(\Gamma\frac{\partial c}{\partial y})\right] + S \qquad \textbf{(10)}$$

where: ϕ = porosity of the porous media,

c = chemical species concentration in the pore volume (kg/m^3),

v_p = average (laminar) velocity of the pore fluid phase (m/s),

y = length in the vertical direction (m),

Γ = diffusion coefficient (m^2/s), and

S = net rate of internal production of the chemical species mass per unit volume of pore fluid ($kg \bullet m^{-3} \bullet s^{-1}$).

The net rate of internal production of the chemical species is the difference between the rate of internal production of the chemical species and the rate of the chemical species transfer from the fluid to the solid phase (sorption-desorption).

Equation 10 can be solved using the finite difference or the finite element method to obtain the average laminar velocity of gas in the pore space of a porous medium. This equation expresses the velocity as a function of the concentration gradient thus eliminating the need for measurements of temperature and pressure gradients.

3.3 NATURAL CONVECTION IN TYPICAL CANADIAN GRAIN BINS

3.3.1 The concept

The hypothesis of how natural convection affects airflow and temperature distribution in a filled grain bin appears to be primarily focussed on research done in the area of moisture migration and heat transfer in grain bins. Stewart (1975) describes the mechanisms of diffusion and natural convection which cause moisture migration in stored grain. Stewart (1975) concluded that although instantaneous localized diffusion rates can be high, convective air currents are the primary mechanism for moisture migration during seasonal storage. When studying movement of fumigants through wheat bulk, Gilby (1983) also concluded that the main driving force for the transfer of fumigants in grain silos is the pressure gradient due to density differences which cause natural convection in the gas phase. Most research agrees with Stewart's and Gilby's conclusions and similar explanations appear in textbooks, but these explanations should not be regarded as fact because there is no direct evidence to support these explanations.

In a grain bin, natural convection is thought to occur in the following way. When a warm grain bulk is below and in contact with a cool grain bulk, the interstitial air in the warm grain bulk, having a lower density, will be displaced by the heavier air from the cool grain bulk and thus the air will move upward into the cool grain bulk. Since the thermal capacity of the grain is much higher than the air and the magnitude of the air velocity is slow, the cool air entering the warm grain bulk quickly equilibrates to the temperature of the grain bulk. Similarly, the warm air entering the cool grain bulk quickly equilibrates to the temperature of the cool grain bulk. Once the air has equilibrated to the temperature of the surrounding grain bulk, the same air movement occurs once again, creating a continuous flow cycle. This flow cycle will continue as long as a temperature difference is maintained between the warm and cool grain bulks. For this scenario to take place in a grain bin, temperature gradients must be present.

3.3.2 Temperature gradients in grain bins

Temperature changes in a grain bulk can be caused by localized regions of microbial spoilage or insect infestation, diurnal and seasonal changes in external ambient temperature, or solar radiation. The thermal properties of the grain, the initial temperature of the grain as it enters storage, and the rate of weather change also have a major influence on the temperature gradients that can exist during a particular period of storage.

Muir and Sinha (1976) measured the temperature of wheat at the time of harvest and monitored the changes in grain bulk temperature in a stored bulk 5.6 m in diameter and 2.7 m high over a storage period of 29 mo at Winnipeg, Manitoba. The average temperature at the time of harvest was 36°C and after 3 mo of storage (mid-November) the temperature of the wheat near the centre of the bin was 27°C while the temperature at the wall was -6°C. Temperatures near the centre of the bin after 23 mo of storage (July) were still as low as 5°C while the temperatures near the wall were 26°C. This large time delay in temperature change in the wheat bulk can be attributed to the low thermal diffusivity of wheat. Considering the periods of extreme cold on the Canadian Prairies, which occasionally fall to -40°C for short periods, it would be reasonable to assume that the difference in grain bulk temperature between the centre of the bin and that near the bin wall could be as large as 50°C or possibly greater in large diameter bins. Measurements of temperature changes of wheat stores in sub-tropical Australia showed similar effects but the gradients experienced were generally of a much lower magnitude (White 1988).

3.3.3 Pattern of interstitial air circulation

Measurements by Muir and Sinha (1976) in Canada and White (1988) in Australia have shown how the temperature distribution in a grain bin changes during storage. The temperature difference affects the direction with which convection currents will circulate the interstitial air in the grain bulk. In winter the interstitial air in the centre of the bin is warm relative to the temperature of the grain bulk near the bin wall and thus the interstitial air in the centre of the bin should be less dense than near the bin wall. As a result, the air near the centre of the grain bulk will rise, since it is being displaced by the cooler interstitial air near the bin wall which will have a tendency to sink to the bottom of the grain bulk. The cool air replacing the displaced warm air will be heated by the surrounding grain bulk and it will be displaced upward, resulting in a circulation of the interstitial air. The opposite is true during summer when the interstitial air near the wall rises, because of warm outside conditions, and is replaced with cooler air from the centre of the bin that falls toward the bottom of the bin. In either case, it is unlikely that circulation takes place in a perfectly closed loop (Fig. 1). Instead, short circuiting of the circulation may take place and it is likely that the rising interstitial air will move into the headspace of a grain bin since it offers the path of least resistance.

3.3.4 Effects of geometry and particle size

Stewart (1975) indicated that the magnitude of convective currents in a grain bulk will increase as the height to width ratio increases. This is because of the differences in air pressure at the bottom of the columns of cold and hot grain bulk become greater as the height of the grain bulk increases. The size of the grain bulk will also determine how long a temperature gradient is present and thus how long natural convection will occur. The constantly fluctuating temperature conditions in the Canadian Prairies almost always ensure the presence of temperature gradients within stored grain bulks.

Stewart (1975) also demonstrated that a reduction in

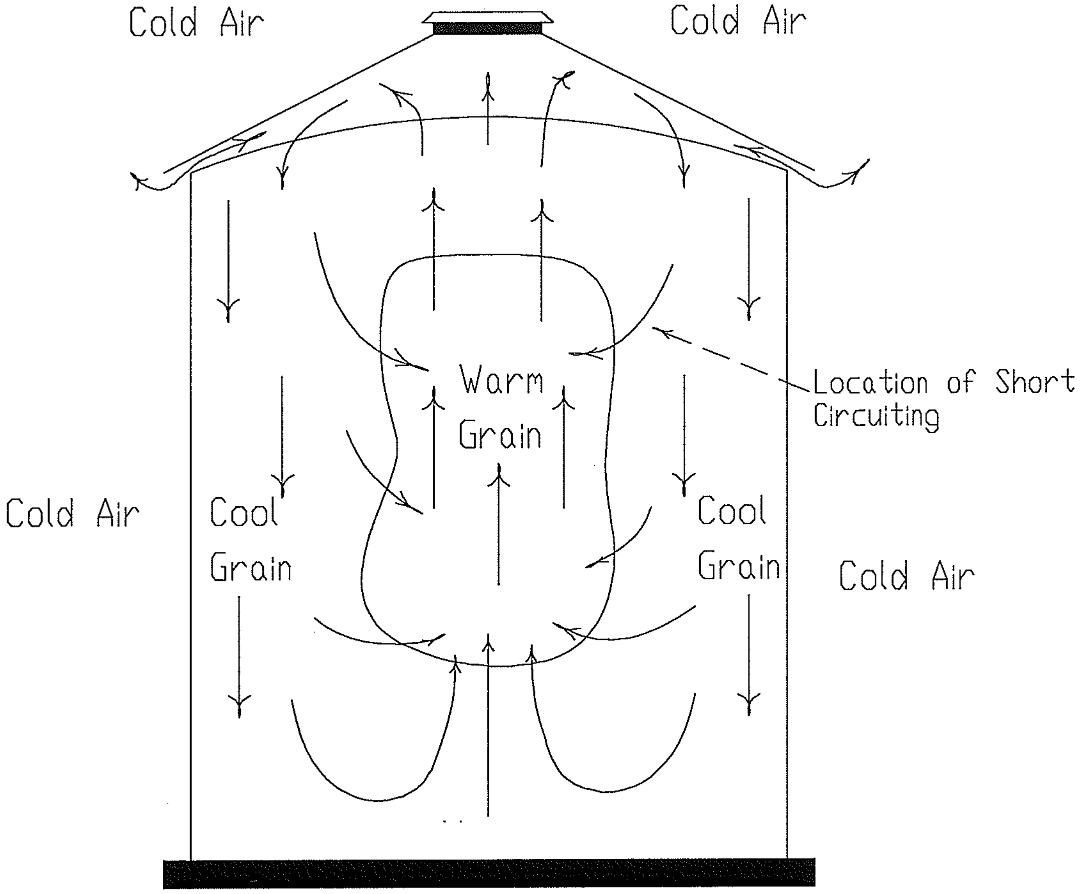

Figure 1. Circulation pattern of interstitial air in an non-aerated grain bin subjected to temperature gradients during winter storage conditions on the Canadian Prairies.

grain bulk particle size and a reduction in void fraction will reduce the magnitude of convection currents present in the grain bulk.

3.4 NATURAL CONVECTION AND CONTROLLED ATMOSPHERE STORAGE

Circulation patterns resulting from natural convection would affect the distribution of gases used in CA storage. If the circulation of air through a grain bulk is of a large enough rate then it may be possible to use it to create and maintain a uniform distribution of CO_2 during CA storage. The circulation may also result in an increased loss of CA gases in a non-airtight storage structure since these gases will now reach areas of leakage more quickly. In either case knowing the magnitude of these convection currents would be useful when modelling a CA storage system.

3.5 MATHEMATICAL MODELS

3.5.1 Models for non-agricultural products

Numerous mathematical models have been developed for natural convection in porous media (Prasad and Chui 1989, Moya et al. 1987, Trevisan and Bejan 1985). Most of these models use the governing equations of continuity, momentum, and energy and were developed from a standpoint other than that of grain storage. Experimental validation of such models has either been done on scale models under controlled conditions or has yet to be successfully completed. The results from most models focus mainly on isotherms and streamlines developed in the porous media by natural convection. Few studies have reported the actual magnitudes of the rate of fluid movement predicted by the models. In the following sections the mathematical models which were specifically developed to investigate the effects of natural convection in stored agricultural products will be discussed.

3.5.2 Natural convection in potato bulks

Beukema (1980) used the governing equations for natural convection in porous media to develop a relationship for the velocity of natural convection currents in a cylinder of porous media with permeable top and bottom and internal heat generation. Natural convection was the only form of heat transfer considered. The analysis showed that the magnitude of the velocity of natural convection is directly proportional to the square root of both the internal heat generation and the height of the cylinder.

In the same analysis Beukema (1980) developed a model to predict the temperature and moisture changes in a vertical cylinder of porous medium with internal heat generation. In this analysis an expression for the natural convection velocity, v_{NC}, of moist air moving upward through a vertical cylinder of potatoes was derived:

$$v_{NC}=\frac{K}{\mu}\rho g[\beta(T_p-T_o)+\beta_c(c_m-c_{m_o})] \quad (11)$$

where: T_p = average temperature of potatoes (°C or K),

T_o = temperature of inlet air (°C or K),

β_c = concentration expansion coefficient (m^3/kg),

c_m = moisture concentration of air near the potatoes (kg/m^3), and

c_{mo} = moisture concentration of the inlet air (kg/m^3).

In this equation the permeability was calculated using the corrected Ergun equation for particles of non-uniform shapes. The permeability is a function of the porosity and particle diameter of the porous medium and also a function of the Reynolds number of the moist air (Beukema 1980).

An experimental bin was used to validate the accuracy of this model. A model material was created that had similar dimensions, heat capacities, and similar rates of internal heat generation as real potatoes. This model material was placed in the experimental bin. Since it was difficult to directly measure the velocity of natural convection it was obtained indirectly based on the temperature gradients which were predicted accurately by the model. The velocity was calculated as a function of the internal heat generation of the porous medium, the temperature gradient, the density, and the specific heat capacity of the air.

Beukema et al. (1983) continued work using the model material and developed a mathematical model of three-dimensional natural convection in a confined porous medium with internal heat generation. Experiments were performed using the model material from the previous study (Beukema 1980). The three-dimensional model was able to accurately predict the temperature changes in a rectangular container filled with the model material. The air velocity was indirectly measured as before and it increased with increasing temperature gradients within the container which is expected based on the way the velocity was determined. The flow in the container was described as downwards near the cold walls and upwards in the central part of the container. The higher air velocity of natural convection was believed to be the cause of a more effective heat transport when the rates of internal heat generation were increased. Beukema's models were validated using large sized products like potatoes but no work was done to investigate the validity of the mathematical model when applied to a porous medium with the small pore spaces that would be present in grain bulks.

3.5.3 Natural convection in grain bulks

Smith and Sokhansanj (1990) presented a model for heat and mass transfer in grain based on the governing equations for continuity, momentum, and energy. The effects of the porous medium were taken into account by the simplifications previously described and using a variation of Darcy's law that took into account the influence of gravity. A general form of the Raleigh number, Ra, was defined as:

$$Ra = \frac{K \rho_a g \beta A L}{\alpha \mu} \qquad (12)$$

where: ρ_a = density of dry air (kg/m^3),

A = amplitude of the seasonal temperature variation (°C or K),

L = height of cylindrical grain bin (m), and

α = thermal diffusivity of mixture of air and grain (m^2/s).

Comparison of the results of their model and published data on moisture migration and temperature distribution in typical stored grain bulks led to the conclusion that natural convection is a significant form of heat transfer when the Raleigh number is larger than a critical value. This critical value was given as a function of the dimensions of a cylindrical bin, the density, thermal diffusivity, heat capacity, and porosity of the grain bulk, and the particle diameter of the grain. It was also stated that the air velocity in the grain bin due to natural convection will increase with increasing values of the Raleigh number. If this is the case then all the variables in Eq. 12 will significantly influence the rate of gas flow caused by natural convection in the grain bulk.

Results from the Smith and Sokhansanj (1990) model also indicated a significant interstitial air velocity near the outer wall of the bin circulating in a counterclockwise direction in the summer after 28 wk of storage. The velocities ranged from 4.0×10^{-6} m/s for $Ra=10^2$, to 4.0×10^{-3} m/s for $Ra=10^5$, at a location midway along the height at the outer radius of a cylindrical grain bulk. The velocities were a factor of 10 smaller near the centre of the grain bulk than near the wall. When the height to radius ratio of a cylindrical grain bulk was unity the model predicted that the velocity of interstitial air caused by natural convection will exceed 3.0×10^{-2} m/s for $Ra=10^6$. For a Raleigh number greater than 10^6, the Darcy's law equation that was used was no longer valid thus limiting their analysis. Unfortunately, the temperature gradients within the grain bulk were not reported for these predicted velocities. Since the Raleigh number, defined by Eq. 12, is a function of temperature change, it is reasonable to say that the convective velocity should increase with an increasing temperature difference in the grain bulk.

Dona and Stewart (1988) modelled transient heat-transfer caused by natural-convection in two-dimensions, in high moisture corn. The streamlines and isotherms were predicted for different height to radius (aspect) ratios of cylindrical bins. The flow cells of the convection currents in a bin with a large aspect ratio were unicellular while multicellular flows developed for some low aspect ratios. This demonstrates that the size and shape of the grain bin will significantly affect the distribution of gases caused by natural convective currents. Over time the location of the streamlines shifted toward the centre and the top of the bin suggesting an overall upward movement of airflow in the bin. The numerical analysis also showed a compression of streamlines near the wall suggesting a larger downward air velocity near the bin wall than near the centre of the bin. No experimental validation was done for this model and the presentation of the streamline data was done to only demonstrate the relative velocities within the grain bulk. Accurate and reliable information about the actual magnitude of the air velocity was difficult to obtain from the reported streamlines in Dona and Stewart's work. Therefore, comparisons with the experimental results were not made.

Yaghoubi et al. (1991) completed a numerical analysis of transient laminar flow within a cylindrical enclosure containing porous media to study natural convection in grain silos with a uniform rate of heat generation. A finite difference method was used to solve the equations of continuity, momentum, and energy. A grain silo 50 m high having a diameter of 9.2 m was analyzed. Grain bulk parameters similar to wheat were used. This model predicted that when the temperature of the grain bulk on the centre-line of the silo was 48°C and the temperature near the wall was 28°C (a difference of 20°C) the interstitial air moved down, near the wall at a velocity of 3.0×10^{-2} m/s while the interstitial air moved upward, near the centre-line at a velocity of approximately 1.5×10^{-2} m/s. This result supports the upper limit of interstitial air velocity predicted by Smith and Sokhansanj (1990). For temperature differences of 30°C (45°C near the centre-line and 15°C near the wall) and 60°C (90°C near the centre-line and 30°C near the wall) the interstitial air velocities near the wall were 4.0×10^{-2} and 8.0×10^{-2} m/s downward, respectively. The velocities near the centre-line were approximately one half the velocity near the silo wall in the opposite direction. The predictions of this model indicate that the interstitial air velocity resulting from natural convection increases with increasing temperature gradient. No experiments were carried out on the silo to validate the results of the model.

Nguyen (1986) presented a two-dimensional transient model for natural convection which simulates airflow patterns and temperature distributions in a grain bulk. No experimental validation was done for this model. The grain bins modelled were given an initially uniform grain temperature of 30°C and a constant wall temperature of 42°C. The grain bulk considered was 10 m × 10 m × 10 m. Conduction was responsible for establishing temperature gradients but the model showed significant distortions of these gradients due to movement of warm air into cool regions of the grain bin. Velocities of the air through the grain bulk were calculated to study the most effective location to introduce fumigants into the grain store. The maximum velocities ranging from 3.0×10^{-4} to 6.0×10^{-4} m/s were predicted at the middle one-third of the hot vertical wall. The velocity is very likely dependant upon other factors of geometry particularly the height of the grain bulk which is supported by the significantly larger velocities predicted by the Yaghoubi et al. (1991) model for a grain bulk five times as high.

3.6 EXPERIMENTAL DETERMINATION OF NATURAL CONVECTION VELOCITY

To validate the accuracy of the predictions made by mathematical models it is necessary to compare these predictions with representative experimental measurements. Beukema (1980) did these comparisons indirectly relying on the relationship between natural convective velocities and temperature differences. Nguyen (1986), Smith and Sokhansanj (1990), and Yaghoubi et al. (1991) also predicted natural convective velocities but did not compare them to actual measured velocities. Experiments have been conducted that have attempted to measure the rate of airflow through grain bulk caused by natural convection directly and are based on the time it took a known quantity of gas to travel a known distance through the grain bulk. The results of these studies are summarized in the following paragraphs.

Berck (1975) measured the velocity caused by free-convection by tracking the movement of a tracer gas (sulphur hexafluoride) through a large diameter cylindrical shaped grain bulk. The measured airflow speeds were between 2.1×10^{-5} and 7.5×10^{-4} m/s. The temperatures ranged from 8.6 to 20.6°C in hard red spring wheat at 12.2% moisture content wet basis (wb). The air velocity through the grain bulk depended on the physical characteristics of the grain and the temperature gradients in the grain bulk. The measured airflow velocity was not correlated to the temperature difference within the grain bulk.

Airflow caused by natural convection in a grain bulk was also studied by Booy (1985). The effects of porosity, grain type, and temperature difference within the grain bulk on the interstitial air velocity through the grain bulk were investigated. Approximate predictions of airflow rates were based on temperature differences between two grain bulks and an empirical equation relating the pressure drop to the airflow rate through the grain. These predictions were compared to those measured in a closed-loop experimental apparatus. By controlling the temperatures of the vertical grain-filled, columns of this apparatus, temperature differences between the columns were established. A tracer gas was used to measure the air velocity through the grain bulk in each column. In general the measured air velocity increased with increasing temperature difference over a range from 10 to 45°C. Increasing the porosity increased the magnitude of the air velocity since there would be less resistance to airflow. For wheat having a porosity of 44%, the measured air velocity ranged from 0.66×10^{-4} m/s at a 10°C temperature difference to 3.19×10^{-4} m/s at a 45°C temperature difference. The measured results showed a large disagreement with the predicted air velocity especially for relatively low air velocities. For the predictions an empirical relationship between pressure drop and airflow rate was used for low flow rates even though the relationship was not developed for these relatively low airflow rates.

Gough et al. (1987) investigated the magnitude of convection currents through a maize bulk. An experimental apparatus similar to the one used by Booy (1985) was used along with a similar tracer gas technique to measure the interstitial air velocity through the grain bulk caused by natural convection. The effect of temperature difference between two vertical columns of maize was the only variable studied. Measured air velocities were in the range of 3.2×10^{-4} m/s for a 7°C temperature difference to 6.0×10^{-4} m/s for a 26°C temperature difference. These measurements were compared to predicted velocities based on an estimation of a pressure drop over the airflow path and the use of an existing empirical relationship between pressure drops and airflow rates through a maize bulk. The measured airflows were proportional to temperature differences in the range of 17 to 25°C between the two vertical columns and these measured values agreed with predicted values over this range. This range in temperature difference is not representative for all conditions which may occur on the Canadian Prairies. The fact that the predictions of air velocity did not agree at low values may have been due to the lack of information on pressure drop at very low airflows. Accuracy of flow meters in this low range of velocity is also questionable.

An attempt was made by Gough et al. (1990) to measure the airflow rate caused by convective currents in 250-t of maize stored in a cylindrical metal silo using three measurement techniques. These techniques included a soap film method, a tracer gas method, and an indirect method using measured pressure drops in the grain. Measurements were taken in the early morning and afternoon from the top of the silo to a depth of only 1.5 m. Measurements in the early morning indicated that the airflow rates were maximum and downward near the wall and moved upward near the centre of the grain bulk. Measurements in the early afternoon suggested that the entire flow was directed upward into the head space. For a temperature difference of 10°C between the centre of the grain bulk and the silo wall, the measured average air velocity through the grain bulk was 1.7×10^{-4} m/s which was reported to agree with the predicted velocity (Gough et al. 1987), although no explanation was given for the method of prediction in such a large storage structure. The measurements taken at dawn did not agree with the predicted air velocity and it was believed that the temperature condition was not yet stable at dawn and therefore the convection currents were unsteady. The problems encountered in this study demonstrate the extreme difficulty and limitations of experiments involving on site measurements of the velocity of natural convection currents through large grain bulks.

3.7 SUMMARY

Results from numerical models do show some agreement in the predicted convective velocity although this velocity appears to be highly dependent upon the geometry of the grain bulk being modelled. Previous experimental work for the determination of airflow through a grain bulk has failed to validate the numerical models reviewed in this thesis. In previous experimental work the rate of airflow caused by natural convection was determined based on the use of tracer gases. The published research has not investigated the movement of a large quantity of gas other than air in a grain bulk. Such a situation occurs when large quantities of gas like CO_2 are introduced in grain stores during CA storage. The rate and direction of the movement of large quantities of gases due to natural convection could be studied by carefully monitoring gas concentrations in a grain bulk while a known quantity of concentrated gas disperses and reaches a uniform concentration.

4. METHODS AND MATERIALS

4.1 AN OVERVIEW

To achieve the objectives given in Chapter 2, a number of variables were measured or controlled or both. These included temperature, CO_2 concentration, moisture content of the grain bulk, and the porosity of the grain bulk. An apparatus was designed and constructed so that controlled experiments could be conducted to determine an average convective-pore velocity and to aid in understanding the natural convection process within stored grain bulks.

4.2 EXPERIMENTAL EQUIPMENT

4.2.1 Components of the system

The design of the test system, used in the experiments, was based on the criteria that the system be able to control temperature and air circulation in the grain bulk, while being large enough so that boundary effects would have little or no influence on the objectives of this thesis. The test system, used to conduct the controlled experiments, consisted of three subsystems. These subsystems included an experimental apparatus to contain a bulk of grain, a temperature control system to control the temperature of the grain bulk, and a gas sampling network used to monitor CO_2 concentrations in the interstitial air of the grain bulk. A schematic representation of the test system is shown in Fig. 2 and each component is discussed in further detail in the following sections.

4.2.2 Experimental Apparatus

An apparatus was designed to simulate the expected circulation of air in a typical stored grain bulk caused by natural convection. One vertical column was used to represent the hot region of the grain bulk during winter near the centre of a grain store and the other, to represent the cold region

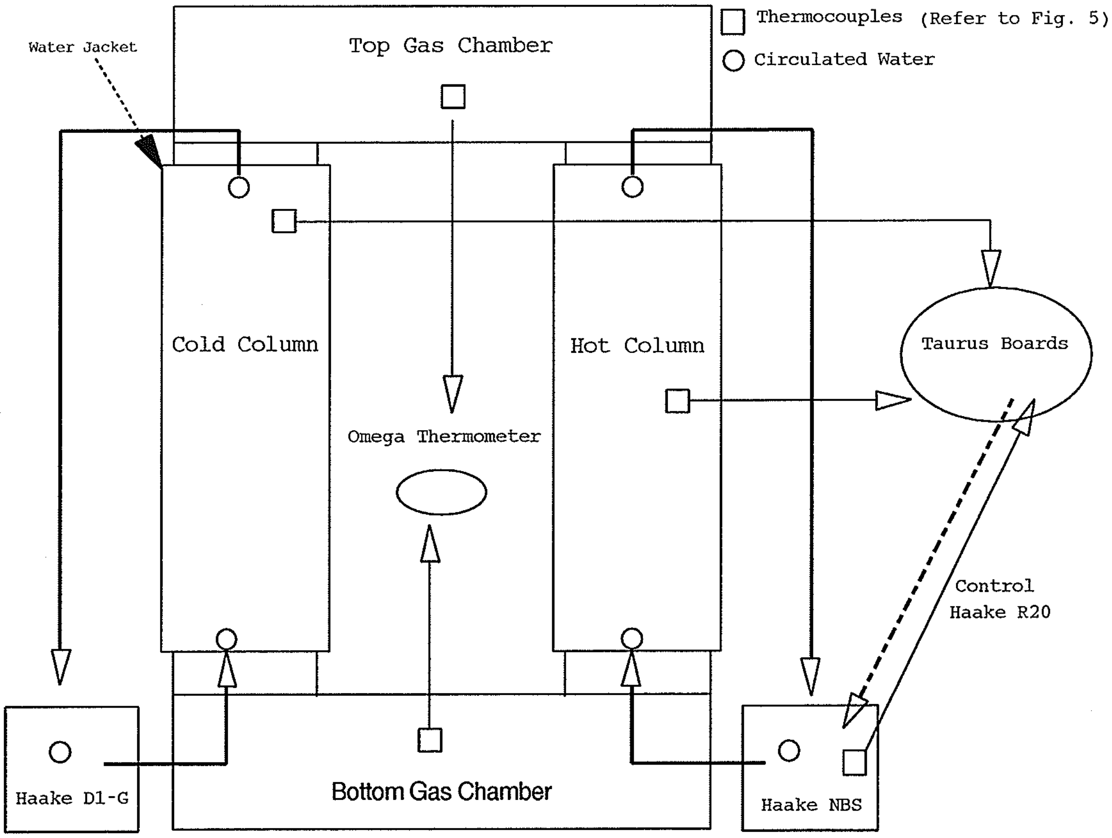

Figure 2. Schematic diagram of the test system.

of the grain bulk near the edge or wall of a grain store (Fig. 3).

These vertical grain columns were open at the ends and were connected at the top and bottom by gas chambers. The gas chambers allowed confined, free passage of air between the two columns and were used as locations for introducing CO_2 into the grain bulk. Sliding-gate valves were installed at each end of the vertical columns. The valves were used to control the movement of interstitial air between the grain columns.

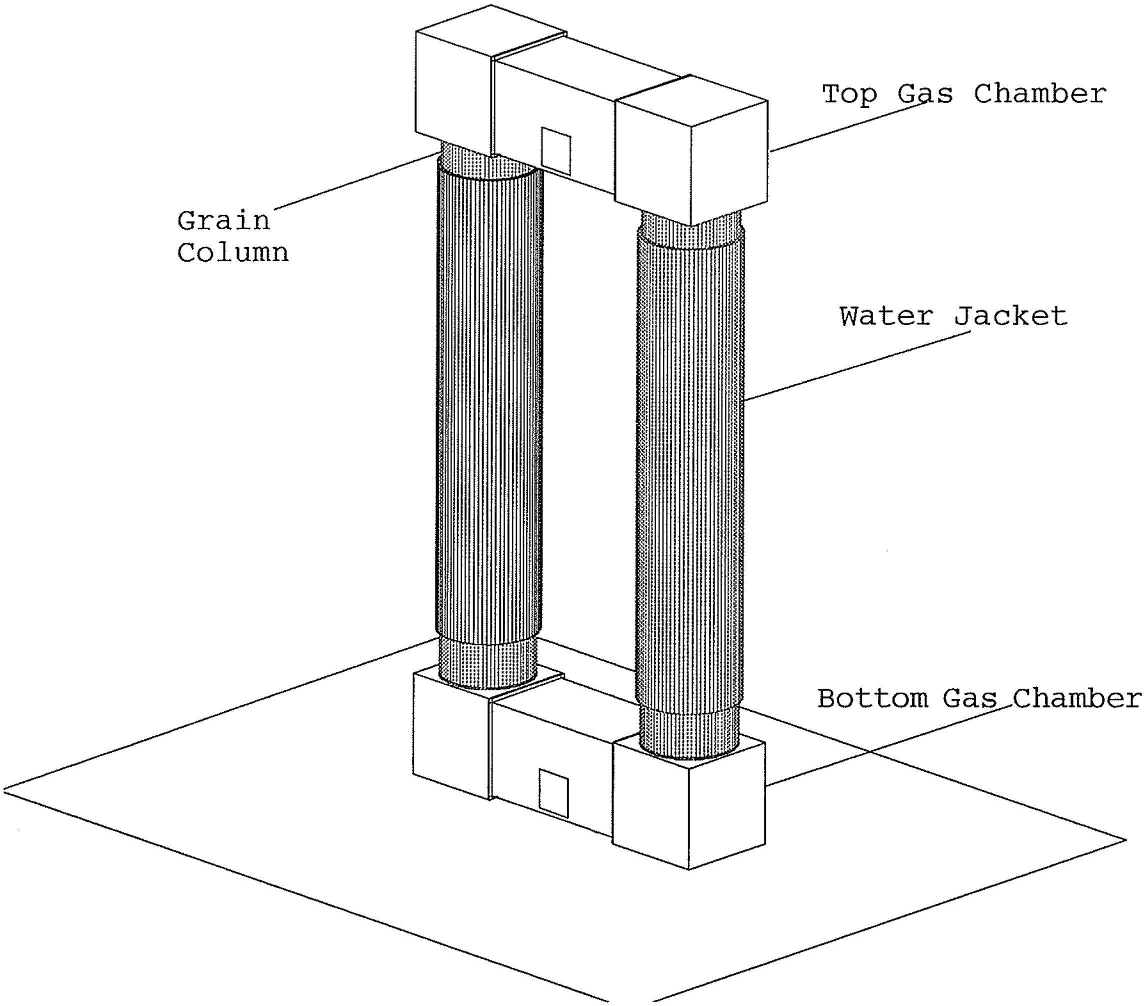

Figure 3. Three-dimensional view of the experimental apparatus.

This was done by having any combination of the sliding-gate valves opened or closed at any given time. Perforated flooring, similar to that found in typical grain bins equipped with drying or aeration systems, was installed at the bottom of each vertical column to prevent the grain from entering the bottom gas chamber. The openings in the perforated flooring were rectangular approximately 1 mm × 5 mm.

All the components were constructed from 1-mm-thick sheet metal. The vertical grain columns were 1778 mm long and were rolled and welded to a diameter of 305 mm. The maximum volume of a grain column was approximately 0.13 m^3 and the masses of grain bulk used to fill a column ranged from 108 kg for lentils to 86 kg for barley. The top and bottom gas chambers were bent to form rectangular chambers that were 330 mm square and 1245 mm long. Acrylic sheets, 9-mm-thick, were used to construct the sliding-gate valves in the gas chambers and the view ports in each gas chamber which were used for visual inspection of dry ice sublimation. Water jackets made of the sheet metal were permanently fixed to each grain column but were part of the temperature control system and will be discussed in further detail in a later section.

A number of details were incorporated into the design to improve the functionality of the apparatus during the experiments. The bottom gas chamber was reinforced with 2-mm-thick, angle iron so that it would withstand the load of the vertical grain columns resting on it. To ensure stability of the entire apparatus the grain columns were fixed to a structural support column in the laboratory. The top gas chamber was removable to allow for the filling of the vertical grain columns. To empty the grain columns, access ports were made below each water jacket. Each access port was large enough to allow a standard shop vacuum hose to clean out any grain not removed through gravity discharge. Access ports were also made in the gas chambers so that dry ice, the source of the CO_2 gas used in the experiments, could readily be placed in each chamber.

Sealing the entire apparatus to maintain concentrations of CO_2 was important since any leak would distort the results of the experiment. The experimental apparatus was tested for air-tightness to ensure no detectable leaks existed. Where necessary, joints and access ports were sealed with silicone caulking. In the top gas chamber, the caulking on the joints was replaced regularly. This replacement was required because of the oxidation of the metal beneath the caulking that took place during the course of the experiments.

A sliding-gate valve sealed each end of the grain columns by placing a rubber O-ring between two flat plates of acrylic. This particular seal in itself was not satisfactory. The slides, that allowed the valves to move into an open or closed position, had to allow for a loose fit between the two pieces of acrylic otherwise the O-ring tended to catch on the edges of the opening of the grain column and was torn from its groove, allowing leakage to occur. The sheets of acrylic had to be pressed tightly together to create a seal. This problem was remedied by allowing a very loose sliding fit and adding a compression mechanism which pressed the sheets of acrylic together and sealed the end of each grain column (Fig. 4). Metal rods (push-pull rod) were used to open and close the compression mechanism. The access holes for these mechanisms were also sealed using compression O-ring arrangements.

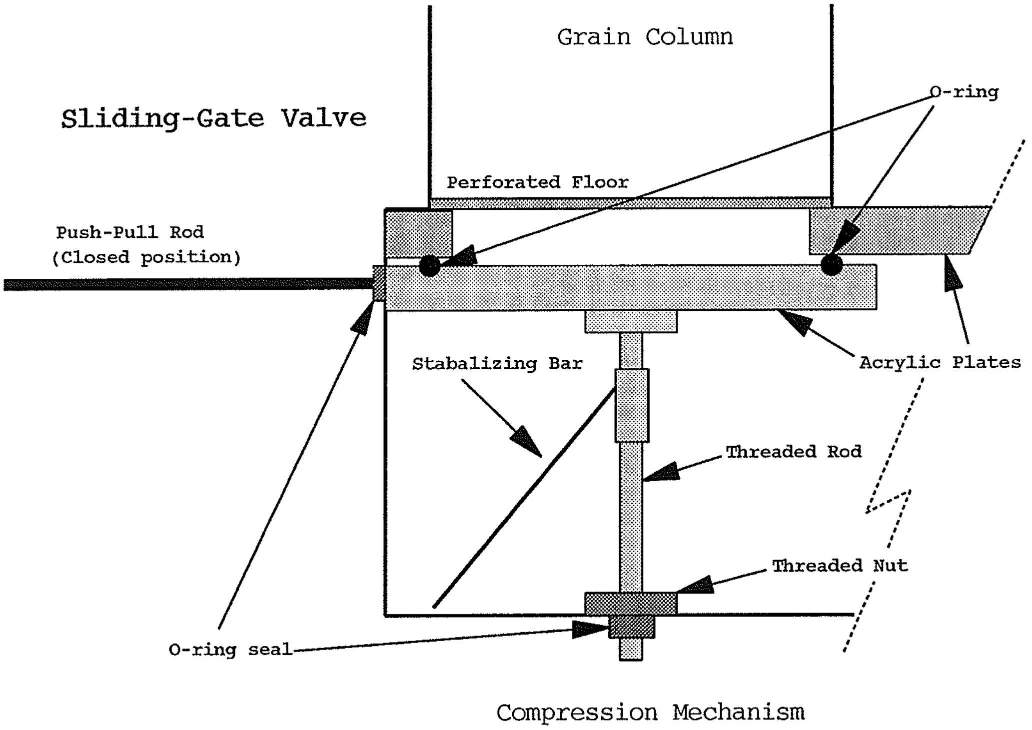

Figure 4. Side view of sliding-gate valve cross-section showing a compression mechanism in the bottom gas chamber.

4.2.3 Temperature control and data acquisition systems

The temperature of the grain bulk in each column was controlled by circulating water at constant temperature through a water jacket surrounding the outer surface of each column. Each water jacket consisted of an annular cavity approximately 7 mm wide, around almost the entire surface of each column. The top 102 mm and the bottom 152 mm of the vertical grain columns were not covered by the water jackets. The circulating water entered the water jackets through inlets at the bottom of the water jackets and exited through outlets near the top.

Circulators were used to move and control the temperature of the water. A refrigerated bath and circulator (Model D1-G, Haake, Berlin, Germany) was used to control the temperature of the water in the jacket surrounding the cold column, while another water circulator (Model NBS, Haake, Berlin, Germany) equipped with a heating element and a controller (Model R20, Haake, Berlin, Germany) was used to control the temperature of the water in the jacket surrounding the hot column.

The outside of each jacket was insulated with foil-backed insulation that was approximately 64 mm thick. Plastic tubing (food grade 3.2 mm internal diameter), which connected the water jackets and circulators, was insulated using the same insulation.

Copper-constantan (T-type) thermocouples were used to measure the temperature of the grain bulk. Thermocouples were placed along the length of each grain column at evenly spaced locations and at the top, centre, and bottom cross-sections of each column (Fig. 5). Outputs of 24 thermocouples within the grain bulk were recorded every 15 min during a test period using three data acquisition boards (Model KS102, Taurus, Ottawa, ON) and a personal computer (PC-XT IBM Compatible).

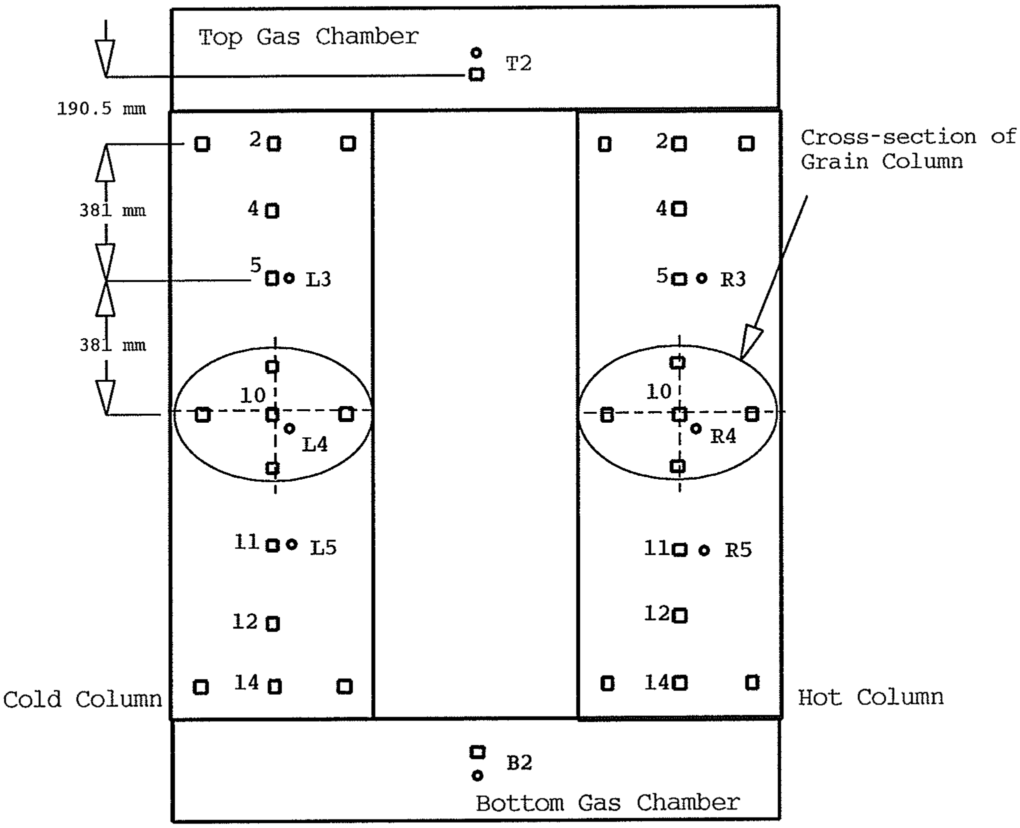

Figure 5. Thermocouple and gas sampling locations. Thermocouple locations that are not numbered were not used to calculate the temperature difference between the grain columns (Note the symmetry of the dimensions and that the drawing is not to scale.).

○ Gas sampling locations (points) (Numbers preceded by letters)
☐ Thermocouple locations (Numbers only)

Prior to their use in the test system, all thermocouples were calibrated and the acquisition boards were adjusted to give the measurements of temperature within ± 1°C. A computer program was written in Quick-Basic to collect temperature data. The recorded temperatures were saved to floppy disk for later analysis.

The rest of the thermocouples, namely those monitoring the temperatures of the top and bottom cross-section and the top and bottom gas chambers, were recorded manually using a multi-switch junction box, connected to a temperature indicator (Microprocessor Thermometer, Model HH23, Omega, Stanford, CT). Thermocouples were also used to monitor the temperature of the laboratory and to control the water temperature of the hot water circulator.

Temperature was measured in the grain bulk to ensure that the desired temperature difference between the two columns was achieved and that the temperature of the grain bulk in each column was uniform across a given horizontal cross-section. This was important since temperature gradients along horizontal cross-sections may cause convection cells within a column and possibly block or distort the convective flow of interstitial air in the grain bulk along a column's length. The temperature at a given location was used to convert the measured CO_2 concentrations to densities (mass concentration) using the ideal gas law (Appendix A).

4.2.4 Gas sampling network

A method to monitor the CO_2 concentrations at various locations in the grain bulk of each grain column was required. The method used for this purpose made use of tubes to extract a sample of interstitial air from a given location by means of a syringe. Polyvinyl chloride (PVC) tubing was threaded through holes in the wall of the grain column and was attached with wire to the desired sampling locations (Fig. 5). The holes and the wires were also used to install the thermocouples at the designated locations in the grain columns. The holes were sealed with silicone caulking. The ends of the PVC tubes were fitted with 3.2 mm rubber septa which were fixed to the end of each tube by means of silicon caulking. Silicone made a good seal and when the septum became worn out (due to needle puncture) and required replacement, the tubing was not damaged since the silicone caulking easily pealed off the tubing.

4.3 PARAMETERS STUDIED

4.3.1 Temperature difference

The temperature difference considered was the average difference in temperatures measured by the thermocouples in each of the two vertical grain columns. This average excluded the measurements in the upper and lower 50 mm of each vertical grain column. The temperature differences investigated were

20, 40, and 56°C. These temperature differences were chosen to represent typical temperature differences found in stored grain bulks on the Canadian Prairies.

To achieve the desired temperature differences between the columns of grain, the temperatures of the grain bulk in the hot and cold columns were maintained at certain set values. For a temperature difference of 20°C the cold column was maintained at 10°C while the hot column was maintained at 30°C. For temperature differences of 40 and 56°C, the hot column temperatures were maintained at 45 and 61°C, respectively and the cold column temperature was maintained at 5°C.

4.3.2 Grain types

The grain types used in the experiments represent different shapes and sizes of grains typically grown on the Canadian Prairies. Each grain type represented a different porosity. The grain types included: barley, canola, lentils, and wheat. All of the grain bulks used in the experiments were purchased from Parent Seed Farms Ltd., St. Joseph, MB and were grown near the community of St. Joseph, MB. A more detailed discussion of the grain properties is given in Chapter 6.

4.3.3 Locations for introducing carbon dioxide

In previous experiments of CA storage using CO_2 to disinfest grain near Winnipeg, the CO_2 (in the form of dry ice) was introduced to the storage structure in one of two locations (Alagusundaram et al. 1994). These were either the aeration plenum under the grain bulk or on the top surface of the grain bulk. Therefore, the effects on the convective-pore velocity of CO_2 were investigated for introducing CO_2 into the bottom and the top gas chambers.

4.4 EXPERIMENTAL PROCEDURES

4.4.1 Filling procedure

Prior to each repetition or set of experiments the vertical grain columns were filled with grain. The top gas chamber was removed from the experimental apparatus. Scaffolding was used to allow easy removal of the top gas chamber and the filling of the vertical grain columns. Two sections of PVC pipe of different lengths (one 1830 mm; the other 914 mm) and a funnel, were used to fill the columns with grain. The mass of the grain was measured and recorded prior to pouring into the PVC pipe. The mass of the grain in each column was used in the calculation of the porosity of the grain bulk in each column. The PVC pipes had 90° elbows at their ends. As the pipes were filled a small amount of grain would exit the bottom of the pipe until it was blocked by the formation of a small pile of grain at the end of the pipe. When the pipe was full, it was elevated a small amount and the grain exited the bottom of the pipe as if it was dropped from a zero height. This was done to ensure that the porosity would be as uniform as possible throughout the entire length of each grain column. After filling was complete the grain bulk settled to a height 12 mm below the top of the grain column. This settling was taken into account when the geometric parameters used in later analysis were determined and in the calculation of the porosity.

4.4.2 Temperature equilibration period

After the vertical grain columns were filled for each repetition, a minimum period of 12 h was allowed for grain temperature to become uniform at the desired value. To achieve the uniformity in the 12 h period, the temperature of the hot circulated water was set to approximately 10°C above the desired temperature and the temperature of the cold circulated water was set to 10°C below the desired temperature for approximately the first 4 h. After this 4 h period the temperature settings were returned to their desired levels. This procedure reduced the time it took for the grain bulk in each column to reach a uniform temperature and to achieve the desired overall temperature difference.

Occasionally the 12 h period was extended because the temperature of the grain bulk was not yet uniform.

Preliminary testing showed that after a long period of time (3-4 d) a 1°C temperature difference still existed between the centre of the grain column and that near the wall. This temperature difference is within the accuracy of the thermocouples used. It was assumed that a measured difference of 1°C would have negligible effects on the experiment and the column temperature was considered uniform when such a temperature difference within a cross-section was achieved.

The ends of the columns were not insulated and as a result a significant temperature gradient in the grain bulk existed near the ends of the columns. This may have affected the results but the effect was not investigated further.

4.4.3 Sublimation of dry ice

Dry ice pellets (315 to 320 g) were placed into either the top or bottom gas chambers and allowed to sublimate at atmospheric pressure. This resulted in no pressure gradient when the gate valves were opened. This also reduced the leakage through the sliding-gate valves in comparison to sublimation under pressure which did not occur in any of the replicates. The leakage distorted the initial CO_2 concentration in the grain bulk.

The dry ice was placed into the gas chambers through access ports. These ports were closed, but a small opening in each port was allowed by not tightening the top three wing nuts used to seal the access ports to prevent an increase in gas pressure within the apparatus. Sublimation occurred with all sliding-gate valves in the "closed" position. This was done to ensure that at time zero, when the sliding-gate valves were opened, the interstitial air in the grain bulk would contain ambient levels of CO_2. The sublimation period ended when it was determined, via visual inspection through the view ports of the gas chambers, that no more dry ice was present in the gas chambers. The access port was then sealed by tightening the wing nuts and applying silicone caulking to the joint.

4.4.4 Primary testing procedure

The concentration of CO_2 in the interstitial gas at various locations in the apparatus were monitored at regular times. A "no-flow test" and a "bulk flow test" were done for each location of introducing CO_2 and for each temperature difference. For three temperature differences and two locations of introducing CO_2, 12 experiments were done and these 12 experiments represented one repetition. Three repetitions were done for the wheat and one repetition was done for each of the other grain types.

In the no-flow test, the sliding-gate valves, in the gas chamber where the dry ice was placed, were moved to the "open" position after initial samples of interstitial gas in the grain bulk and air in the gas chambers were taken. The sliding-gate valves in the other gas chamber remained closed (i.e. the loop remained closed). Therefore, the flow between the grain columns caused by natural convection was eliminated. The no-flow test could not be termed a "diffusion" test because the flow that occurred was not that of pure diffusion. The initial increase or decrease in temperature of the CO_2 as it entered the grain bulk would affect the rate of flow.

In the bulk flow test, the combined effects of no-flow ("diffusion") and natural convection were investigated. After initial samples of interstitial gas were taken, all of the sliding-gate valves were moved to the "open" position. This allowed for an open circuit through which interstitial gas could circulate. The air exiting the top or bottom of a column was allowed to move into the second column and return to its starting point.

A sample of interstitial gas was obtained from the grain bulk in the following manner. Plastic syringes (10-mL capacity) were capped at the ends with rubber septa. A 25 mm, 26 gauge needle was fixed to the end of another syringe that was used for extracting gas samples from the sampling location in the grain bulk. The tubing used for sampling, was flushed by drawing gas out with the needled syringe and discarding it to the atmosphere. A 5-mL sample of interstitial gas was then drawn out of the grain bulk and transferred to the septum covered syringe. A sample set consisted of one sample from each of the seven gas sampling locations.

Each set of samples was analyzed using a gas chromatograph (Model-HP 5895A GC Workstation, Hewlett Packard Chemstation, Mississauga, ON). The gas chromatograph had a thermal conductivity detector. The carrier gas used was helium at a flow rate of 40 mL/min. The gas chromatograph was calibrated using samples of known concentrations of CO_2 that were in the range of the measured concentrations. This calibration was checked regularly and was repeated when deviations from the standard samples became significant (i.e. 10% of reading).

The intervals at which interstitial gas samples were taken were chosen so that trends in CO_2 movement could be easily deduced but also allow enough time to analyze samples between sample sets. A sample set was always taken prior to opening any of the sliding-gate valves to give the initial concentration of CO_2 in the vertical grain columns.

For temperature differences of 20 and 40°C, two more sample sets were taken at 15 min and 45 min, before the analysis of the first (initial) sample set began. It took approximately 30 min to analyze a sample set consisting of seven samples. Therefore, three sample sets were taken and then the first two sample sets were analyzed using the gas chromatograph. The fourth sample set was taken and the third and fourth sets were analyzed. Sample sets were then taken and analyzed at hourly intervals for the next 6 h or until the concentrations of CO_2 no longer changed (i.e. the concentration became uniform throughout the columns).

For the temperature difference of 56°C, a similar sampling procedure was used with the following exceptions. The first two sample sets were taken at 10 min and 20 min, with an extra sample set taken at 50 min. This meant that only the first set was analyzed before the fourth sample set was taken. The extra sample set, taken at 50 min, was necessary because the movement of CO_2 during the first hour was much faster compared to the other temperature differences.

4.4.5 Purging the grain bulk

Once the primary testing procedure was complete all sliding-gate valves were placed in the "open position" (if they were not already) and the access ports to the gas chambers were opened. This allowed the CO_2 in the closed circuit to escape and allowing the CO_2 concentration of the interstitial gas in the grain bulk to return to ambient levels (9 to 10 h). During preliminary tests, a small fan was attached to the access port of the bottom gas chamber. This forced ambient air through the grain bulk thus, speeding up the purging process (4 to 5 h). Forcing ambient air through the grain bulk also increased the amount of heat transfer between the interstitial gas and the grain and the temperature in the grain bulk in both columns quickly equilibrated to the air temperature of the laboratory. Returning the grain bulk in each grain column to its set temperatures took a considerably longer time than if the columns were allowed to purge without the forced air. Therefore, this method of purging the grain bulk was abandoned due to the savings in time between experiments.

After the grain bulk had been purged of CO_2, all the sliding-gate valves where closed. The grain bulk was allowed to equilibrate with the temperature of the water jackets for approximately 8 to 9 h prior to the start of the next experiment. This was necessary because during the purging period, the temperature at the ends of the grain columns began to equilibrate with the ambient temperature of the laboratory.

4.4.6 Collection of grain samples after a repetition

After a repetition was completed samples of the grain from both columns were collected and the moisture content measured to check if moisture migration occurred within the grain columns during a repetition. One sample of grain was taken from the top of each column prior to emptying the grain columns. Samples were then taken while the columns were being emptied. Since the discharge from each column resulted in mass flow (plug flow) discharge, a crude approximation of the location from where each sample was taken could be obtained.

4.4.7 Measurement of grain properties

The initial and final moisture content of each grain type were measured using ASAE Standard S352.2 DEC92 (ASAE 1993). The particle densities were measured using an air comparison pycnometer (Model 930, Beckman, Mississauga, ON). The porosities of samples were calculated as the ratio of pore volume to bulk volume. The pore volume was taken as the bulk volume (column volume) minus the solid volume. The solid volume was calculated as the mass of the grain bulk in a grain column divided by the particle density.

5. ANALYSIS

5.1 OVERVIEW

A combined diffusion-convection equation (Eq. 10) was solved using a finite difference method for a one-dimensional case. The diffusion coefficient in Eq. 10 was called the no-flow coefficient for two reasons. First, the process that occurred in the no-flow tests was not pure diffusion as explained previously. Second, the resulting predicted coefficient from the model for no-flow tests did not agree with previous work that determined the apparent diffusion coefficients of CO_2 through grain bulks (Singh et al. 1984). During the no-flow tests, "no" flow of CO_2 caused by natural convection was believed to have occurred. The velocity in Eq. 10 was called the convective-pore velocity because it represented the velocity of CO_2 caused by natural convection through the pore space of the grain bulk. To obtain a bulk velocity the convective-pore velocity must be multiplied by the porosity of the grain bulk.

The predicted CO_2 concentrations for given parameters of no-flow coefficient or convective-pore velocity were compared at three gas sampling locations to the measured concentrations. These parameters were varied individually at each gas sampling location to obtain a minimum average-absolute difference between predicted and measured CO_2 concentrations. The values of the parameters that gave the lowest difference were considered to best describe the processes occurring during each experiment.

5.2 EXPERIMENTAL DATA

The temperatures at the centre of each grain column were averaged over the time period of an experiment at each location (locations: 4, 5, 10, 11, and 12, in Fig. 5). The average column temperature was calculated by averaging these time averaged temperatures. Due to the large temperature gradient at the ends of each column, locations 2 and 14 (Fig. 5) were excluded from the calculation of the average column temperature. The difference between the average column temperatures represented the temperature difference between the grain columns and this value was always within 2°C of the nominal temperature differences given in this thesis.

The CO_2 concentrations (percent volume basis) obtained from the gas chromatograph were converted to density (mass concentration) at the measured temperature and pressure using the ideal gas law (Appendix A). The temperature used in this conversion was the average column temperature. For CO_2 concentrations in the gas chambers, an average recorded temperature for the gas chamber was used. The pressure used in this conversion was the atmospheric pressure at the time of the experiment. Hourly atmospheric pressure data were obtained from the Winnipeg weather station of Environment Canada. These pressures are corrected for sea level and not the true pressure but for Winnipeg the difference would be small. The experimental data for each repetition are summarized in Appendix D.

5.3 DIFFUSION-CONVECTION MODEL

The general transport equation which incorporates flow caused by diffusion and convection, Eq. 10, was solved for unsteady, one-dimensional movement of CO_2 through a grain bulk using the finite difference method. The derivation and the final form of the discretized equations are given in Appendix B. A computer program, written in FORTRAN, was used to determine the average convective-pore velocity. A listing of the FORTRAN code and examples of an input data file and an output data file may be obtained on request from Dr. Jayas or the Head, Department of Agricultural Engineering, University of Manitoba, Winnipeg. The computer program calculated the CO_2 concentration as a function of position in the column and time for a given no-flow coefficient and convective-pore velocity. Geometric parameters used in the model were based on the experimental apparatus. The grid geometries were set up so that grid points in the model coincided with experimental gas sampling locations 3, 4, and 5 (R3, R4, and R5 in the hot column and L3, L4, and L5 in the cold column; Fig. 5). For experiments where the CO_2 was introduced from the bottom gas chamber, data from the hot column were used. For experiments where the CO_2 was introduced from the top gas chamber, data from the cold column were used. The data, from the grain column which the CO_2 entered first, during an experiment, was used in the model since, during certain experiments for temperature differences of 20°C, the CO_2 did not circulate through the entire apparatus but always travelled through the first column it entered.

The CO_2 concentrations measured as a function of time in the top and bottom gas chambers were fitted to exponential equations that were used in the model as the boundary conditions at the inlet and outlet of the grain column used in the model (Appendix D). In some instances the exponential fit to the concentration data for bulk flow tests at the outflow boundary of a grain column was poor. According to Patankar (1980), no outflow boundary-condition is needed if it is assumed that the no-flow coefficient at the outflow boundary is small. Therefore, the presence of outflow data for boundary conditions was not critical and was omitted if the fit was poor.

For the no-flow test the convective-pore velocity was set to a very small value while the no-flow coefficient was varied. The convective pore-velocity could not be set to zero because of divisions by zero in the discretized equations. As the no-flow coefficient was varied the predicted CO_2 concentrations were compared to those determined in the experiments. The no-flow coefficient was varied until a minimum average-absolute difference between predicted and experimental concentrations was found. This minimization was carried out for each of the three gas sampling locations (3, 4, and 5 in Fig. 5). Figures 6 and 7 illustrate how the average-absolute difference varied with the no-flow coefficient. These figures also illustrate that the value of the no-flow coefficient which gave the minimum average-absolute difference was not the same for each gas sampling location. In comparing Figs. 6 and 7 it is apparent that the no-flow coefficient at the minimum average-absolute

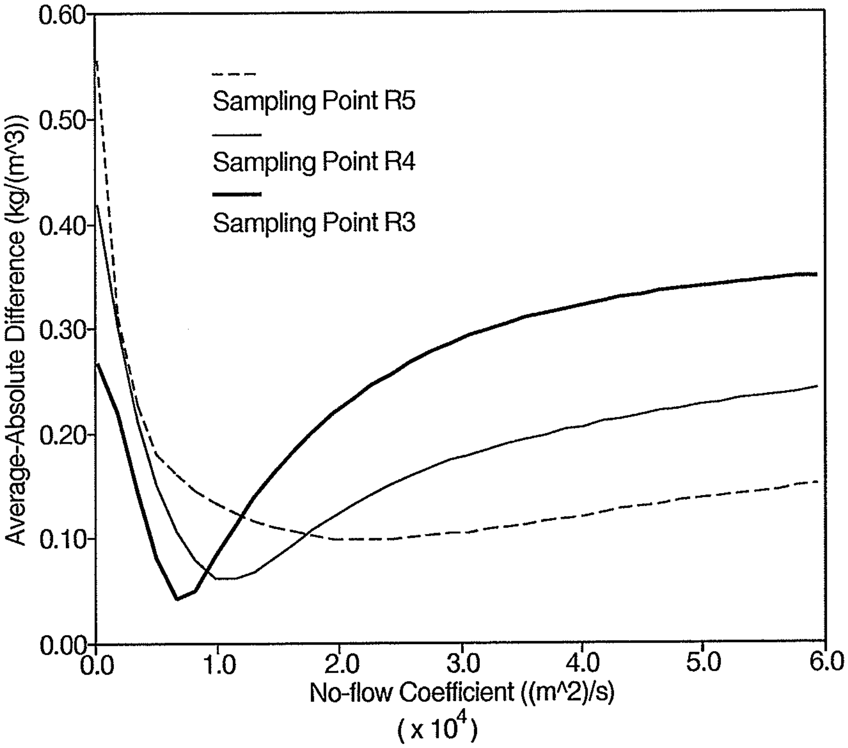

Figure 6. The minimum average-absolute difference between predicted and experimental CO_2 concentrations (wheat repetition #1; August 19, 1993; no-flow test; temperature difference=56°C; CO_2 introduced into the grain bulk from the bottom gas chamber).

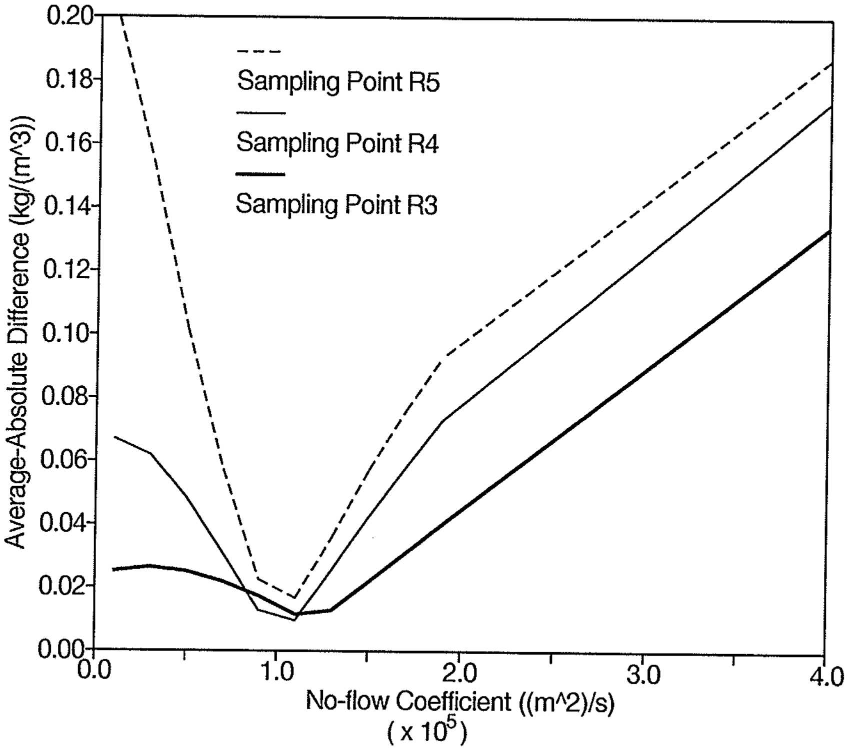

Figure 7. The minimum average-absolute difference between predicted and experimental CO_2 concentrations (wheat repetition #2; October 26, 1993; no-flow test; temperature difference=56°C; CO_2 introduced into the grain bulk from the bottom gas chamber).

difference fell in a larger range for the experiment conducted on August 19 than the one conducted on October 26. The values of no-flow coefficient for each gas sampling location and repetition were averaged. The averaged no-flow coefficient was used in the calculation of the convective-pore velocity.

For a bulk flow test the same algorithm as for the no-flow test was followed but the no-flow coefficient remained fixed while the convective-pore velocity was varied. An average convective-pore velocity was obtained by again minimizing the average-absolute difference at each gas sampling location (Figs. 8 and 9). The three values of convective-pore velocities were averaged to give an average convective-pore velocity.

The minimization algorithm, for determining the converged convective-pore velocity or no-flow coefficient, was very simple in structure. Given a starting value, the minimization algorithm incremented the convective-pore velocity or no-flow coefficient and compared the average-absolute difference

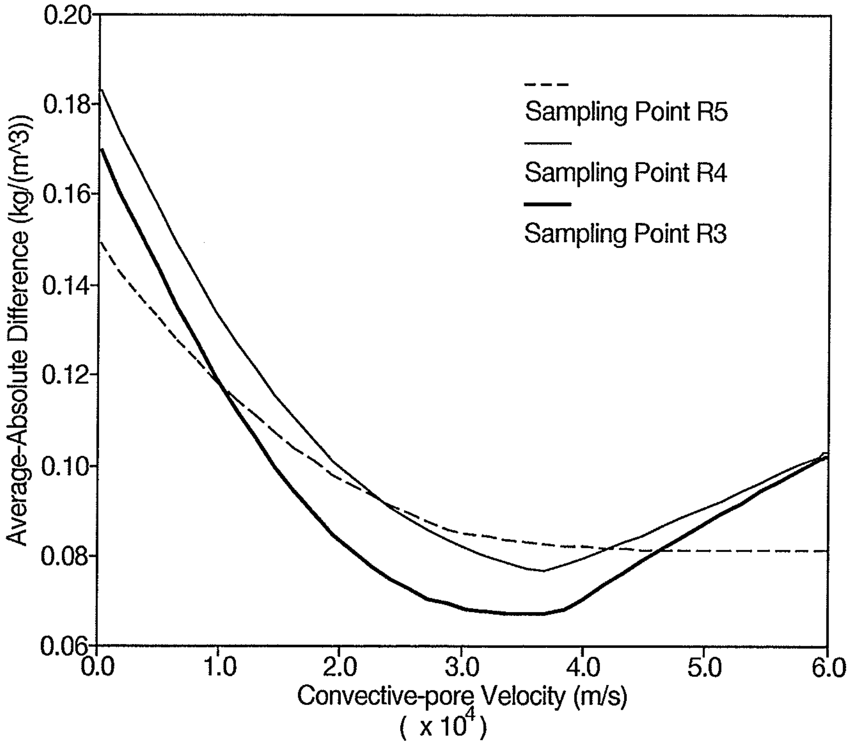

Figure 8. The minimum average-absolute difference between predicted and experimental CO_2 concentrations (wheat repetition #1; August 20, 1993; bulk flow test; temperature difference=56°C; CO_2 introduced into the grain bulk from the bottom gas chamber).

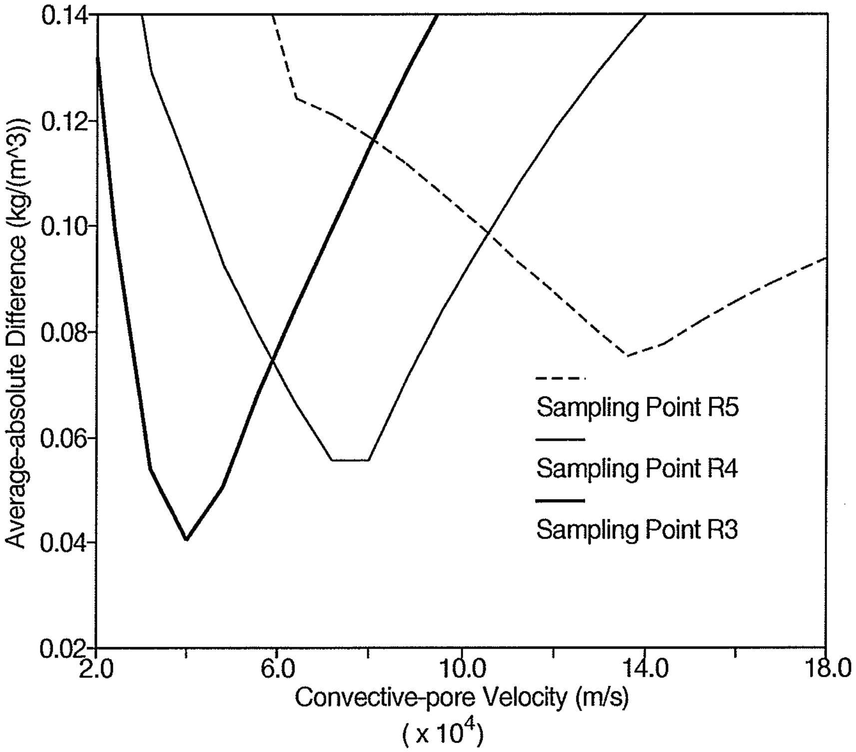

Figure 9. The minimum average-absolute difference between predicted and experimental CO_2 concentrations (wheat repetition #2; October 27, 1993; bulk flow test; temperature difference=56°C; CO_2 introduced into the grain bulk from the bottom gas chamber).

between the predicted and experimental CO_2 concentrations. This increment was usually in the range of 1.0×10^{-7} to 3.0×10^{-6} m^2/s or m/s depending on the experiment. The incrementing continued until the difference was greater than that calculated in the previous step. The algorithm considered this final value of convective-pore velocity or no-flow coefficient which gave the minimum average-absolute difference to be the converged value. The minimization procedure was carried out for the three gas sampling locations (Fig. 5).

The experimental concentrations did not vary smoothly with time. In certain instances, local minimums occurred in the absolute difference (Fig. 10). These local minimums were avoided by initially using a large increment of the parameter being minimized to arrive in the vicinity of the global minimum. The increment was decreased and a new starting value of the parameter was set close to the global minimum to obtain the desired degree of precision.

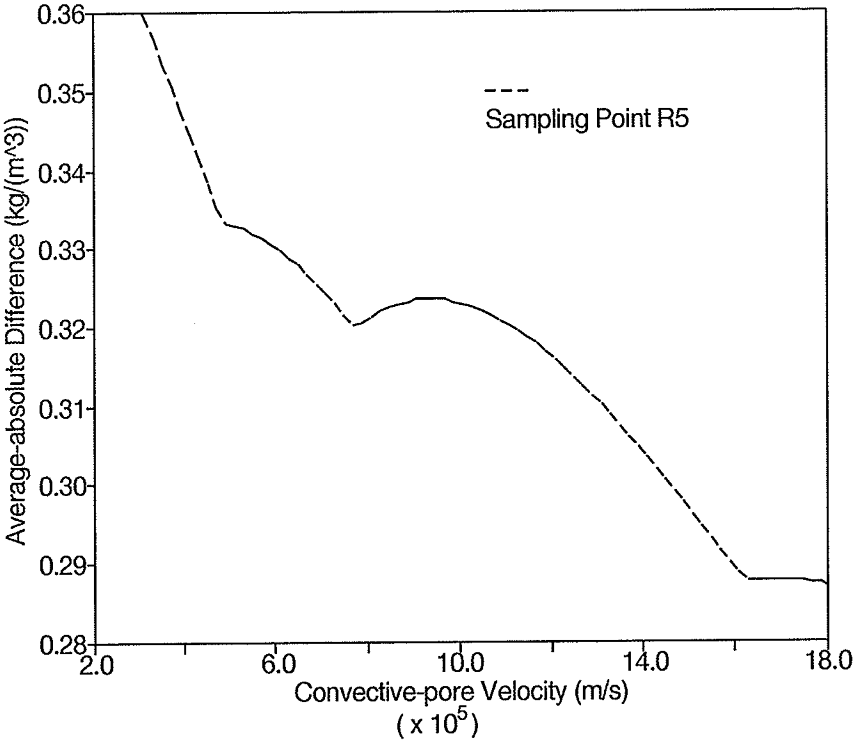

Figure 10. Example of the local minimum problem (wheat repetition #2; October 27, 1993; bulk flow test; temperature difference=56°C; CO_2 introduced into the grain bulk from the bottom gas chamber).

The criteria for minimum average-absolute difference was used for convergence instead of minimum percent error because the minimum percent error frequently was not the lowest when the minimum average absolute difference was in fact the lowest. This contradiction may have occurred when a very large difference occurred between an experimental and a predicted concentration. Also the experimental values being both higher and lower than a predicted CO_2 concentration may have contributed to this contradiction.

Analysis was performed on the no-flow coefficients and the average convective-pore velocities to see if they were statistically different from one another for different temperature differences and for different grain types or different porosities. A Student's t-test for unknown variances was used for this purpose and a confidence level of 5% ($P<0.05$) was used as the criterion for significance (Beyer 1991).

5.4 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to determine the effect of changing the no-flow coefficient or the convective-pore velocity on the CO_2 concentration at a gas sampling location and the effect they had on each other in the model. The analysis was performed using simulated CO_2 concentrations by the model as "experimental" input concentrations. This was done to eliminate the effect of variation in experimental data so that a true sensitivity of one parameter to another could be obtained. The CO_2 concentration profiles that were generated and used in the sensitivity analysis are shown in Fig. 11. The convective-pore velocity and no-flow coefficient used to generate simulated concentrations were chosen to be of a similar magnitude to those found for the experimental data.

First, the effect of changing the no-flow coefficient on the CO_2 concentration was examined while the convective-pore velocity remained constant. The value of the no-flow

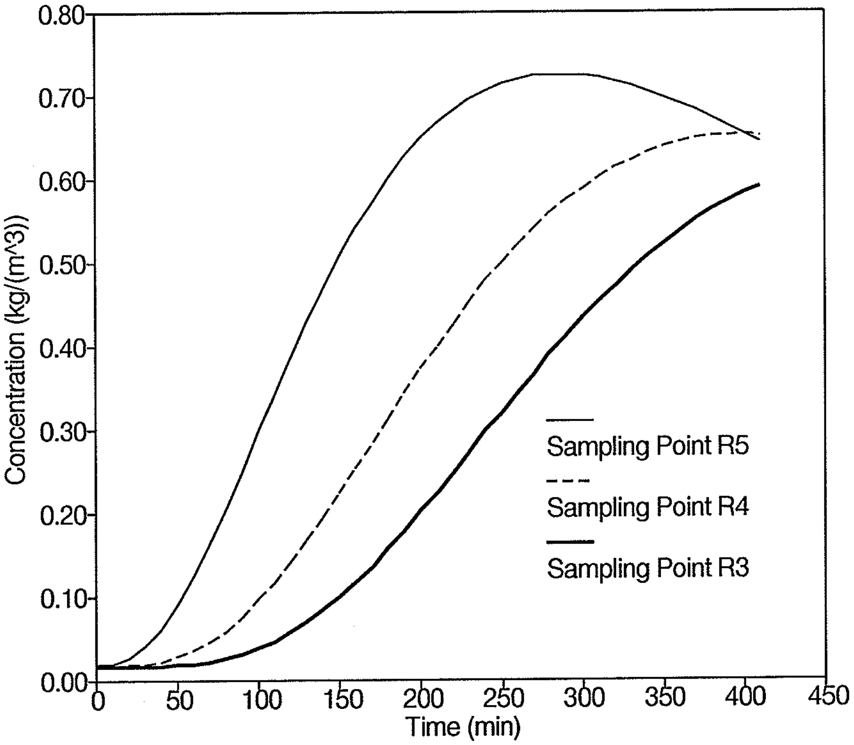

Figure 11. Simulated CO_2 concentrations (kg/m^3) for the three sampling locations (convective-pore velocity=6.55×10^{-5} m/s; no-flow coefficient= 3.42×10^{-6} m^2/s; CO_2 introduced from the bottom gas chamber).

coefficient in Fig. 11 was changed by ±20%. The model was then run using the simulated results as input. The CO_2 concentrations changed very little (Fig. 12). When the no-flow coefficient was increased by 40% (i.e. from -20% to +20%) the CO_2 concentration at any particular gas sampling location increased by less than 4%. This demonstrates that a considerably large error in the value of the no-flow coefficient will have little effect on the predicted CO_2 concentration at a location in the grain column.

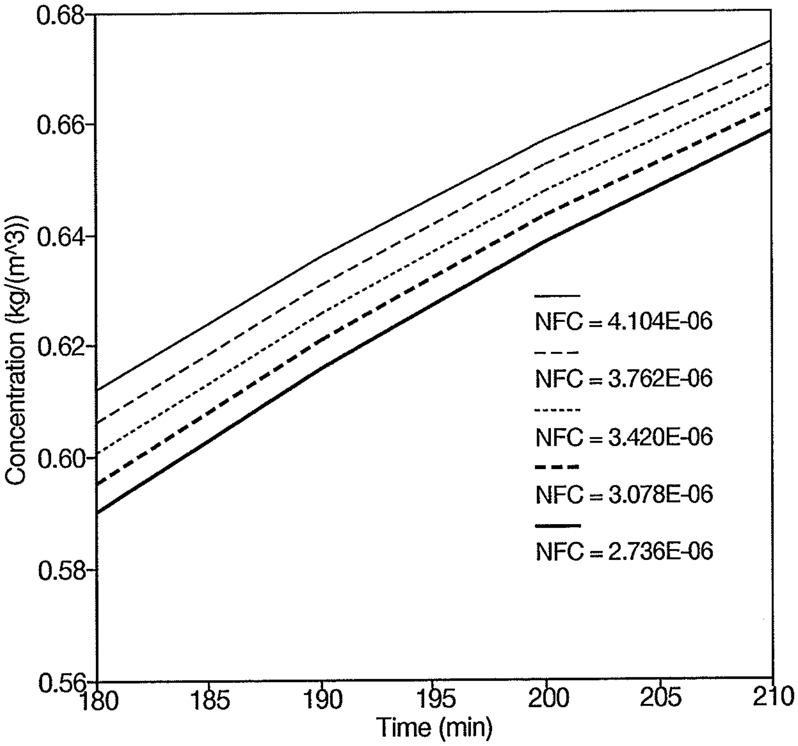

Figure 12. The effect of varying the no-flow coefficient (NFC), (m^2/s), on the CO_2 concentration at sampling location R5 (convective-pore velocity=6.55×10^{-5} m/s).

Second, the effect of changing the convective-pore velocity on the CO_2 concentration was examined while the no-flow coefficient remained constant. The convective-pore velocity was changed by ±20%. The resulting change in CO_2 concentration at any particular time was much larger than when the no-flow coefficient was changed. The farther the CO_2 travelled from the entrance of the grain column, the larger was the change in CO_2 concentration. For a 40% increase (i.e. from -20% to +20%) in convective-pore velocity, this change was as large as 83% at gas sampling location R5, 300 min after the start of the simulation (Fig. 13). As a comparison, the change at gas sampling location R3 was only as large as 50%, 200 min after the start of the simulation.

Third, the effect of changing the no-flow coefficient on the convective-pore velocity was examined. The no-flow coefficient was again changed by ±20%. A 40% increase (i.e. from -20% to +20%) in the no-flow coefficient resulted in a 4.5% decrease in the convective-pore velocity at gas sampling location R3 (Fig. 14). It is also apparent, from Fig. 14, that as the distance from the entrance of the grain column increased, the effect of changing the no-flow coefficient on the convective-pore velocity decreased. This sensitivity analysis shows that the no-flow coefficient has small effect when bulk flow is present in the system.

The no-flow coefficient results from the model indicates a large disagreement with diffusion coefficients from previous

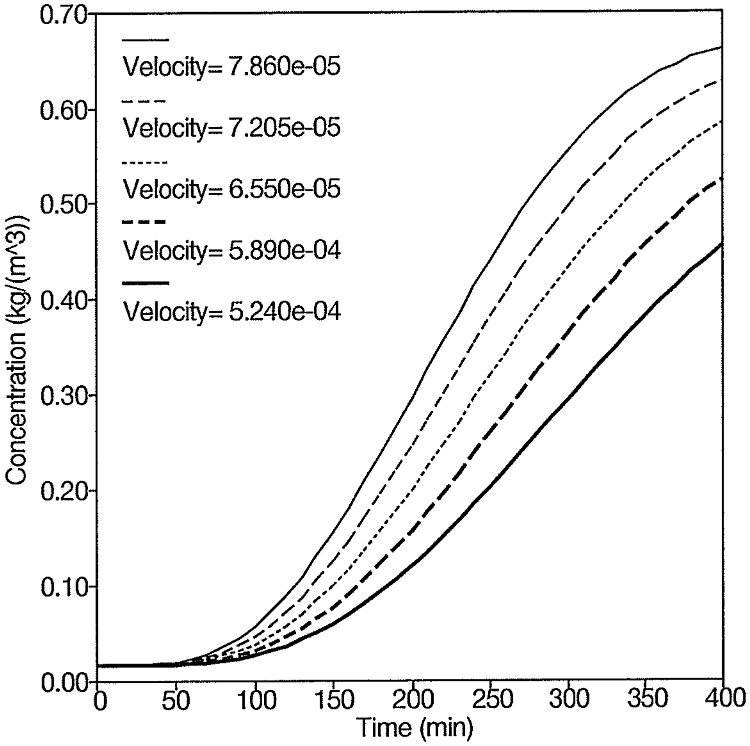

Figure 13. The effect of changing the convective-pore velocity, (m/s) on the CO_2 concentration for sampling location R5 (No-flow coefficient=3.42×10^{-6} m^2/s).

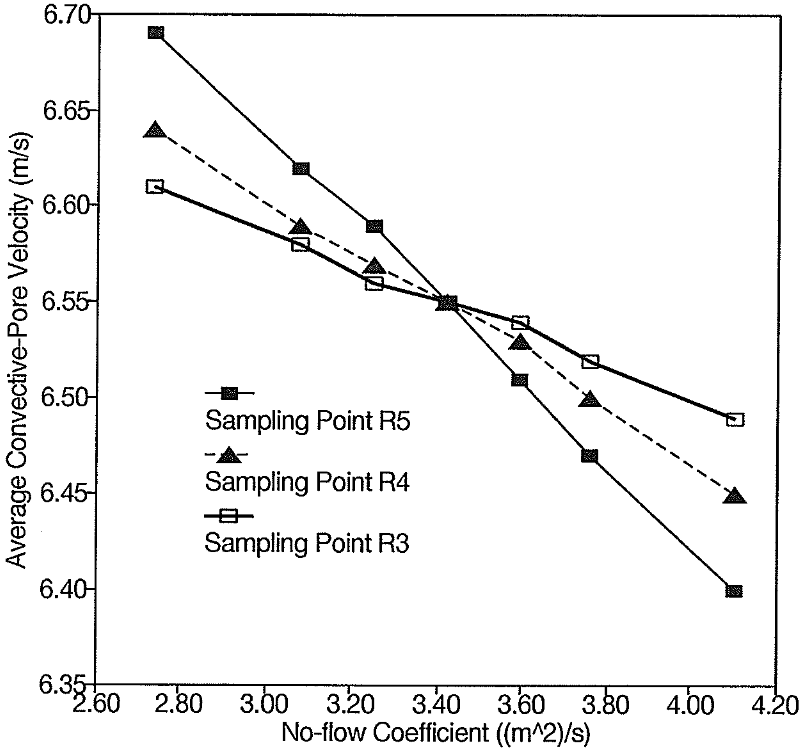

Figure 14. The effect of changing the no-flow coefficient on the convective-pore velocity (convective-pore velocity×10^{-5} m/s; no-flow coefficient×10^{-6} m^2/s).

work (Singh et al. 1984). For example, Singh et al. (1984) reported a diffusion coefficient of CO_2 moving through wheat bulk as 3.46×10^{-6} m^2/s. The lowest no-flow coefficient through wheat bulk determined in this analysis was 6.70×10^{-6} m^2/s. Because the no-flow coefficient has little effect on the convective-pore velocity a large error in the calculated no-flow coefficients from this study would not result in a large error in the determination of the convective-pore velocity. Therefore the no-flow coefficients calculated in this study were used to determine the convective-pore velocities.

6. RESULTS AND DISCUSSION

6.1 GRAIN PROPERTIES

The grain properties of the grain bulks used in this study are summarized in Table 1.

Table 1. Description and physical properties of the types of grain studied.

Crop	Cultivar	Statutory Grade	Initial Moisture Content (% wb)	Porosity (ϕ)	Particle Density (kg/m^3)
Barley	Bonanza	Canada certified No. 1 seed	11.8	0.51	1381.4
Canola	A C Excel	Canada certified No. 1 seed	6.2	0.38	1118.5
Lentils	Eston	Canada certified No. 1 seed	11.2	0.40	1374.6
Wheat	Katepwa	Canada certified No. 1 seed	13.3	0.43	1412.2

6.2 EXPERIMENTAL RESULTS

6.2.1 Trends in CO_2 concentrations during no-flow tests

For the no-flow tests, no distinct peaks were observed. Instead, the CO_2 concentrations increased at a fast rate at the beginning of the experiment and after this initial movement, the rate of concentration increase gradually slowed as the experiment progressed. When the CO_2 was introduced from the bottom gas chamber the concentrations throughout a grain column never reached a uniform concentration during the 6-h-experiment. When the CO_2 was introduced from the top gas chamber a similar trend was observed, however, the concentrations reached a uniform level in the cold column during the 6-h experiment.

The rate of increase in the concentration of CO_2 was not the same in the cold and hot columns during a no-flow test and the movement of CO_2 appeared to depend on where the CO_2 was introduced. When introduced from the bottom gas chamber, the CO_2 moved much quicker into the hot column while the movement into the cold column appeared to be blocked. When the CO_2 was introduced into the top gas chamber the CO_2 moved quickly down the cold column while appearing to be blocked from moving into the hot column. These blockages may be explained in the following way. The temperature of the air in the gas chambers was always at or near the ambient temperature of the laboratory (approximately 20°C). The air temperature inside the gas chambers was always warmer than the grain in the cold column and cooler than the grain in the hot column. At the entrance to the cold column, in the bottom gas chamber for instance, an unstable situation would arise between the cool interstitial air in the grain bulk and the warm air in the bottom gas chamber. Therefore, a small convection cell may have formed at the entrance to the columns and thus stopping the CO_2 from penetrating any deeper into the grain bulk in that column, than the convection cell would allow. In certain instances when the CO_2 was introduced from the top gas chamber there was an initial rise in CO_2 concentration in the hot column and then a steady decrease. In these cases it may have taken a longer time for the formation of such a convection cell thus delaying the blockage.

6.2.2 Trends in CO_2 concentrations during bulk flow tests

When the CO_2 was introduced into the grain bulk from the bottom gas chamber, it rose through the hot column, entered the top gas chamber, and then fell down through the cold grain column. For temperature differences of 40 and 56°C, the CO_2 had sufficient time during a 6-h experiment to circulate within the apparatus and create a uniform concentration throughout the grain bulk. For a 20°C temperature difference, CO_2 concentrations did not become uniform in 6 h. The direction of movement of CO_2 was the same when the CO_2 was introduced from the top gas chamber. In this case, however, it took much less time (about 3 h) for CO_2 concentrations to become uniform. Even for a temperature difference of 20°C a uniform concentration was reached.

At a gas sampling location during bulk flow tests, the CO_2 concentration increased to a peak value and then decreased to a level that was equal for all sampling locations (i.e. uniform concentration). The peak value of CO_2 concentration decreased as the distance from the source of the CO_2, in the direction of movement, increased and as the temperature difference decreased. As an example, for wheat having a temperature difference of 56°C, the peak CO_2 concentration was 0.8517 kg/m^3 for gas sampling location R5, 0.8197 kg/m^3 for gas sampling location R4, and 0.7627 kg/m^3 for gas sampling location R3 when CO_2 was introduced from the bottom gas chamber (p.D11 Appendix D). For wheat having a temperature difference of 20°C, the peak CO_2 concentration was 0.3860 kg/m^3 for gas sampling location R5 when CO_2 was introduced from the bottom gas chamber (p.D3 Appendix D).

6.2.3 Moisture migration

Moisture migration in grain bulks is believed in part to be the result of natural convection. The moisture contents taken at the end of each repetition indicate that some moisture migration may have occurred. The moisture content of the grain increased by as much as 6 percentage points (wb) in the upper levels of the hot grain column and increased 2 percentage points (wb) in the upper levels of the cold grain column for wheat and barley repetitions. As the warm interstitial air rose through the grain bulk it contacted the cooler air in the top gas chamber. Some of the moisture in the air condensed and then adsorbed, or was adsorbed by the grain in the upper levels of both grain columns. The presence of condensation on the interior walls of the top gas chamber was evidence the moisture had condensed out of the air and this moisture may have contributed to the increase in moisture content of the grain in the upper levels. The lentil and canola tests did not exhibit this moisture migration possibly due to their lower porosity and thus lower average convective-pore velocity or because of different equilibrium relative humidities.

6.2.4 Sorption-desorption

The effect of sorption-desorption was observed when the initial sample set from an experiment was analyzed. In the hot grain column, the CO_2 concentration in the pore space of the grain bulk was higher than the normal ambient concentrations with the highest CO_2 concentrations located near the top of the grain column. The similar effect was observed in the cold grain column but this time higher CO_2 concentrations were located near the bottom of the grain column. The CO_2 concentrations increased as the number of experiments increased during a repetition. The amount of CO_2

present, when this phenomena occurred, varied with the type of grain being tested and was in the range of 0.0002 to 0.1845 kg/m^3 of CO_2. The lower limit of this range (p.D12 Appendix D) is lower than normal atmospheric level (0.0006 kg/m^3) and was likely due to large errors caused by the gas chromatograph when measuring such low CO_2 concentrations. The rates of this sorption-desorption were not measured during or after any of the experiments.

6.3 RESULTS FROM THE DIFFUSION-CONVECTION MODEL

6.3.1 Verification of the concentration-time relationship

When comparison was made between the results from the model and those of experiments for no-flow tests good agreement existed (Fig. 15). Although the agreement between the results of the model and those from the experiments for bulk flow tests was not as good (Fig. 16), the trend is similar especially for the sampling locations closest to the source of the CO_2. In general, the average-absolute difference between measured and predicted CO_2 concentrations was lower for no-flow tests than for bulk flow tests (Appendix C). The poor agreement between the predicted and the experimental results for the bulk flow tests may be the result of invalidity of some of the assumptions. First, the flow through the column was assumed as one-dimensional. Second, the temperature of the grain bulk in each column was assumed

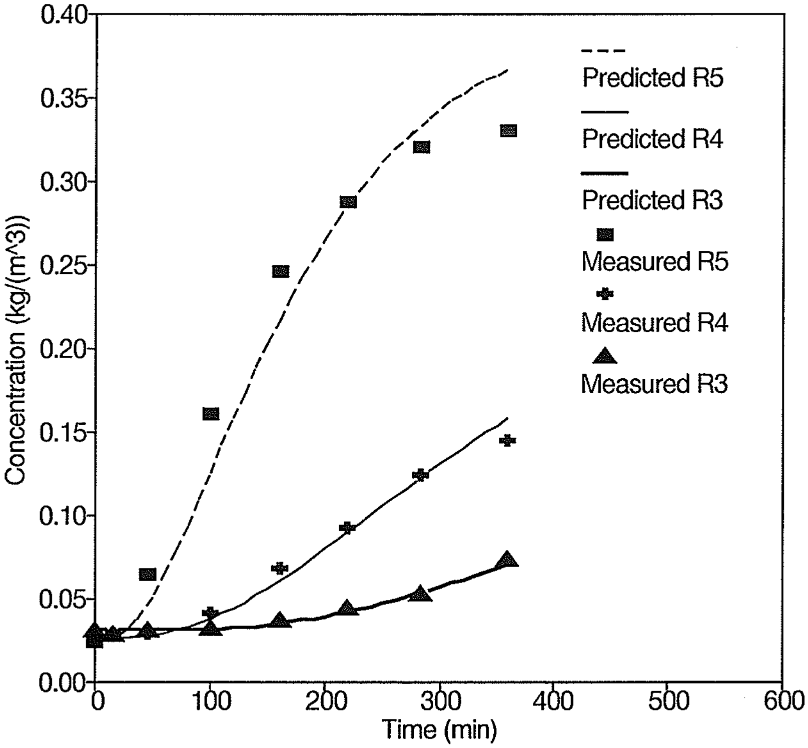

Figure 15. Comparison of predicted and measured CO_2 concentrations at the three sampling locations for a no-flow test (wheat repetition #3; November 5, 1993; temperature difference=40°C; CO_2 introduced into the grain bulk from the bottom gas chamber; average no-flow coefficient=8.5×10^{-6} m^2/s). The no-flow coefficient was an average of those determined through minimization at each gas sampling location and was used to generate the predicted curves.

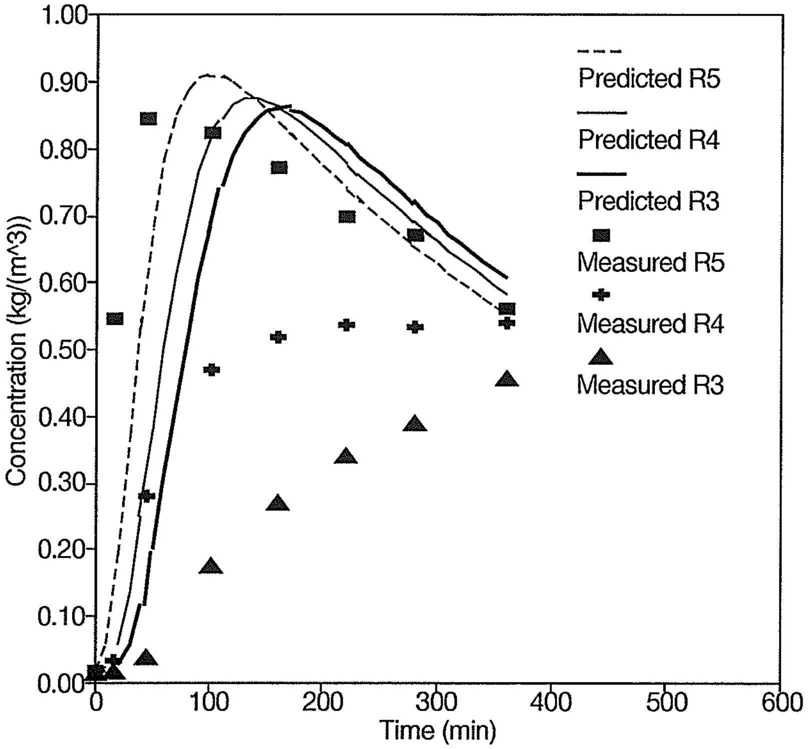

Figure 16. Comparison of predicted and measured CO_2 concentrations at the three sampling locations for a bulk flow test (wheat repetition #3; November 6, 1993; temperature difference=40°C; CO_2 introduced to the grain bulk from the bottom gas chamber; average no-flow coefficient=8.5×10^{-6} m^2/s; average convective-pore velocity=2.637×10^{-4} m/s). The average convective-pore velocity was an average of those determined through minimization at each gas sampling location and was used to generate the predicted curves.

to be uniform. Large temperature gradients existed at the ends of each column which had an effect on the results of the model which was unaccounted for. Finally the effects of sorption-desorption were neglected in the diffusion-convection model and would have had an effect on the results.

6.3.2 Statistical comparison

The no-flow coefficients and average convective-pore velocities are given in Tables 2-5. Statistical comparisons were done for no-flow coefficients and average convective-pore velocities to investigate the effects of temperature difference and grain type.

For a given grain type the no-flow coefficients were not affected by the temperature difference between the columns when the CO_2 was introduced into the top gas chamber (Table 2). This is reasonable since the no-flow coefficient was determined using data from the cold grain column. The average temperature of this column remained the same for each temperature difference and was increased by 5°C for a temperature difference of 20°C between the columns. When the CO_2 was introduced from the bottom gas chamber (Table 3) the no-flow coefficients increased significantly with increases in temperature difference. This is also reasonable since the temperature of the hot column was increased each time the temperature difference between the columns was increased as previously stated in section 4.3.1.

Table 2. No-flow coefficient when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	No-flow Coefficient (m^2/s) ($\times 10^4$)		
		Mean	SD♣	CV♠
Wheat n=9 ϕ=0.43	20	1.96_{ax}	0.67	34
	40	2.44_{ax}	1.27	52
	56	2.40_{ax}	0.87	36
Barley n=3 ϕ=0.51	20	2.31_{acxy}	0.31	14
	40	1.30_{by}	0.15	12
	56	2.93_{bcxy}	1.05	36
Lentils n=3 ϕ=0.40	20	2.63_{ay}	0.38	15
	40	2.99_{ax}	0.35	12
	56	3.15_{ay}	0.22	7
Canola n=3 ϕ=0.38	20	0.40_{az}	0.09	23
	40	0.66_{bz}	0.09	13
	56	0.76_{bz}	0.21	27

♣ SD = Standard Deviation, calculated from n samples.
♠ CV = Coefficient of Variation, (CV = (100 × SD)/ Mean).
ϕ = porosity of the grain bulk.

The values followed by the same letter (a, b, c) for the same grain type were not statistically different (Student's t-Test; $P>0.05$) for temperature differences. The values followed by the same letter (x, y, z) for the same temperature difference were not statistically different (Student's t-Test; $P>0.05$) for various grain types.

Table 3. No-flow coefficient when CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	No-flow Coefficient (m^2/s) ($\times 10^5$) Mean	SD♣	CV♠
Wheat n=9 ϕ=0.43	20	0.67_{ax}	0.06	9
	40	1.11_{bxyz}	0.46	41
	56	4.98_{bxyz}	6.76	136
Barley n=3 ϕ=0.51	20	0.73_{ayz}	0.02	3
	40	0.91_{bxw}	0.02	2
	56	1.31_{cxw}	0.10	8
Lentils n=3 ϕ=0.40	20	0.62_{axyz}	0.08	13
	40	0.89_{byw}	0.03	3
	56	1.66_{cy}	0.04	2
Canola n=3 ϕ=0.38	20	0.74_{axyz}	0.08	11
	40	1.04_{bz}	0.08	8
	56	1.32_{cwz}	0.08	6

♣ SD = Standard Deviation, calculated from n samples.
♠ CV = Coefficient of Variation, (CV = (100 × SD)/ Mean).
ϕ = porosity of the grain bulk.

The values followed by the same letter (a, b, c) for the same grain type were not statistically different (Student's t-Test; P>0.05) for temperature differences. The values followed by the same letter (w, x, y, z) for the same temperature difference were not statistically different (Student's t-Test; P>0.05) for various grain types .

Table 4. Average convective-pore velocity when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	Average Convective-pore Velocity (m/s) ($\times 10^3$)		
		Mean	SD[♣]	CV[♠]
Wheat n=9 ϕ=0.43	20	[†]0.83_{ax}	0.40	49
	40	[†]2.42_{bw}	1.08	45
	56	2.02_{bx}	1.36	67
Barley n=3 ϕ=0.51	20	1.33_{ay}	0.36	27
	40	1.50_{ax}	0.30	20
	56	1.37_{ax}	0.51	38
Lentils n=3 ϕ=0.40	20	0.83_{axy}	0.31	37
	40	1.00_{axyz}	0.42	42
	56	1.12_{axz}	0.50	45
Canola n=3 ϕ=0.38	20	0.30_{az}	0.05	18
	40	0.47_{bz}	0.10	22
	56	0.48_{abz}	0.16	33

[♣] SD = Standard Deviation, calculated from n samples.

[♠] CV = Coefficient of Variation, (CV = (100 × SD)/ Mean).

ϕ = porosity of the grain bulk.

[†] Mean of eight samples (n=8)

The values followed by the same letter (a, b, c) for the same grain type were not statistically different (Student's t-Test; P>0.05) for temperature differences. The values followed by the same letter (w, x, y, z) for the same temperature difference were not statistically different (Student's t-Test; P>0.05) for various grain types .

Table 5. Average convective-pore velocity when CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	Average Convective-pore Velocity (m/s) ($\times 10^5$)		
		Mean	SD♣	CV♠
Wheat n=9 $\phi=0.43$	20	1.68_{ax}	0.37	22
	40	22.68_{abx}	24.23	107
	56	75.05_{bx}	49.14	65
Barley n=3 $\phi=0.51$	20	1.85_{ax}	0.34	18
	40	35.07_{abxz}	31.57	90
	56	77.71_{bx}	19.08	25
Lentils n=3 $\phi=0.40$	20	1.23_{ay}	0.19	15
	40	20.80_{abxy}	28.75	138
	56	61.47_{bxy}	22.47	37
Canola n=3 $\phi=0.38$	20	0.43_{az}	0.08	19
	40	✣0.94_{bzy}	0.01	1
	56	11.90_{baz}	9.62	81

♣ SD = Standard Deviation, calculated from n samples.

♠ CV = Coefficient of Variation, (CV = (100 × SD)/ Mean).
ϕ = porosity of the grain bulk.

✣ Predicted result may be unreliable. The minimization algorithm was unable to locate a minimum average-absolute difference in the range of 0.0 to 0.1 m/s for the convective-pore velocity.

The values followed by the same letter (a, b, c) for the same grain type were not statistically different (Student's t-Test; P>0.05) for temperature differences. The values followed by the same letter (x, y, z) for the same temperature difference were not statistically different (Student's t-Test; P>0.05) for various grain types .

A problem was found through the statistical comparison of the average convective-pore velocity at different temperatures for a given grain type when the CO_2 was introduced from the top gas chamber (Table 4). In almost all the cases there was no statistical difference among the values at any temperature difference for a given grain type, except wheat. This may be the result of gravity having a significant effect on the values of the no-flow coefficient and average convective-pore velocity. The gravity effect was not accounted for in the general transport equation. The exception for wheat may also indicate a need for more than a single repetition for the other grain types but the standard deviation and coefficient of variation for different grain types are lower than those for wheat suggesting that this is not the case.

Statistical comparison of the average convective-pore velocities between the temperature differences for a given grain type indicates that the average convective-pore velocity increases with increasing temperature difference, when CO_2 was introduced from the bottom gas chamber (Table 5). This relationship is based on the fact that significant differences in the average convective-pore velocity occur between the temperature differences of 20 and 56°C. The lack of significant difference between values for temperature differences of 20 and 40°C and between values for 40 and 56°C may be the result of errors in the method of determining the average convective-pore velocity.

When CO_2 was introduced from the top gas chamber, the no-flow coefficients (Table 2) for cereal grain types (barley and wheat) and lentils were significantly higher than those found for canola at all temperature differences. When CO_2 was introduced from the bottom gas chamber some significant differences between grain types exist for no-flow coefficients (Table 3) but, it is difficult to conclude any trends that may result from varying the porosity in this case.

When CO_2 was introduced from the top and bottom gas chambers the average convective-pore velocities (Tables 4 and 5) for cereal grain types and lentils were significantly larger than for canola at all temperature differences. The highest porosity was obtained when using barley (0.51) and the lowest porosity was obtained when canola (0.38) was used. The lower porosity of canola (0.38) and higher porosity of barley (0.51), lentils (0.40), and wheat (0.43) suggests that the average convective-pore velocity increases with increasing porosity. This however, cannot be generalized because considerably large differences between the porosity of barley and wheat did not give an increase in the average convective-pore velocity. Therefore it is likely that the shape of the kernels plays a major role in affecting the average convective-pore velocity.

A statistical comparison was not made between the values of average convective-pore velocity and no-flow coefficient found when the CO_2 was introduced from the top gas chamber, and those found when CO_2 was introduced from the bottom gas chamber. By inspection alone, it is apparent that the no-flow coefficients and average convective-pore velocities increase when CO_2 was introduced from the top gas chamber instead of the bottom gas chamber. This result suggests that gravity has a large effect on the no-flow coefficient and the average convective-pore velocity. For temperature differences of 20°C the factor of increase in average convective-pore velocity was much higher than for temperature differences of 56°C.

6.3.3 Comparison with previous research

Comparison of the average convective-pore velocity determined in this study with the published results indicate that the results obtained are realistic. The previous models suggest that the downward convective velocity should be higher than the upward convective velocity (Dona and Stewart 1980, Yaghoubi et al. 1991). Yaghoubi et al. (1991) predicted that the downward convective velocity was approximately double the velocity of upward convective movement. The significantly higher average convective-pore velocity when CO_2 was introduced to the top gas chamber than when it was introduced to the bottom gas chamber does support their findings. This may be due to differences in the cross-sectional areas through which the interstitial air was passing through in the grain store.

For mathematical models where the convective velocities were reported (Smith and Sokhansanj 1990, Nguyen 1986), the convective velocities were all within the range of average convective-pore velocities determined in this study. The exception to this was the results of Yaghoubi et al. (1991), where the convective velocities for all the temperatures studied were at least 100 times larger than the average convective-pore velocities found in this study. This exception may be indicative of the effect of the height of the grain bulk on the convective velocity since the height of the grain bulk modelled by Yaghoubi et al. (1991) was over 25 times as high as the apparatus used in this study.

The average convective-pore velocities are close to those measured experimentally using the tracer gas method. For wheat bulk at a temperature difference of 20°C, Berck (1975) reported a convective velocity of interstitial air of 7.5×10^{-4} m/s. In this study an average convective-pore velocity of CO_2 for the same parameters was 8.24×10^{-4} m/s when the CO_2 was introduced from the top gas chamber. For wheat bulk having a temperature difference of 45°C, Booy (1985) reported a convective velocity of interstitial air of 3.19×10^{-4} m/s which is similar to an average convective-pore velocity of CO_2 of 2.27×10^{-4} m/s when the CO_2 was introduced into the bottom gas chamber at a temperature difference of 40°C.

The average convective-pore velocities determined in this study are similar to those reported in published work (Berck 1975, Booy 1985). Better agreement may be possible by refining experimental techniques and conducting a more detailed investigation of the data from the literature.

7. CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. The CO_2 rises in the hot grain bulk and falls in the cold grain bulk. The temperature difference between the columns, the grain type, and the location of introducing CO_2 into the grain bulk had no effect on the direction of the convective flow of CO_2 through the grain bulk.

2. The average convective-pore velocity through the wheat bulk was between 1.68×10^{-5} m/s for a temperature difference of 20°C and 7.51×10^{-4} m/s for a temperature difference of 56°C, when CO_2 was introduced into the grain bulk from the bottom surface. When CO_2 was introduced from the top surface of the grain bulk the average convective-pore velocity of CO_2 through the wheat bulk was between 8.25×10^{-4} m/s for a temperature difference of 20°C and 2.02×10^{-3} m/s for a temperature difference of 56°C. The average convective-pore velocities for the other grain types were of similar orders of magnitude except for canola. When CO_2 was introduced into the canola bulk from the bottom surface the average convective pore-velocity of CO_2 through this grain bulk was 4.30×10^{-6} m/s for a temperature difference

of 20°C.

3. The average convective-pore velocity increased as the temperature difference increased for all grain types studied, when the CO_2 was introduced into the grain bulk from the bottom surface ($P<0.05$).

4. Increasing the porosity of the grain bulk resulted in an increase in the average convective-pore velocity.

5. The average-convective pore velocity was greater when CO_2 was introduced from the top surface than when CO_2 was introduced from the bottom surface.

6. The diffusion-convection model, when used to determine the average convective-pore velocity, was poor.

8. RECOMMENDATIONS

1. The CO_2 concentrations within the grain bulk should be monitored continuously to get a clearer picture of how the CO_2 moves through a grain bulk with time. Three possible options were investigated prior to construction of the test system and may merit further investigation if follow up studies are done. The first option was a solid state sensor used in pollution monitoring described by Maruyama (1991). This sensor was able to remotely monitor CO_2 concentrations on a continuous basis but it would be necessary to heat the sensor to a temperature of 500°C for it to work properly. Laser Doppler anemometry was another possible option which was abandoned due to financial and time limitations. An infra-red analyzer, equipped with an automatic sampler that would not affect the bulk flow of gas through the columns, may be another possible option. If any of the options could be used in the test system it would reduce the work load required for an experiment and result in fewer human errors during an experiment.

2. The movement of CO_2 caused by temperature differences within the grain bulk should be compared with the movement caused by forced airflow of similar magnitude with no temperature difference between the two columns of

grain. This would eliminate the possibility that something other than temperature gradients affected the flow of the CO_2.

3. The test system should be modified so that the moisture content of the grain bulk at various locations along the length of each column can be monitored. Experiments should be continued for a period longer than 6 h to determine the rate at which moisture migration takes place.

4. Longer time should be allowed to purge the CO_2 out of the grain bulk. This would require more time between experiments or purging with forced air may be necessary. Allowing this longer time between experiments would ensure that the initial CO_2 concentrations for all experiments would be the same. Although this should have had no effect on the results of the model it would be useful to verify that this was indeed the case.

5. More repetitions should be conducted for barley, lentils, and canola to ensure no errors were made in the single repetitions of grain types done during this study.

6. The minimization algorithm used in the computer model should be refined to avoid local minimum without the computer operator manually changing the increment.

7. More work should be done to improve the diffusion-convection model so that it will give a more accurate prediction of the average convective-pore velocity. It is likely that a more complex model, which uses the equations of momentum and energy (including a gravity term) should be solved.

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APPENDIX A - Converting CO_2 concentrations to densities for a given temperature and pressure

The measured CO_2 concentrations were converted to density by using the ideal gas law (Kotz and Purcell, 1987):

$$\rho = \frac{PM}{RT} \tag{1}$$

where: ρ = density of pure gas (g/L),

P = pressure (atm),

R = universal gas constant ($L \bullet atm \bullet {}^{\circ}K^{-1} \bullet mol^{-1}$),

= 0.082058, and

T = Temperature (K).

When the concentration of CO_2 was less then 100% the density was corrected as:

$$\rho[c] = \frac{\rho c}{100} \tag{2}$$

where: $\rho[c]$ = density of chemical species at concentration, c (kg/m^3),

ρ = density of pure chemical species, and

c = % concentration of chemical species in gas sample.

Combining Eqs. 1 and 2 and converting units of pressure and temperature to kPa and °C respectively, we get:

$$\rho[c] = \frac{0.4343 Pc}{8.2058(273.15+T)} \qquad (3)$$

where: P = pressure (kPa) and

T = temperature (°C).

APPENDIX B - Discretization of the general transport equation

The governing transport equation that describe unsteady, one-dimensional movement of a given chemical species through a porous media is as follows (Bear 1979, Fried and Combarnous 1971, Ebach and White 1958, Hensley and Schofield 1991):

$$\frac{\partial(\phi c)}{\partial t} + \frac{\partial(\phi c v_p)}{\partial y} = \frac{\partial}{\partial y}\left[\phi(\Gamma\frac{\partial c}{\partial y})\right] + S \qquad \textbf{(1)}$$

where: ϕ = porosity of the porous media (grain bulk),

c = CO_2 concentration in the pore volume (kg/m^3),

t = time (s),

v_p = average (laminar) velocity of fluid in the pore volume (m/s),

y = length in vertical direction (m),

Γ = no-flow coefficient of CO_2 through grain bulk (m^2/s), and

S = net rate of internal production of CO_2 mass per unit volume of pore fluid ($kg \bullet m^{-3} \bullet s^{-1}$).

The net rate of internal production of CO_2 is the gross rate of internal production of CO_2 minus the CO_2 transferred from fluid to solid phase (sorption-desorption effects). In this study, v_p is given the name convective-pore velocity.

Assuming n(y,t) as constant, Eq. 1 gives:

$$\phi \frac{\partial c}{\partial t} + \phi \frac{\partial (c v_p)}{\partial y} = \phi \frac{\partial}{\partial y} (\Gamma \frac{\partial c}{\partial y}) + S \tag{2}$$

Dividing Eq. 2 by the porosity

$$\frac{\partial c}{\partial t} + \frac{\partial (c v_p)}{\partial y} = \frac{\partial}{\partial y} (\Gamma \frac{\partial c}{\partial y}) + \frac{1}{\phi} S \tag{3}$$

The general transport equation can also be manipulated by using a spatial averaging theorem over the fluid phase (Whitaker 1967, Ruth and Suman 1992) to give the following form:

$$\frac{\partial [c]^f}{\partial t} + \frac{v_b}{\phi} \frac{\partial [c]^f}{\partial y} = \frac{\partial}{\partial y} (\Gamma \frac{\partial [c]^f}{\partial y}) + \frac{1}{\phi} S \tag{4}$$

where: $v_b = \phi [v]^f$, bulk velocity taken over the entire area of the control volume including solids (m/s).

$[v]^f$ = velocity averaged over the pore volume only ($v_p = [v]^f$) (m/s),

$[c]^f$ = average CO_2 concentration in the pore volume.

Since Eqs. 3 and 4 are essentially the same, Eq. 3 was used to model the flow of CO_2 through grain columns in the experiments.

Eq. 3 was discretized for a fully implicit time scheme using the nomenclature shown in Fig. B.

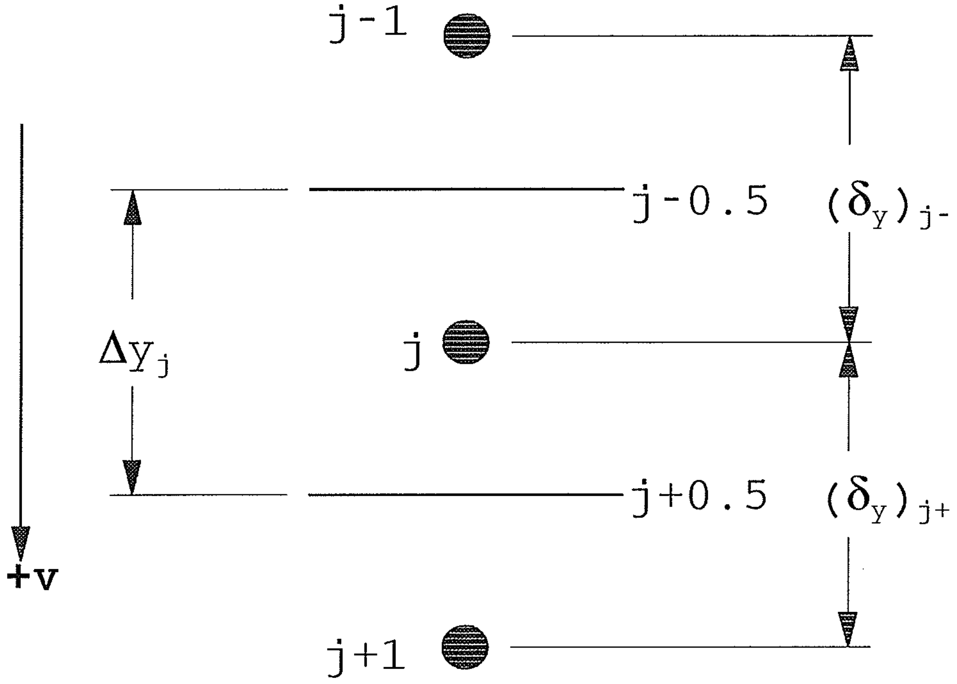


Figure B. Nomenclature for discretization of a one-dimensional control volume with unit area.

Before discretizing Eq. 3 the convection and diffusion terms were combined as the vector, J_y.

$$J_y = cv_p - \Gamma \frac{\partial c}{\partial y} \tag{5}$$

Substituting Eq. 5 into Eq. 3 we get:

$$\frac{\partial c}{\partial t} + \frac{\partial J_y}{\partial y} - \frac{1}{\phi}S = 0 \tag{6}$$

Integrating Eq. 6 over the grid volume Δy of unit area and a time step, Δt, where n represents the old time and n+1 represents the new time, gives:

$$\int_{j-0.5}^{j+0.5}\int_{n}^{n+1}\frac{\partial c}{\partial t}\,dt\,dy + \int_{n}^{n+1}\int_{j-0.5}^{j+0.5}\frac{\partial J_y}{\partial y}\,dy\,dt - \int_{n}^{n+1}\int_{j-0.5}^{j+0.5}\frac{1}{\phi}S\,dy\,dt = 0 \qquad (7)$$

The time dependant term in Eq. 7 becomes:

$$\int_{j-0.5}^{j+0.5}\int_{n}^{n+1}\frac{\partial c}{\partial t}\,dt\,dy = (c_j^{n+1} - c_j^{n})\Delta y \qquad (8)$$

The flux term in Eq. 7 becomes:

$$\int_{n}^{n+1}\int_{j-0.5}^{j+0.5}\frac{\partial J_y}{\partial y}\,dy\,dt = \left[(J_y)_{j+0.5}^{n+1} - (J_y)_{j-0.5}^{n+1}\right]\Delta t \qquad (9)$$

The source term in Eq. 7 becomes:

$$\int_{n}^{n+1}\int_{j-0.5}^{j+0.5}\frac{1}{\phi}S\,dy\,dt = \frac{1}{\phi}S_j^{n+1}\Delta y\Delta t \qquad (10)$$

Collecting terms from Eqs. 8, 9, and 10 into Eq. 7 gives:

$$(c_j^{n+1} - c_j^{n})\Delta y + \left[(J_y)_{j+0.5}^{n+1} - (J_y)_{j-0.5}^{n+1}\right]\Delta t - \frac{1}{\phi}S_j^{n+1}\Delta y\Delta t = 0 \qquad (11)$$

Dividing by Δt:

$$\frac{(c_j^{n+1} - c_j^n)\Delta y}{\Delta t} + (J_y)_{j+0.5}^{n+1} - (J_y)_{j-0.5}^{n+1} - \frac{1}{\phi} S_j^{n+1} \Delta y = 0 \tag{12}$$

Due to errors in the solution when the central difference and upwind schemes are used (Patankar 1980), the exponential scheme was used here which is exact for a one-dimensional case. For the following equation:

$$\frac{\partial J_y}{\partial y} = 0$$

where: Γ = constant and

for the domain $0 \leq y \leq L$ and the boundary conditions:

$c=c_o$ at $y=0$

$c=c_L$ at $y=L$

the exact solution is:

$$c = c_o + (c_L - c_o)\left[\frac{\exp(Pe\left(\frac{y}{L}\right)) - 1}{\exp(Pe) - 1}\right] \tag{13}$$

where Pe is the Peclet number defined by:

$$Pe = \frac{v_p L}{\Gamma}$$

and letting $v_p=F$, Eq. 5 may be written as:

$$J_y = Fc - \Gamma \frac{\partial c}{\partial y} \tag{14}$$

The Peclet number is actually the ratio of the convective flux, F, divided by the diffusive flux, D. The total flux in the y-direction could be written as:

$$J_y = Fc - Dc$$

Making the following assumptions:

- grid boundaries are located midway between the grid points, y/L=0.5
- $c_o=c_j$, $c_L=c_{j+1}$, and $L=(\delta_y)_{j+}$

Now, Eq. 13 and its derivative, with respect to y, can be substituted into Eq. 14 to give $(J_y)_{j+0.5}$ in Eq. 12 as:

$$\begin{aligned}(J_y)^{n+1}_{j+0.5} = F^{n+1}_{j+0.5}&\left[c^{n+1}_j + (c^{n+1}_{j+1} - c^{n+1}_j)\left[\frac{\exp(Pe^{n+1}_{j+0.5}(\frac{1}{2})) - 1}{\exp(Pe^{n+1}_{j+0.5}) - 1}\right]\right] \\ &- \Gamma^{n+1}_{j+0.5}\left[(c^{n+1}_{j+0.5} - c^{n+1}_j)\frac{Pe^{n+1}_{j+0.5}}{(\delta_y)_{j+}}\left[\frac{\exp(Pe^{n+1}_{j+0.5}(\frac{1}{2}))}{\exp(Pe^{n+1}_{j+0.5}) - 1}\right]\right]\end{aligned} \tag{15}$$

From the definition of the Peclet number:

$$\Gamma^{n+1}_{j+0.5} = \frac{v_{p\,j+0.5}^{\,n+1} L}{Pe^{n+1}_{j+0.5}} = \frac{F^{n+1}_{j+0.5}(\delta_y)_{j+}}{Pe^{n+1}_{j+0.5}}$$

Using this relationship in Eq. 15 we get:

$$(J_y)_{j+0.5}^{n+1} = F_{j+0.5}^{n+1} c_j^{n+1} + F_{j+0.5}^{n+1} (c_{j+1}^{n+1} - c_j^{n+1}) \left[\frac{\exp(Pe_{j+0.5}^{n+1}\left(\frac{1}{2}\right)) - 1}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right]$$

$$- F_{j+0.5}^{n+1} \left[(c_{j+0.5}^{n+1} - c_j^{n+1}) \left[\frac{\exp(Pe_{j+0.5}^{n+1}\left(\frac{1}{2}\right))}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right] \right]$$

Expanding this equation:

$$(J_y)_{j+0.5}^{n+1} = F_{j+0.5}^{n+1} c_j^{n+1} + F_{j+0.5}^{n+1} (c_{j+1}^{n+1} - c_j^{n+1}) \left[\frac{\exp(Pe_{j+0.5}^{n+1}\left(\frac{1}{2}\right))}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right]$$

$$- F_{j+0.5}^{n+1} (c_{j+0.5}^{n+1} - c_j^{n+1}) \left[\frac{1}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right]$$

$$- F_{j+0.5}^{n+1} \left[(c_{j+0.5}^{n+1} - c_j^{n+1}) \left[\frac{\exp(Pe_{j+0.5}^{n+1}\left(\frac{1}{2}\right))}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right] \right]$$

From this expansion we see that the second and fourth terms are equal and due to their signs, drop out of the equation. Thus, the resulting equation becomes:

$$(J_y)_{j+0.5}^{n+1} = F_{j+0.5}^{n+1} \left[c_j^{n+1} + \left[\frac{(c_j^{n+1} - c_{j+1}^{n+1})}{\exp(Pe_{j+0.5}^{n+1}) - 1} \right] \right] \qquad \textbf{(16)}$$

By analogy the $(J_y)_{j-0.5}$ term in Eq. 12 can be written as:

$$(J_y)_{j-0.5}^{n+1} = F_{j-0.5}^{n+1} \left[c_{j-1}^{n+1} + \left[\frac{(c_{j-1}^{n+1} - c_j^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1} \right] \right] \qquad \textbf{(17)}$$

Combining Eqs. 12, 16, and 17:

$$\frac{(c_j^{n+1} - c_j^{n})\Delta y}{\Delta t} + F_{j+0.5}^{n+1}\left[c_j^{n+1} + \left[\frac{(c_j^{n+1} - c_{j+1}^{n+1})}{\exp(Pe_{j+0.5}^{n+1}) - 1}\right]\right] - F_{j-0.5}^{n+1}\left[c_{j-1}^{n+1} + \left[\frac{(c_{j-1}^{n+1} - c_j^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1}\right]\right] = \frac{1}{\phi} S_j^{n+1}\Delta y \tag{18}$$

The concentration coefficients will be arranged into the standard form (Patankar 1980):

$$a_j^{n+1} c_j^{n+1} = a_{j+1}^{n+1} c_{j+1}^{n+1} + a_{j-1}^{n+1} c_{j-1}^{n+1} + b_j^{n+1} \tag{19}$$

Expanding equation 18 we get:

$$c_j^{n+1}\frac{\Delta y}{\Delta t} - c_j^{n}\frac{\Delta y}{\Delta t} + F_{j+0.5}^{n+1} c_j^{n+1} + F_{j+0.5}^{n+1}\left[\frac{(c_j^{n+1} - c_{j+1}^{n+1})}{\exp(Pe_{j+0.5}^{n+1}) - 1}\right] - F_{j-0.5}^{n+1} c_{j-1}^{n+1} - F_{j-0.5}^{n+1}\left[\frac{(c_{j-1}^{n+1} - c_j^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1}\right] = \frac{1}{\phi} S_j^{n+1}\Delta y \tag{20}$$

Expanding further by multiplying F into each exponential term and arranging the old, n, concentration on the right side of the equation:

$$c_j^{n+1}\frac{\Delta y}{\Delta t} + F_{j+0.5}^{n+1}c_j^{n+1} + \frac{F_{j+0.5}^{n+1}c_j^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1} - \frac{F_{j+0.5}^{n+1}c_{j+1}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1}$$

$$- F_{j-0.5}^{n+1}c_{j-1}^{n+1} - \frac{F_{j-0.5}^{n+1}c_{j-1}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1} + \frac{F_{j-0.5}^{n+1}c_j^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1}$$

$$= \frac{1}{\phi}S_j^{n+1}\Delta y + c_j^n\frac{\Delta y}{\Delta t}$$

Gathering coefficients in the form of Eq. 19 gives:

$$\left[\frac{\Delta y}{\Delta t} + F_{j+0.5}^{n+1} + \frac{F_{j+0.5}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1}\right]c_j^{n+1}$$

$$= \left[\frac{F_{j+0.5}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1}\right]c_{j+1}^{n+1} + \left[F_{j-0.5}^{n+1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1}\right]c_{j-1}^{n+1} \tag{21}$$

$$+ \frac{1}{\phi}S_j^{n+1}\Delta y + c_j^n\frac{\Delta y}{\Delta t}$$

Therefore the coefficients of Eq. 19 become:

$$a_j^{n+1} = \frac{\Delta y}{\Delta t} + F_{j+0.5}^{n+1} + \frac{F_{j+0.5}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1} \tag{22}$$

$$a_{j+1}^{n+1} = \frac{F_{j+0.5}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1} \tag{23}$$

$$a_{j-1}^{n+1} = F_{j-0.5}^{n+1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1} \tag{24}$$

$$b_j^{n+1} = \frac{1}{\phi} S_j^{n+1} \Delta y + c_j^n \frac{\Delta y}{\Delta t} \tag{25}$$

Simplifying Eq. 22:

$$a_j^{n+1} = \frac{\Delta y}{\Delta t} + a_{j+1}^{n+1} + F_{j+0.5}^{n+1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1} + F_{j-0.5}^{n+1} - F_{j-0.5}^{n+1}$$

$$a_j^{n+1} = a_{j+1}^{n+1} + a_{j-1}^{n+1} + F_{j+0.5}^{n+1} - F_{j-0.5}^{n+1} + \frac{\Delta y}{\Delta t} \tag{26}$$

Simplifying Eq. 24:

$$a_{j-1}^{n+1} = \frac{F_{j-0.5}^{n+1}(\exp(Pe_{j-0.5}^{n+1}) - 1)}{\exp(Pe_{j-0.5}^{n+1}) - 1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1}$$

$$a_{j-1}^{n+1} = \frac{F_{j-0.5}^{n+1}\exp(Pe_{j-0.5}^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1} - \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1} + \frac{F_{j-0.5}^{n+1}}{\exp(Pe_{j-0.5}^{n+1}) - 1}$$

$$a_{j-1}^{n+1} = \frac{F_{j-0.5}^{n+1}\exp(Pe_{j-0.5}^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1} \tag{27}$$

Therefore, the discretized equations for one-dimensional implicit simulation are:

$$a_j^{n+1} c_j^{n+1} = a_{j+1}^{n+1} c_{j+1}^{n+1} + a_{j-1}^{n+1} c_{j-1}^{n+1} + b_j^{n+1} \tag{19}$$

$$a_j^{n+1} = a_{j+1}^{n+1} + a_{j-1}^{n+1} + F_{j+0.5}^{n+1} - F_{j-0.5}^{n+1} + \frac{\Delta y}{\Delta t} \tag{26}$$

$$a_{j+1}^{n+1} = \frac{F_{j+0.5}^{n+1}}{\exp(Pe_{j+0.5}^{n+1}) - 1} \tag{23}$$

$$a_{j-1}^{n+1} = \frac{F_{j-0.5}^{n+1} \exp(Pe_{j-0.5}^{n+1})}{\exp(Pe_{j-0.5}^{n+1}) - 1} \tag{27}$$

$$b_j^{n+1} = \frac{1}{\phi} S_j^{n+1} \Delta y + c_j^n \frac{\Delta y}{\Delta t} \tag{25}$$

where:

$$F_{j+0.5}^{n+1} = v_{p_{j+0.5}}^{n+1} \qquad F_{j-0.5}^{n+1} = v_{p_{j-0.5}}^{n+1} \tag{28}$$

$$Pe_{j+0.5}^{n+1} = \frac{F_{j+0.5}^{n+1} (\delta_y)_{j+}}{\Gamma_{j+0.5}^{n+1}} \qquad Pe_{j-0.5}^{n+1} = \frac{F_{j-0.5}^{n+1} (\delta_y)_{j-}}{\Gamma_{j-0.5}^{n+1}} \tag{29}$$

The following assumptions were applied to a given control volume:

(i) The no-flow coefficient is constant.

$$\Gamma_{j+0.5}^{n+1} = \Gamma_{j-0.5}^{n+1} = \Gamma^{n+1}$$

(ii) For bulk flow tests the average convective-pore velocity is constant over the control volume.

$$F_{j+0.5}^{n+1} = F_{j-0.5}^{n+1} = F^{n+1}$$

(iii) There is no generation of CO_2 and no sorption-desorption of CO_2.

$$S_j^{n+1} = 0$$

APPENDIX C - Output results from the diffusion-convection model

The average-absolute difference between experimental and predicted CO_2 concentrations was used as the criteria for minimization in the diffusion-convection model. The average percent difference was not used since it was found that for certain simulations, where the average-absolute difference was minimum, the average percent difference was not minimum. Tables C.1-C.4 give the average-absolute difference between predicted and measured CO_2 concentrations.

The no-flow coefficients and convective-pore velocities for the gas sampling locations (Fig. 5 or D) and for all repetitions are given in Tables C.5-C.8. These values were averaged together and reported in Chapter 6.

Table C.1. Average-absolute difference for calculating the no-flow coefficient when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	Average-absolute Difference (kg/m^3)		
		Minimization At Sampling Location		
		L3	L4	L5
Wheat Rep. #1 ϕ=0.43	20	0.0609	0.0655	0.0637
	40	0.0308	0.0278	0.0207
	56	0.0564	0.0354	0.0283
Wheat Rep. #2 ϕ=0.43	20	0.0773	0.0470	0.0350
	40	0.0378	0.0558	0.0856
	56	0.0777	0.0584	0.0348
Wheat Rep. #3 ϕ=0.43	20	0.0432	0.0659	0.0553
	40	0.0628	0.0693	0.0737
	56	0.0556	0.0467	0.0713
Barley ϕ=0.51	20	0.0716	0.0549	0.0856
	40	0.0349	0.0489	0.1112
	56	0.0627	0.0533	0.0916
Lentils ϕ=0.40	20	0.0444	0.0448	0.0580
	40	0.0464	0.0745	0.0659
	56	0.0690	0.0992	0.0825
Canola ϕ=0.38	20	0.1442	0.1399	0.1077
	40	0.1905	0.1572	0.0952
	56	0.2188	0.1850	0.1187

ϕ = porosity of the grain bulk
Rep. = repetition

Table C.2. Average-absolute difference for calculating the no-flow coefficient when the CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	Average-absolute Difference (kg/m^3)		
		Minimization At Sampling Location		
		R5	R4	R3
Wheat Rep. #1 $\phi=0.43$	20	0.0323	0.0021	0.0020
	40	0.0102	0.0089	0.0037
	56	0.0972	0.0613	0.0401
Wheat Rep. #2 $\phi=0.43$	20	0.0293	0.0031	0.0002
	40	0.0241	0.0050	0.0013
	56	0.0126	0.0068	0.0099
Wheat Rep. #3 $\phi=0.43$	20	0.0228	0.0024	0.0001
	40	0.0194	0.0041	0.0013
	56	0.0091	0.0047	0.0158
Barley $\phi=0.51$	20	0.0190	0.0030	0.0003
	40	0.0157	0.0045	0.0046
	56	0.0190	0.0600	0.0044
Lentils $\phi=0.40$	20	0.0314	0.0038	0.0004
	40	0.0283	0.0048	0.0007
	56	0.0097	0.0057	0.0022
Canola $\phi=0.38$	20	0.0415	0.0119	0.0019
	40	0.0323	0.0111	0.0063
	56	0.0248	0.0108	0.0069

ϕ = porosity of the grain bulk
Rep. = repetition

Table C.3. Average-absolute difference for calculating the convective-pore velocity when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	Average-absolute Difference (kg/m^3) Minimization At Sampling Location L3	L4	L5
Wheat Rep. #1 ϕ=0.43	20	0.0562	0.0633	0.0513
	40	0.0732	0.0790	0.0667
	56	†0.0920	0.1101	0.1063
Wheat Rep. #2 ϕ=0.43	20	†0.1219	0.0798	0.0612
	40	†0.0922	0.0623	0.0470
	56	0.0630	0.1257	0.1596
Wheat Rep. #3 ϕ=0.43	20	0.0710	0.0521	0.0423
	40	0.2255	0.2225	0.2259
	56	0.0660	0.0839	0.1185
Barley ϕ=0.51	20	0.0714	0.0674	0.0453
	40	0.1110	0.1127	0.0978
	56	0.1243	0.1077	0.0832
Lentils ϕ=0.40	20	0.0953	0.0991	0.1115
	40	0.1114	0.1298	0.1165
	56	0.1486	0.2045	0.1486
Canola ϕ=0.38	20	0.1423	0.0956	0.0816
	40	0.0932	0.1566	0.1198
	56	0.0859	0.1341	0.0965

ϕ = porosity of the grain bulk
Rep. = repetition

† The minimization algorithm was unable to find a minimum average-absolute difference in the range of 0.0 to 0.1 m/s for the convective-pore velocity. The velocity corresponding to this value was not used to calculate the average and standard deviation reported in Table 2.

Table C.4. Average-absolute difference for calculating the convective-pore velocity when CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	Average-absolute Difference (kg/m^3)		
		Minimization At Sampling Location		
		R5	R4	R3
Wheat Rep. #1 ϕ=0.43	20	0.1024	0.0213	0.0037
	40	0.0778	0.0301	0.0199
	56	0.0818	0.0772	0.0685
Wheat Rep. #2 ϕ=0.43	20	0.1290	0.0349	0.0092
	40	0.0723	0.1024	0.0515
	56	0.0741	0.0506	0.0433
Wheat Rep. #3 ϕ=0.43	20	0.1065	0.0230	0.0047
	40	0.0467	0.1304	0.0586
	56	0.0529	0.0635	0.0450
Barley ϕ=0.51	20	0.1350	0.0364	0.0081
	40	0.0557	0.1070	0.0530
	56	0.0873	0.1075	0.1189
Lentils ϕ=0.40	20	0.1419	0.0313	0.0074
	40	0.1759	0.1625	0.0615
	56	0.0411	0.0610	0.0702
Canola ϕ=0.38	20	0.0801	0.0248	0.0074
	40	✣0.2090	✣0.3515	✣0.3872
	56	0.0959	0.1269	0.0839

ϕ = porosity of the grain bulk
Rep. = repetition

✣ The minimization algorithm was unable to find a minimum average-absolute difference in the range of 0.0 to 0.1 m/s for the convective-pore velocity.

Table C.5. No-flow coefficient based on each gas sampling location when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	No-Flow Coefficient (m^2/s) ($\times 10^4$) Minimization At Sampling Location L3	L4	L5
Wheat Rep. #1 ϕ=0.43	20	1.66	1.81	1.30
	40	1.62	1.09	0.72
	56	1.78	1.95	1.57
Wheat Rep. #2 ϕ=0.43	20	1.02	2.09	1.69
	40	2.00	3.02	4.04
	56	1.88	1.85	2.27
Wheat Rep. #3 ϕ=0.43	20	2.02	3.28	2.63
	40	2.53	3.49	3.94
	56	2.91	4.24	3.13
Barley ϕ=0.51	20	2.67	2.08	2.20
	40	1.13	1.41	1.37
	56	2.07	2.62	4.10
Lentils ϕ=0.40	20	2.60	3.02	2.26
	40	2.87	2.71	3.39
	56	2.93	3.15	3.37
Canola ϕ=0.38	20	0.34	0.51	0.37
	40	0.63	0.75	0.59
	56	0.60	0.99	0.68

ϕ = porosity of the grain bulk
Rep. = Repetition

Table C.6. No-flow coefficient based on each gas sampling location when CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	No-flow Coefficient (m^2/s) ($\times 10^5$) Minimization At Sampling Location R5	R4	R3
Wheat Rep. #1 ϕ=0.43	20	0.66	0.57	0.66
	40	2.13	1.46	1.39
	56	20.80	9.95	7.00
Wheat Rep. #2 ϕ=0.43	20	0.69	0.66	0.61
	40	0.79	0.82	0.87
	56	1.00	1.00	1.20
Wheat Rep. #3 ϕ=0.43	20	0.76	0.72	0.70
	40	0.84	0.85	0.87
	56	1.15	1.30	1.45
Barley ϕ=0.51	20	0.74	0.74	0.71
	40	0.92	0.89	0.91
	56	1.20	1.36	1.37
Lentils ϕ=0.40	20	0.70	0.61	0.55
	40	0.93	0.87	0.87
	56	1.68	1.68	1.61
Canola ϕ=0.38	20	0.66	0.74	0.82
	40	1.01	0.97	1.13
	56	1.27	1.29	1.41

ϕ = porosity of the grain bulk
Rep. = Repetition

Table C.7. Convective-pore velocity based on each gas sampling location when CO_2 was introduced from the top gas chamber.

Crop Type	Temperature Difference (°C)	Convective-Pore Velocity (m/s) ($\times10^3$)		
		Minimization At Sampling Location		
		L3	L4	L5
Wheat Rep. #1 ϕ=0.43	20	0.09	0.69	0.85
	40	4.44	2.51	2.15
	56	†0.63	1.06	1.37
Wheat Rep. #2 ϕ=0.43	20	†0.40	1.33	1.20
	40	†8.43	3.26	1.42
	56	4.94	0.99	1.35
Wheat Rep. #3 ϕ=0.43	20	0.72	1.09	1.06
	40	2.81	1.56	1.23
	56	3.09	1.97	1.38
Barley ϕ=0.51	20	1.14	1.10	1.75
	40	1.44	1.24	1.83
	56	0.92	1.25	1.93
Lentils ϕ=0.40	20	0.47	0.96	1.04
	40	0.63	0.91	1.45
	56	0.62	1.11	1.63
Canola ϕ=0.38	20	0.24	0.35	0.31
	40	0.47	0.37	0.58
	56	0.35	0.43	0.65

ϕ = porosity of the grain bulk
Rep. = Repetition

† The minimization algorithm was unable to locate a minimum average-absolute difference in the range of 0.0 to 0.1 m/s for the convective-pore velocity. These values were not included when calculating the average and standard deviation reported in Table 2.

Table C.8. Convective-pore velocity based on each gas sampling location when CO_2 was introduced from the bottom gas chamber.

Crop Type	Temperature Difference (°C)	Convective-pore Velocity (m/s) ($\times 10^5$)		
		Minimization At Sampling Location		
		R5	R4	R3
Wheat Rep. #1 ϕ=0.43	20	1.40	1.31	1.40
	40	35.67	9.26	6.24
	56	53.45	35.15	34.55
Wheat Rep. #2 ϕ=0.51	20	1.27	1.69	1.80
	40	61.20	6.60	6.00
	56	138.00	77.52	34.20
Wheat Rep. #3 ϕ=0.43	20	2.21	2.24	1.79
	40	62.97	9.87	6.28
	56	170.50	84.90	47.20
Barley ϕ=0.51	20	2.24	1.63	1.68
	40	68.90	29.90	6.40
	56	91.43	85.78	55.93
Lentils ϕ=0.40	20	1.01	1.38	1.29
	40	54.00	4.00	4.40
	56	81.55	65.65	37.20
Canola ϕ=0.38	20	0.47	0.34	0.48
	40	✥0.95	✥0.94	✥0.93
	56	23.00	6.60	6.10

ϕ = porosity of the grain bulk
Rep. = Repetition

✥ The minimization algorithm was unable to locate a minimum average-absolute difference in the range of 0.0 to 0.1 m/s for the average convective-pore velocity.

APPENDIX D - Experimental Data

The following pages contain experimental concentrations of CO_2 in the grain bulk that have been converted to density (mass concentration) for experimental temperatures and atmospheric pressures (Appendix A). The temperatures in the centre of each grain column are indicated by graphical means. Gas sampling and thermocouple locations are shown in Fig. D.

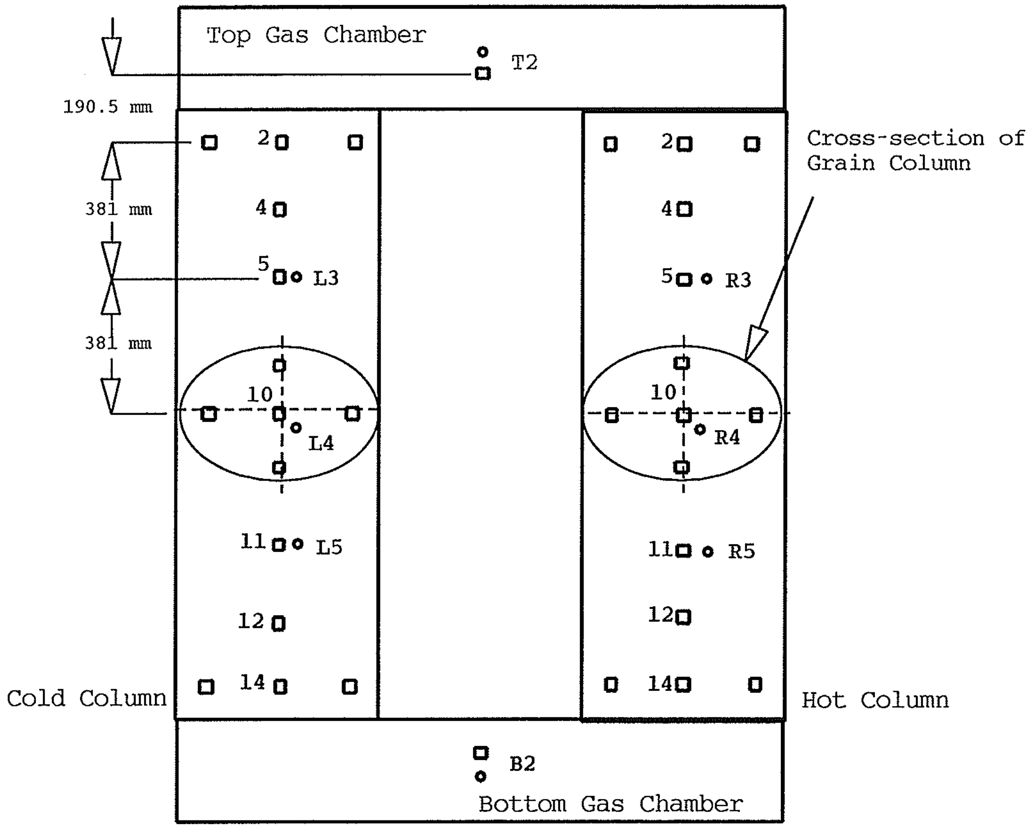
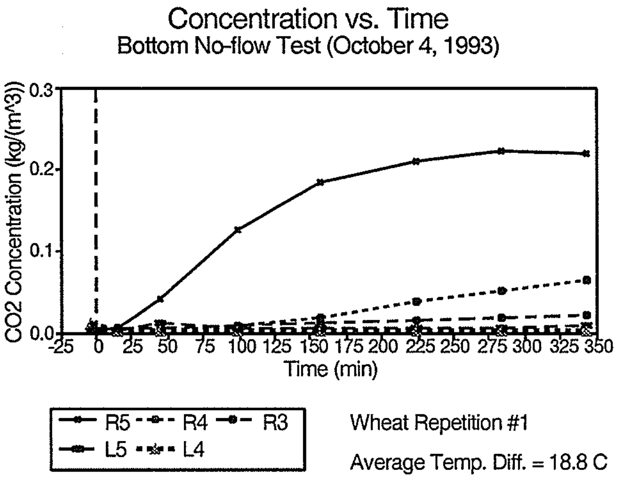


Figure D. Thermocouple and gas sampling locations. Thermocouple locations not numbered were not used to calculate the temperature difference between grain columns. Note the symmetry of dimensions and that the drawing is not to scale.

○ Gas sampling locations (points) (Numbers preceded by letters)
☐ Thermocouple locations (Numbers only)

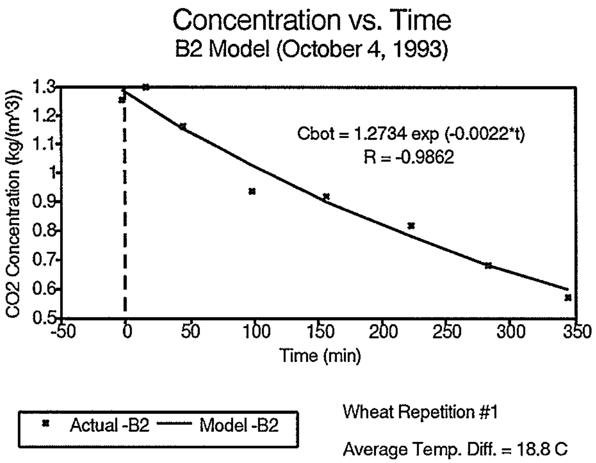
October 4, 1993
Bottom No-flow Test
Temperature Difference = 18.8 C
Wheat Repetition #1

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		L3		
Temperature (C)		30.48		30.48		30.48		20.00			11.69		11.69		11.69		
Time	Pressure								Actual	Model							
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-4	98.95	0.07	0.0012	0.12	0.0020	0.27	0.0046	70.19	1.2538	1.2847	0.12	0.0022	0.58	0.0106	0.11	0.0020	
15	98.98	0.31	0.0054	0.12	0.0020	0.26	0.0045	72.40	1.2938	1.2321	0.17	0.0030	0.15	0.0027	0.13	0.0024	
45	99.01	2.39	0.0412	0.14	0.0025	0.30	0.0052	64.98	1.1615	1.1534	0.55	0.0102	0.14	0.0026	0.12	0.0022	
98	99.02	7.24	0.1250	0.41	0.0071	0.40	0.0069	52.41	0.9369	1.0264	0.25	0.0047	0.15	0.0027	0.10	0.0018	
157	99.02	10.61	0.1831	1.03	0.0177	0.55	0.0095	51.14	0.9142	0.9015	0.18	0.0033	0.13	0.0023	0.07	0.0013	
224	99.01	12.21	0.2107	2.10	0.0362	0.78	0.0135	45.93	0.8210	0.7779	0.19	0.0036	0.09	0.0017	0.07	0.0012	
284	98.99	12.81	0.2211	2.88	0.0497	0.98	0.0170	38.28	0.6841	0.6817	0.19	0.0035	0.07	0.0013	0.08	0.0015	
344	98.99	12.80	0.2208	3.66	0.0631	1.22	0.0211	31.90	0.5701	0.5974	0.39	0.0072	0.08	0.0015	0.08	0.0015	



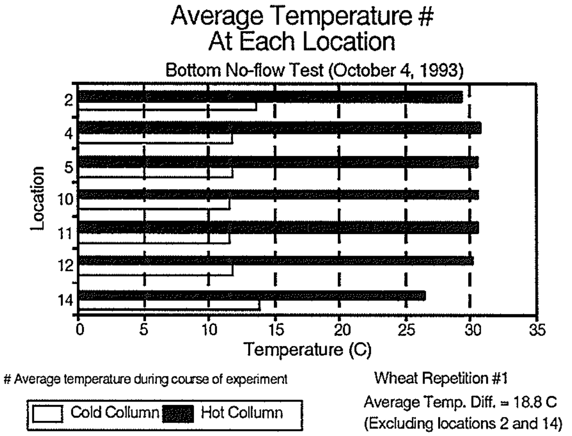
Wheat Repetition #1

Average Temp. Diff. = 18.8 C



Wheat Repetition #1

Average Temp. Diff. = 18.8 C



Average temperature during course of experiment

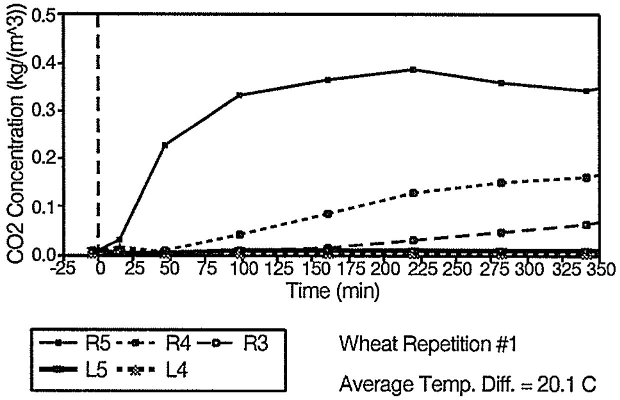
Wheat Repetition #1
Average Temp. Diff. = 18.8 C
(Excluding locations 2 and 14)

October 5, 1993
Bottom Bulk Flow Test
Temperature Difference = 20.1 C
Wheat Repetition #1

** Note: Blank entries in the table represent missing data.

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		31.11		31.11		31.11		20.00			11.04		11.04		11.04	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.88	0.19	0.0033	0.25	0.0043	0.41	0.0070			1.1746	0.58	0.0107	0.29	0.0053	0.19	0.0036
16	98.87	1.79	0.0308	0.25	0.0042	0.34	0.0059	69.26	1.2363	1.1240	0.21	0.0039	0.73	0.0135	0.20	0.0037
46	98.82	13.33	0.2292	0.47	0.0081	0.33	0.0056	56.85	1.0143	1.0522	0.26	0.0047	0.22	0.0040	0.19	0.0035
98	98.74	19.15	0.3290	2.56	0.0440	0.53	0.0091	52.16	0.9298	0.9385	0.67	0.0123	0.22	0.0040	0.19	0.0034
161	98.73	21.24	0.3648	4.98	0.0854	0.99	0.0170	41.16	0.7336	0.8170	0.51	0.0093	0.24	0.0043	0.20	0.0037
221	98.66	22.49	0.3860	7.47	0.1282	1.91	0.0328	41.43	0.7380	0.7160	0.46	0.0084	0.24	0.0044	0.22	0.0040
281	98.52	21.00	0.3599	8.69	0.1489	2.90	0.0496	34.63	0.6160	0.6275	0.46	0.0083	0.22	0.0040	0.22	0.0040
341	98.38	19.95	0.3414	9.57	0.1638	3.70	0.0634	31.10	0.5523	0.5499	0.46	0.0084	0.22	0.0041	0.23	0.0042
401	98.31	21.64	0.3701	10.76	0.1840	4.95	0.0846	27.94	0.4960	0.4819	0.43	0.0078	0.25	0.0046	0.25	0.0046

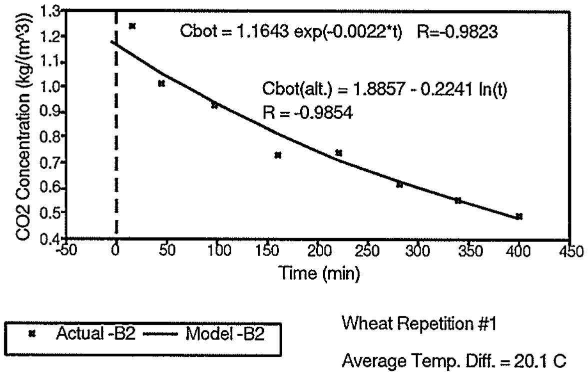
Concentration vs. Time
Bottom Bulk Flow Test (October 5, 1993)



Wheat Repetition #1

Average Temp. Diff. = 20.1 C

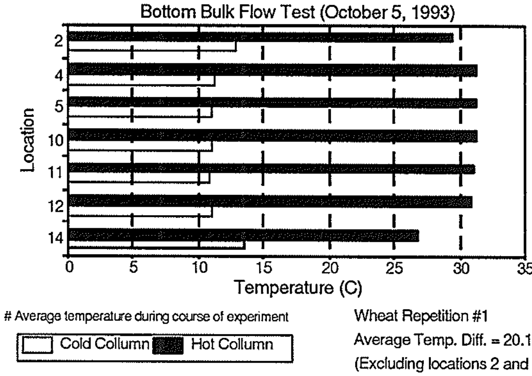
Concentration vs. Time
B2 Model (October 5, 1993)



Wheat Repetition #1

Average Temp. Diff. = 20.1 C

Average Temperature #
At Each Location

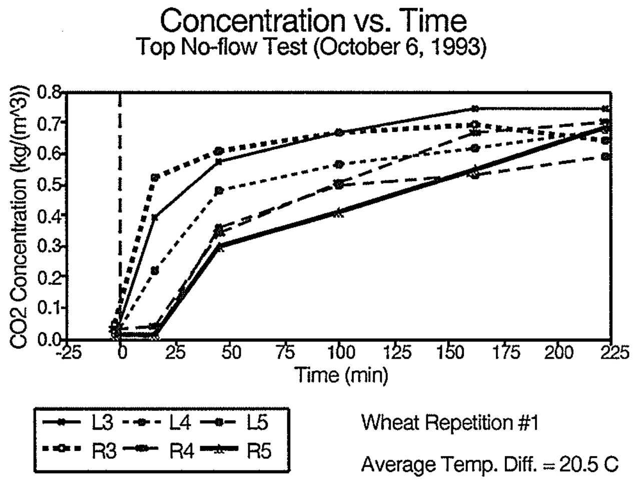


Average temperature during course of experiment

Wheat Repetition #1
Average Temp. Diff. = 20.1 C
(Excluding locations 2 and 14)

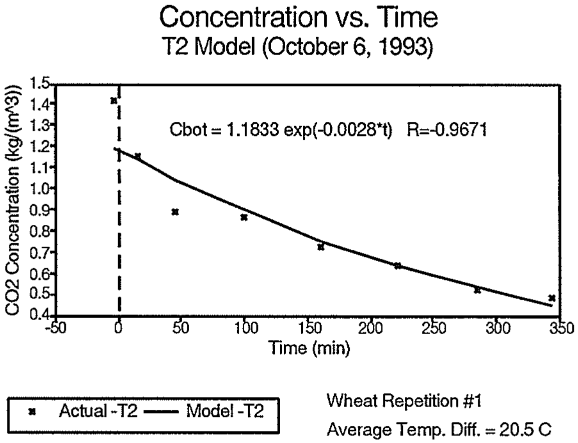
October 6, 1993
Top No-flow Test
Temperature Difference = 20.5 C
Wheat Repetition #1

		Concentration of CO2														
Location		L3		L4		L5		T2			R5		R4		R3	
Temperature (C)		10.78		10.78		10.78		20.00			31.22		31.22		31.22	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	97.67	0.21	0.0039	0.18	0.0032	0.62	0.0113	80.21	1.4144	1.1933	1.05	0.0179	1.99	0.0339	3.12	0.0529
15	97.68	21.54	0.3923	12.11	0.2206	0.58	0.0106	65.46	1.1544	1.1346	1.16	0.0197	2.26	0.0383	30.57	0.5192
45	98.71	31.00	0.5704	26.10	0.4803	19.47	0.3582	50.13	0.8935	1.0432	17.54	0.3010	19.66	0.3374	35.32	0.6063
100	97.74	36.78	0.6701	30.98	0.5644	27.10	0.4938	48.96	0.8639	0.8943	23.87	0.4058	29.91	0.5083	39.49	0.6711
162	97.82	40.81	0.7441	33.68	0.6142	29.11	0.5309	40.88	0.7219	0.7518	32.40	0.5511	39.58	0.6733	41.02	0.6977
222	97.88	40.74	0.7433	36.92	0.6737	32.32	0.5897	35.84	0.6333	0.6355	40.51	0.6894	41.29	0.7028	37.78	0.6430
285	97.97	35.91	0.6558	37.83	0.6909	28.53	0.5209	29.24	0.5172	0.5328	39.90	0.6798	38.77	0.6604	34.53	0.5882
345	98.05	34.63	0.6330	38.77	0.7087	34.41	0.6288	27.53	0.4873	0.4504	38.55	0.6572	35.11	0.5986	31.43	0.5358


Concentration vs. Time
Top No-flow Test (October 6, 1993)

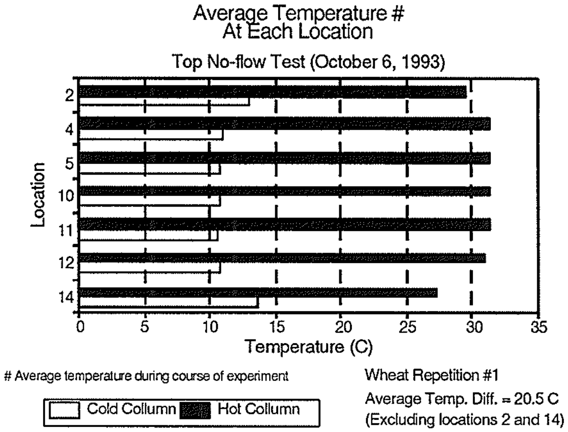
Wheat Repetition #1

Average Temp. Diff. = 20.5 C


Concentration vs. Time
T2 Model (October 6, 1993)

Wheat Repetition #1

Average Temp. Diff. = 20.5 C

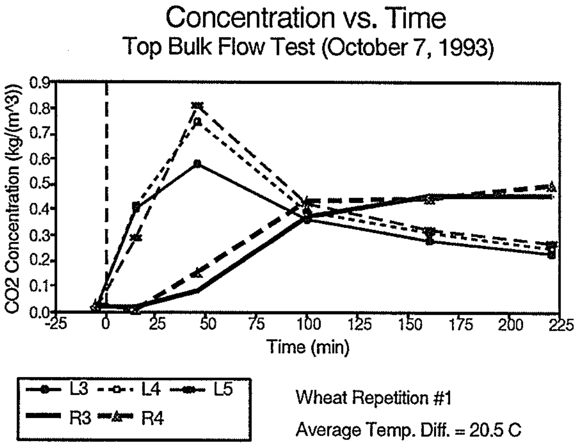

Average Temperature #
At Each Location
Top No-flow Test (October 6, 1993)

Average temperature during course of experiment

Wheat Repetition #1
Average Temp. Diff. = 20.5 C
(Excluding locations 2 and 14)

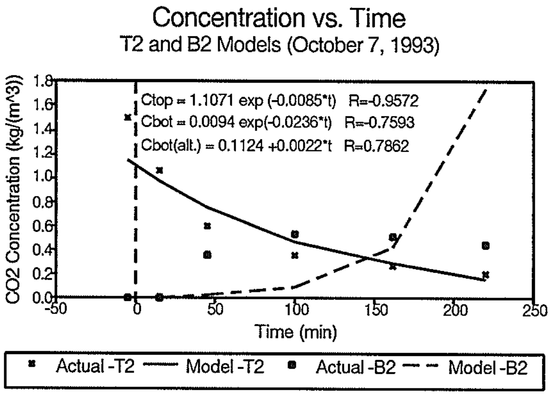
October 7, 1993
Top Bulk Flow Test
Temperature Difference = 20.5 C
Wheat Repetition #1

		Concentration of CO2															
Location		L3		L4		L5		T2			B2			R3		R4	
Temperature (C)		31.27		31.27		31.27		19.00			19.00			10.81		10.81	
Time	Pressure								Actual	Model		Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	99.79	0.58	0.0100	0.53	0.0092	0.59	0.0102	83.10	1.5022	1.1552	0.09	0.0016	0.0084	1.04	0.0193	1.40	0.0260
15	99.79	23.07	0.4002	23.95	0.4156	16.74	0.2904	58.72	1.0615	0.9746	0.19	0.0033	0.0134	0.95	0.0177	0.43	0.0080
45	99.81	33.39	0.5793	43.37	0.7526	46.69	0.8101	33.37	0.6033	0.7552	19.47	0.3521	0.0272	4.26	0.0792	8.13	0.1512
100	99.84	20.64	0.3583	22.41	0.3890	24.42	0.4238	20.06	0.3628	0.4732	29.13	0.5268	0.0996	20.13	0.3746	23.33	0.4341
161	99.84	15.89	0.2759	17.71	0.3073	18.27	0.3172	14.63	0.2646	0.2817	27.78	0.5025	0.4200	24.44	0.4548	24.19	0.4502
221	99.82	12.90	0.2238	14.46	0.2509	15.27	0.2650	11.78	0.2131	0.1692	24.68	0.4463	1.7307	24.41	0.4541	26.48	0.4926

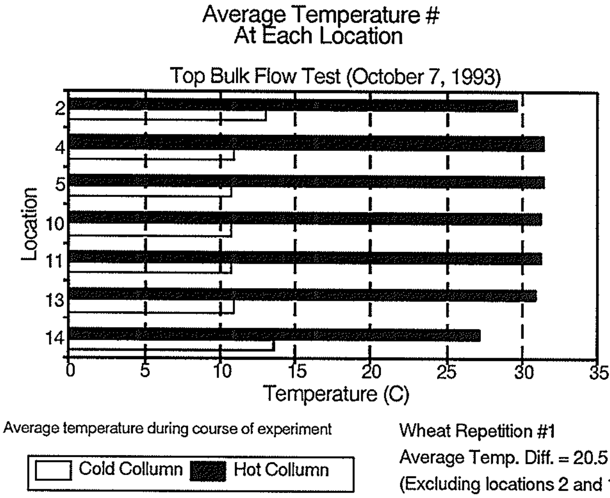


Wheat Repetition #1

Average Temp. Diff. = 20.5 C



Wheat Repetition #1 Average Temp. Diff. = 20.5 C



Average temperature during course of experiment

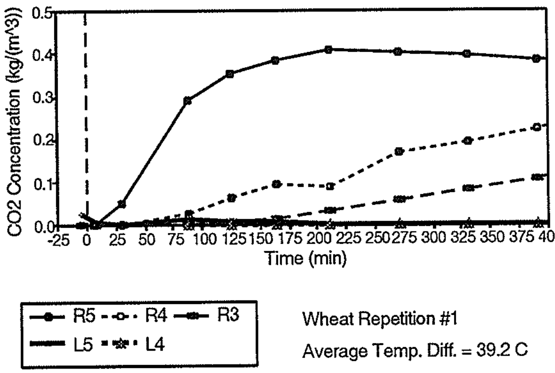
Wheat Repetition #1
Average Temp. Diff. = 20.5 C
(Excluding locations 2 and 14)

August 24, 1993
Bottom No-flow Test
Temperature Difference = 39.2 C
Wheat Repetition #1

** Note: Blank entries in the table represents missing data.

		Concentration of CO2													
Location		R5		R4		R3		B2			L5		L4	
Temperature (C)		43.11		43.11		43.11		26.00			3.88		3.88	
									Actual	Model				
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	97.45	0.01	0.0002	0.02	0.0003	0.03	0.0005	70.33	1.2126	1.2065	1.43	0.0266		
7	97.46	0.01	0.0002	0.02	0.0003	0.03	0.0005	67.85	1.1699	1.1666	0.37	0.0069		
30	97.47	3.21	0.0524	0.02	0.0003	0.03	0.0005	62.55	1.0786	1.0938	0.22	0.0041		
89	97.49	17.88	0.2917	1.47	0.0240	0.11	0.0018	53.54	0.9235	0.9273	0.69	0.0129	0.03	0.0006
125	97.52	21.78	0.3554	4.00	0.0653	0.32	0.0052	46.51	0.8025	0.8384	0.53	0.0099	0.02	0.0004
164	97.55	23.65	0.3861	5.89	0.0962	0.93	0.0152	44.77	0.7727	0.7516	0.35	0.0065	0.01	0.0002
210	97.57	24.86	0.4059	5.30	0.0865	1.95	0.0318	38.36	0.6622	0.6608	0.11	0.0021	0.01	0.0002
270	97.62	24.61	0.4020	10.37	0.1694	3.48	0.0569	33.58	0.5800	0.5586	0.10	0.0019	0.01	0.0002
330	97.69	24.09	0.3938	11.90	0.1945	5.04	0.0824	27.12	0.4687	0.4722	0.10	0.0019	0.01	0.0002
390	97.73	23.67	0.3871	13.79	0.2255	6.34	0.1037	25.08	0.4336	0.3992	0.03	0.0006	0.01	0.0002
440	97.73	22.95	0.3753	14.11	0.2308	7.73	0.1264	18.41	0.3183	0.3470	0.03	0.0006	0.01	0.0002

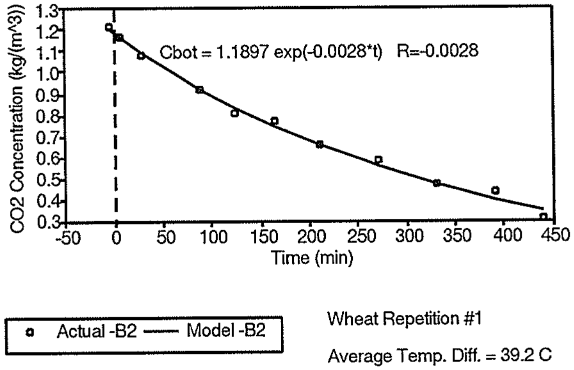
Concentration vs. Time
Bottom No-flow Test (August 24, 1993)



Wheat Repetition #1

Average Temp. Diff. = 39.2 C

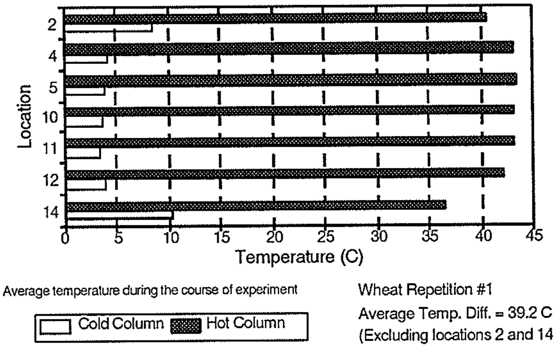
Concentration vs. Time
B2-Model (August 24,1993)



Wheat Repetition #1

Average Temp. Diff. = 39.2 C

Average Temperature #
At Each Location
Bottom No-flow Test (August 24, 1993)



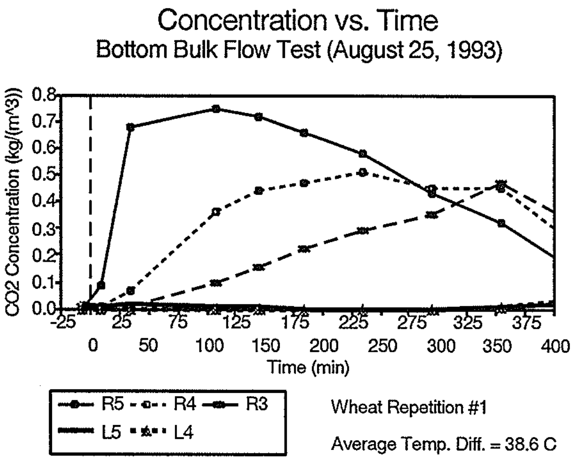
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 39.2 C
(Excluding locations 2 and 14)

August 25, 1993
Bottom Bulk Flow Test
Temperature Difference = 38.6 C
Wheat Repetition #1

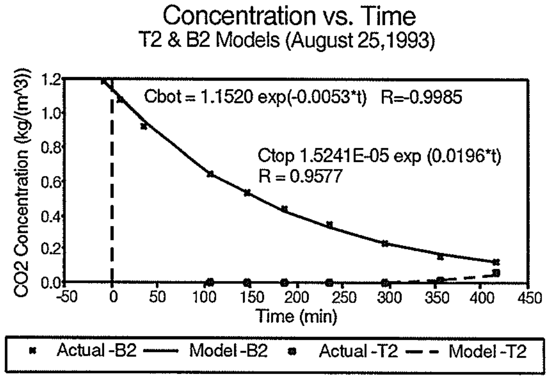
** Note: Empty spaces in the table are due to missing data

	Location	R5		R4		R3		B2			L5		L4		T2		
	Temperature (C)	42.61		42.61		42.61		24.00			4.02		4.02		26.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-7	98.46	0.04	0.0007	0.16	0.0026	0.37	0.0061	68.21	1.1962	1.1955	0.82	0.0154	0.02	0.0004			
10	98.47	4.95	0.0817	0.16	0.0026	0.03	0.0005	61.92	1.0860	1.0925	0.56	0.0105	0.02	0.0004			
35	98.48	41.11	0.6786	4.21	0.0695	0.29	0.0048	52.89	0.9277	0.9570	0.72	0.0135	0.02	0.0004			
108	98.59	45.22	0.7473	21.94	0.3626	6.10	0.1008	36.33	0.6380	0.6499	0.42	0.0079	0.02	0.0004	0.02	0.0003	0.0001
145	98.61	43.36	0.7167	26.47	0.4375	9.73	0.1608	30.96	0.5438	0.5342	0.23	0.0043	0.02	0.0004	0.02	0.0003	0.0003
185	98.64	39.82	0.6584	28.23	0.4667	13.36	0.2209	25.51	0.4482	0.4321	0.12	0.0023	0.02	0.0004	0.02	0.0003	0.0006
235	98.70	34.87	0.5769	31.07	0.5140	17.54	0.2902	19.38	0.3407	0.3315	0.10	0.0019	0.02	0.0004	0.03	0.0005	0.0015
295	98.68	25.82	0.4271	27.45	0.4540	21.58	0.3569	13.80	0.2426	0.2412	0.09	0.0017	0.04	0.0008	0.37	0.0065	0.0049
355	98.68	19.26	0.3186	27.40	0.4532	28.35	0.4689	8.91	0.1566	0.1755	0.36	0.0068	0.42	0.0079	1.23	0.0215	0.0160
415	98.62	9.61	0.1589	15.43	0.2551	20.27	0.3351	7.43	0.1305	0.1277	1.32	0.0249	1.79	0.0337	3.71	0.0647	0.0519

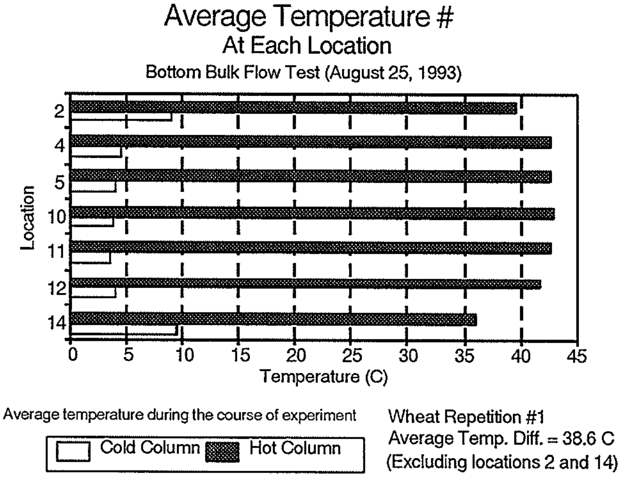


Wheat Repetition #1

Average Temp. Diff. = 38.6 C



Wheat Repetition #1 Average Temp. Diff. = 38.6 C



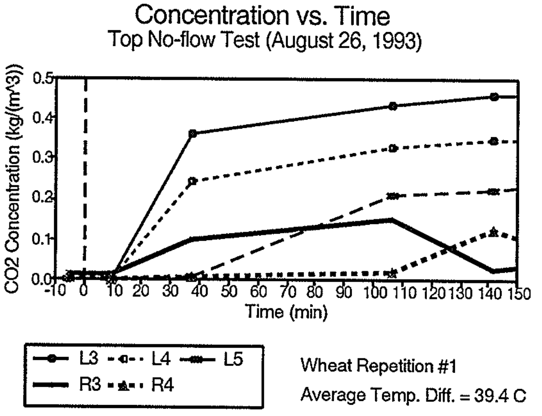
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 38.6 C
(Excluding locations 2 and 14)

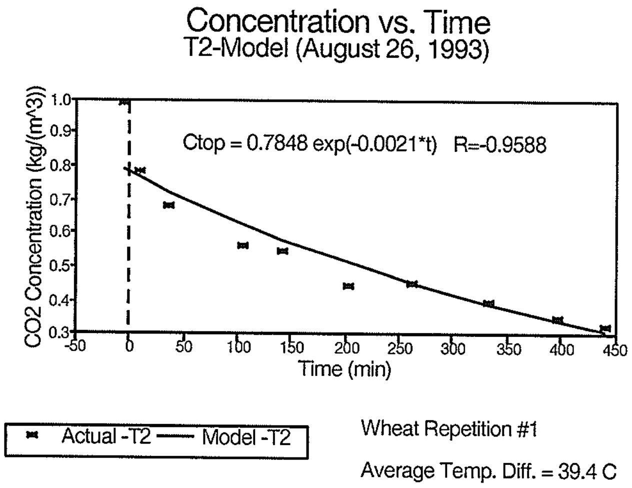
August 26, 1993
Top No-flow Test
Temperature Difference = 39.4 C
Wheat Repetition #1

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		B2	
Temperature (C)		2.95		2.95		2.95		24.00			42.35		42.35		24.00	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	98.91	0.02	0.0004	0.01	0.0002	0.01	0.0002	56.21	0.9903	0.7931	0.91	0.0151	0.21	0.0035		
9	98.90	0.02	0.0004	0.01	0.0002	0.01	0.0002	44.37	0.7816	0.7701	0.82	0.0136	0.15	0.0025		
37	98.90	18.93	0.3589	12.82	0.2430	0.21	0.0040	38.96	0.6863	0.7261	5.87	0.0974	0.21	0.0035		
106	98.86	22.91	0.4342	17.43	0.3303	10.95	0.2075	32.08	0.5649	0.6282	8.96	0.1486	1.10	0.0182	0.01	0.0002
142	98.89	24.28	0.4603	18.37	0.3482	11.95	0.2265	30.91	0.5444	0.5824	1.48	0.0246	7.34	0.1218		
202	98.96	24.81	0.4706	19.45	0.3690	14.02	0.2660	25.28	0.4456	0.5135	5.95	0.0988	1.04	0.0173		
262	98.94	26.32	0.4992	20.86	0.3956	15.61	0.2961	25.62	0.4515	0.4527	4.79	0.0795	0.97	0.0161		
332	98.99	22.59	0.4287	22.22	0.4216	16.12	0.3059	22.54	0.3974	0.3908	3.31	0.0550	0.59	0.0098	0.01	0.0002
397	98.95	21.77	0.4129	21.73	0.4122	18.70	0.3547	19.82	0.3493	0.3409	2.81	0.0466	0.45	0.0075		
442	98.94	20.50	0.3888	21.78	0.4131	19.59	0.3715	18.68	0.3292	0.3102	2.48	0.0412	0.33	0.0055	0.01	0.0002

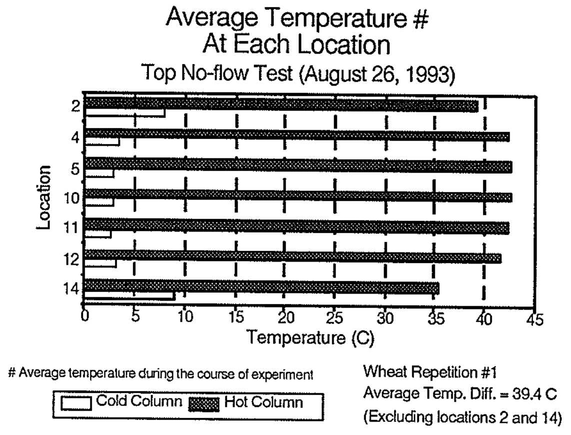


Wheat Repetition #1
Average Temp. Diff. = 39.4 C



Wheat Repetition #1

Average Temp. Diff. = 39.4 C



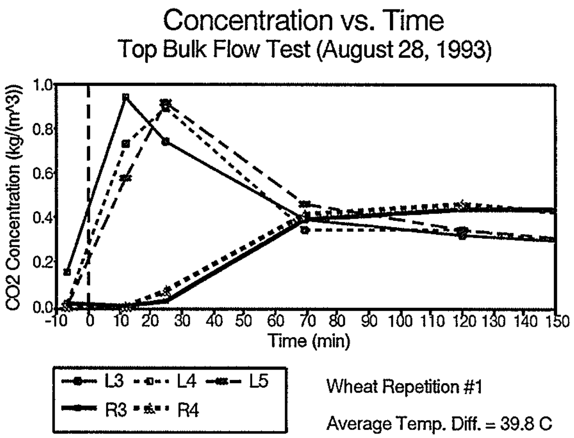
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 39.4 C
(Excluding locations 2 and 14)

August 28, 1993
Top Bulk Flow Test
Temperature Difference = 39.8 C
Wheat Repetition #1

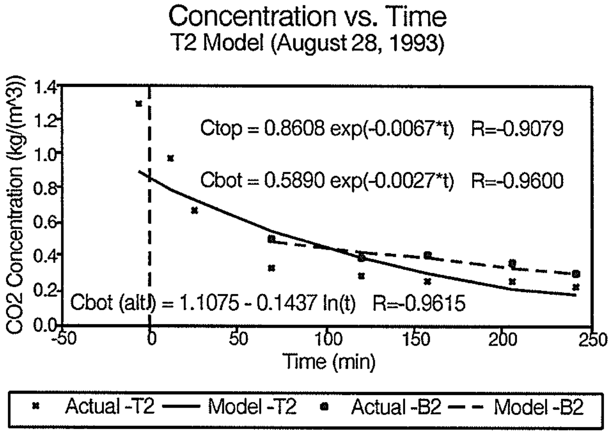
** Note: Blank entries in the table are a result of missing data

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		2.51		2.51		2.51		25.00			42.35		42.35		24.00		
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))
-7	98.86	8.57	0.1627	0.96	0.0182	0.33	0.0063	73.81	1.2953	0.9021	0.88	0.0146	0.31	0.0051			
12	98.68	49.35	0.9350	38.19	0.7236	30.40	0.5760	55.81	0.9776	0.7943	0.28	0.0046	0.13	0.0022			
25	98.68	39.10	0.7408	46.86	0.8878	48.16	0.9125	38.37	0.6721	0.7280	1.56	0.0258	4.95	0.0819			
69	98.67	20.65	0.3912	18.34	0.3474	24.37	0.4617	19.33	0.3386	0.5422	23.66	0.3916	24.92	0.4125	28.50	0.5009	0.48888446
120	98.63	16.72	0.3166	18.04	0.3416	18.20	0.3446	16.67	0.2919	0.3852	26.41	0.4370	27.76	0.4593	22.71	0.3990	0.42599439
158	98.59	15.42	0.2919	15.29	0.2894	16.39	0.3102	14.97	0.2620	0.2986	26.29	0.4348	25.69	0.4249	22.95	0.4030	0.38445478
206	98.56	14.34	0.2714	14.77	0.2795	14.79	0.2799	14.40	0.2519	0.2165	22.17	0.3666	20.91	0.3457	20.43	0.3586	0.33772305
241	98.53	13.69	0.2590	13.00	0.2459	13.52	0.2558	12.54	0.2193	0.1713	18.50	0.3058	17.39	0.2874	17.04	0.2990	0.3072698

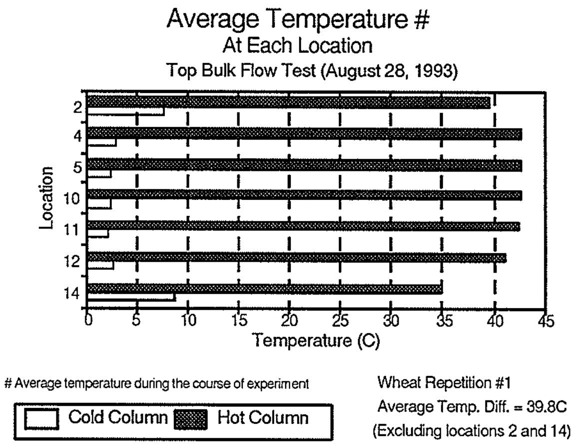


Wheat Repetition #1

Average Temp. Diff. = 39.8 C



Wheat Repetition #1 Average Temp. Diff. = 39.8 C



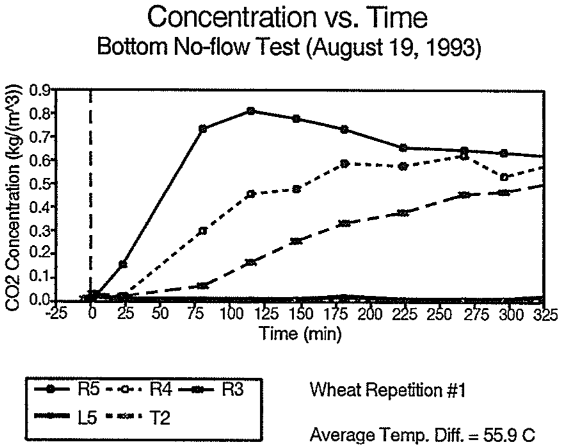
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 39.8C
(Excluding locations 2 and 14)

August 19, 1993
Bottom No-flow Test
Temperature Difference = 55.9 C
Wheat Repetition #1

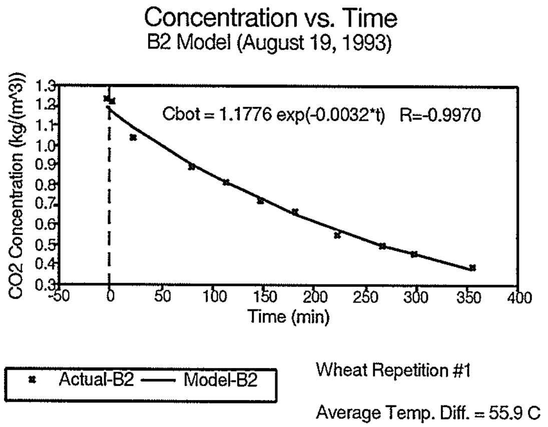
** Note: Blank entries in the table represent missing data.

	Location	R5		R4		R3		B2			L5		T2	
	Temperature (C)	56.35		59.35		59.35		23.00			3.42		23.00	
Time	Pressure								Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.61	0.01	0.0002	0.02	0.0003	0.03	0.0005	70.23	1.2377	1.1890	0.02	0.0004		
2	98.61	0.40	0.0063	0.82	0.0129	1.59	0.0250	68.85	1.2133	1.1701	1.01	0.0191		
23	98.61	9.65	0.1528	0.78	0.0122	1.33	0.0209	58.79	1.0361	1.0940	0.40	0.0075		
81	98.66	45.89	0.7272	18.73	0.2941	3.78	0.0594	50.75	0.8948	0.9087	0.47	0.0089		
114	98.69	50.88	0.8065	28.59	0.4491	10.43	0.1638	45.84	0.8084	0.8176	0.24	0.0045		
148	98.71	49.30	0.7817	30.49	0.4791	16.14	0.2536	40.99	0.7231	0.7334	0.19	0.0036	0.02	0.0004
182	98.76	46.06	0.7307	37.54	0.5901	20.70	0.3254	38.24	0.6749	0.6578	0.65	0.0123	0.02	0.0004
224	98.79	41.44	0.6575	36.53	0.5744	23.92	0.3761	31.39	0.5542	0.5750	0.08	0.0015	0.02	0.0004
267	98.81	40.23	0.6385	39.77	0.6255	28.68	0.4511	28.20	0.4980	0.5011	0.10	0.0019	0.02	0.0004
297	98.87	39.92	0.6340	34.02	0.5354	29.37	0.4622	25.49	0.4504	0.4552	0.30	0.0057	0.02	0.0004
354	98.90	37.97	0.6032	39.64	0.6240	33.93	0.5341	22.04	0.3895	0.3793	1.43	0.0271	0.01	0.0002


Concentration vs. Time
Bottom No-flow Test (August 19, 1993)

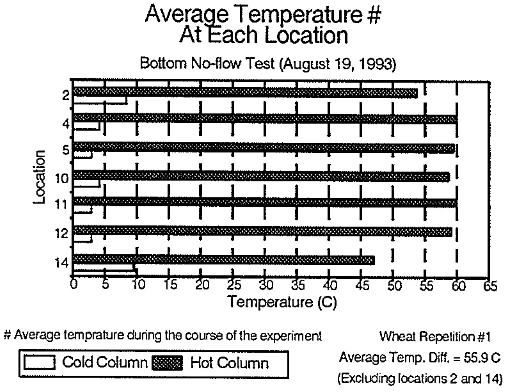
Wheat Repetition #1

Average Temp. Diff. = 55.9 C


Concentration vs. Time
B2 Model (August 19, 1993)

Wheat Repetition #1

Average Temp. Diff. = 55.9 C


Average Temperature # At Each Location
Bottom No-flow Test (August 19, 1993)

Average temprature during the course of the experiment

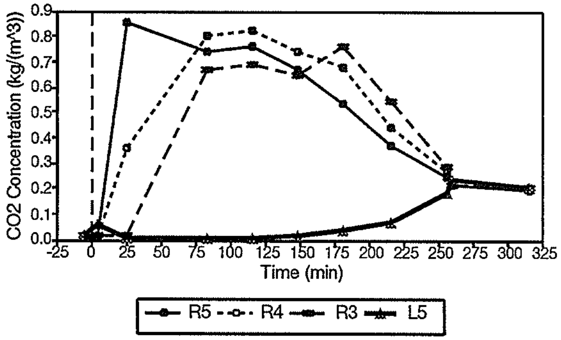
Wheat Repetition #1
Average Temp. Diff. = 55.9 C
(Excluding locations 2 and 14)

August 20, 1993
Bottom Bulk Flow Test
Temperature Difference = 55.7 C
Wheat Repetition #1

** Note: Blank entries in the table represent missing data.

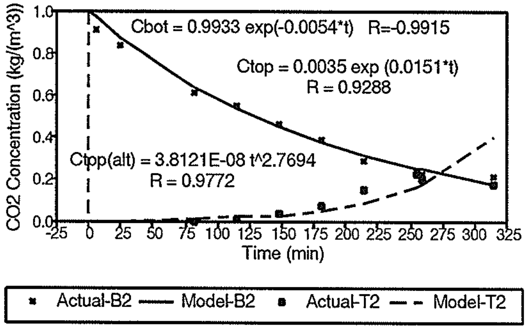
Location		R5		R4		R3		B2			L5		T2		
Temperature (C)		59.18		59.18		59.18		26.00			3.46		27.00		
Time	Pressure								Actual	Model				Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	99.53	0.26	0.0041	0.69	0.0109	1.20	0.0190	66.26	1.1668	1.0205	1.02	0.0194			0.0032
5	99.53	0.24	0.0038	0.42	0.0067	0.90	0.0143	51.75	0.9113	0.9668	3.16	0.0602			0.0038
25	99.53	53.73	0.8517	22.68	0.3595	0.93	0.0147	47.29	0.8327	0.8679	0.38	0.0072			0.0051
83	99.54	46.91	0.7436	50.38	0.7986	41.76	0.6620	34.65	0.6102	0.6345	0.42	0.0080	0.37	0.0065	0.0122
115	99.56	47.89	0.7593	51.70	0.8197	43.27	0.6861	31.28	0.5510	0.5338	0.51	0.0097	1.10	0.0193	0.0196
148	99.55	42.31	0.6708	46.51	0.7374	41.03	0.6505	26.46	0.4660	0.4467	0.72	0.0137	2.30	0.0404	0.0322
180	99.53	33.70	0.5342	42.47	0.6732	48.12	0.7627	21.60	0.3804	0.3758	1.75	0.0333	4.19	0.0735	0.0521
215	99.51	23.22	0.3680	27.83	0.4410	34.14	0.5410	16.56	0.2915	0.3111	3.46	0.0659	8.48	0.1488	0.0880
255	99.49	15.28	0.2421	16.38	0.2595	17.68	0.2801	13.81	0.2431	0.2506	9.63	0.1833	12.82	0.2249	0.1604
260	99.42	13.19	0.2088	13.46	0.2131	13.33	0.2111	12.95	0.2278	0.2440	12.24	0.2328	11.56	0.2027	0.1729
315	99.39	12.42	0.1966	12.77	0.2021	12.91	0.2043	12.00	0.2110	0.1813	10.70	0.2035	10.28	0.1802	0.3946

Concentration vs. Time
Bottom Bulk Flow Test (August 20, 1992)



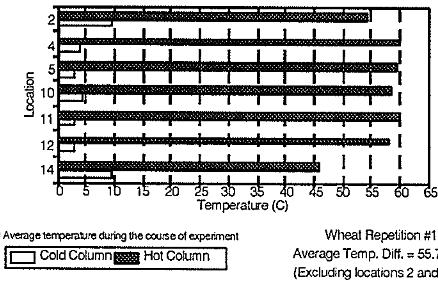
Wheat Repetition #1 Average Temp. Diff. = 55.7 C

Concentration vs. Time
B2 and T2 Model (August 20, 1992)



Wheat Repetition #1 Average Temp. Diff. = 55.7 C

Average Temperature #
At Each Location
Bottom Bulk Flow Test (August 20, 1993)



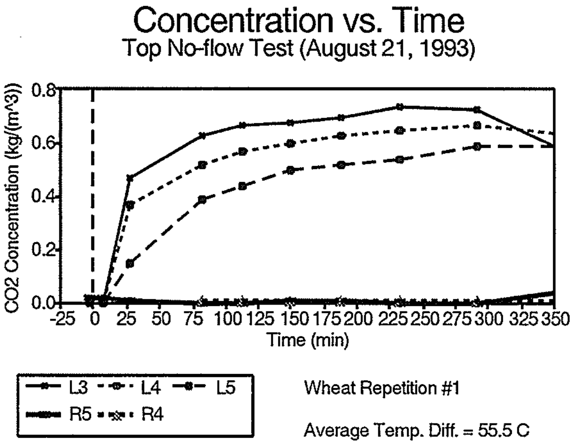
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 55.7 C
(Excluding locations 2 and 14)

August 21, 1993
Top No-flow Test
Temperature Difference = 55.5 C
Wheat Repetition #1

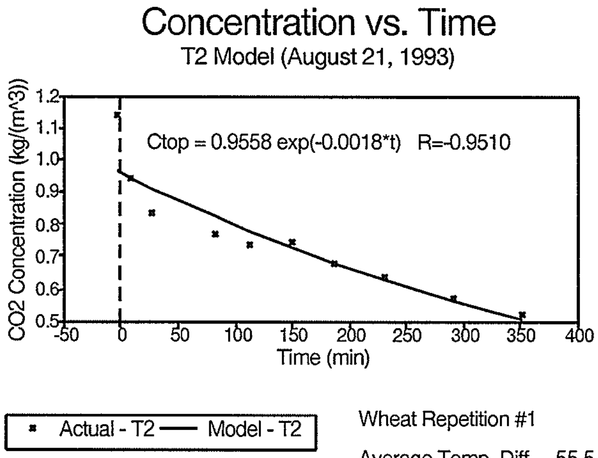
** Note: Blank entries in the table represent missing data.

		Concentration of CO2												
Location		L3		L4		L5		T2			R5		R4	
Temperature (C)		3.67		3.67		3.67		26.00			59.19		59.19	
Time	Pressure								Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.83	0.01	0.0002	0.01	0.0002	0.01	0.0002	64.80	1.1330	0.9610	1.47	0.0231		
7	98.83	0.03	0.0006	0.02	0.0004	0.01	0.0002	53.92	0.9428	0.9438	1.33	0.0209		
27	98.80	24.71	0.4668	19.38	0.3661	8.24	0.1557	47.81	0.8357	0.9105	0.89	0.0140		
82	98.75	32.89	0.6210	27.39	0.5171	20.54	0.3878	43.93	0.7675	0.8246	0.22	0.0035	0.60	0.0094
112	98.72	35.24	0.6651	30.01	0.5664	23.11	0.4362	41.94	0.7325	0.7813	0.19	0.0030	0.94	0.0148
149	98.68	36.00	0.6792	31.65	0.5971	26.58	0.5015	42.75	0.7464	0.7310	1.07	0.0168	0.90	0.0141
187	98.63	36.88	0.6955	32.96	0.6215	27.60	0.5205	38.88	0.6784	0.6826	0.71	0.0112	0.90	0.0141
232	98.53	38.71	0.7292	34.16	0.6435	28.21	0.5314	36.69	0.6396	0.6295	0.18	0.0028	0.92	0.0144
292	98.45	38.66	0.7277	35.25	0.6635	31.31	0.5893	32.98	0.5744	0.5651	0.17	0.0027	0.71	0.0111
352	98.40	30.81	0.5796	33.88	0.6374	31.00	0.5832	29.85	0.5197	0.5072	2.68	0.0420	0.70	0.0110



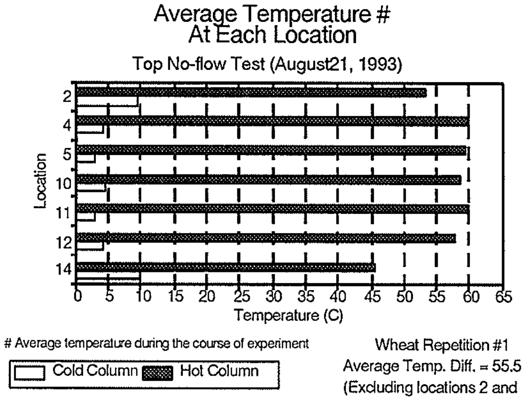
Wheat Repetition #1

Average Temp. Diff. = 55.5 C



Wheat Repetition #1

Average Temp. Diff. = 55.5 C

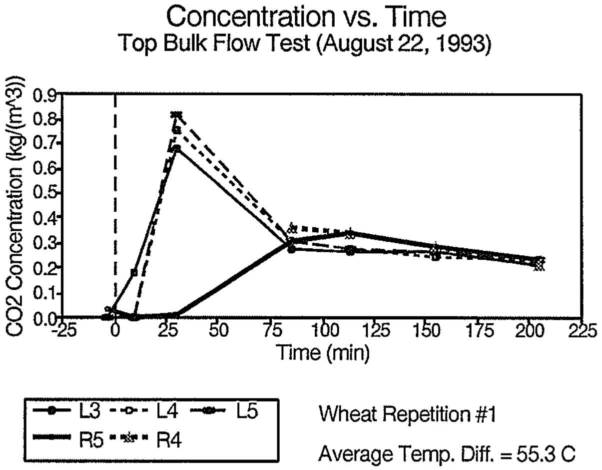


Wheat Repetition #1
Average Temp. Diff. = 55.5 C
(Excluding locations 2 and 14)

August 22, 1993
Top Bulk Flow Test
Temperature Difference = 55.3 C
Wheat Repetition #1

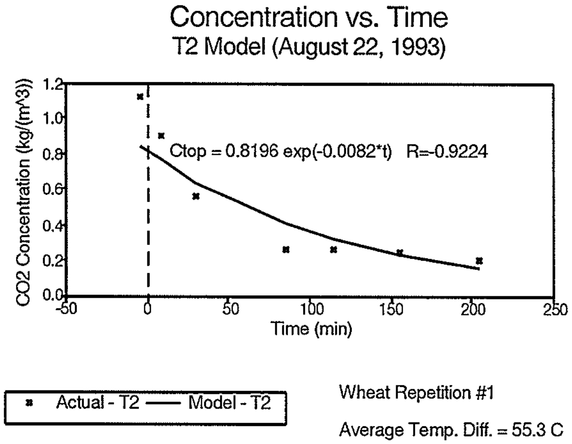
** Note: Blank entries in the table represent missing data.

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		B2	
Temperature (C)		3.65		3.65		3.65		26.00			58.99		58.99		26.00	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	97.8	0.03	0.0006	0.09	0.0017	0.10	0.0019	64.95	1.1238	0.8469	1.78	0.0277				
9	97.8	9.43	0.1763	0.19	0.0036	0.06	0.0011	52.14	0.9022	0.7613	0.34	0.0053				
30	97.78	36.53	0.6830	40.44	0.7561	43.94	0.8215	32.29	0.5586	0.6409	0.47	0.0073				
85	97.75	14.60	0.2729	16.39	0.3063	16.77	0.3134	15.38	0.2660	0.4082	19.89	0.3098	22.95	0.3575		
114	97.73	14.45	0.2700	14.82	0.2769	14.96	0.2796	14.79	0.2557	0.3218	21.57	0.3359	21.59	0.3362		
155	97.71	13.91	0.2599	13.18	0.2462	13.90	0.2597	14.03	0.2425	0.2299	18.30	0.2849	18.42	0.2868	17.34	0.2998
205	97.65	11.29	0.2108	12.40	0.2315	12.41	0.2317	11.54	0.1994	0.1526	15.07	0.2345	13.95	0.2171	15.23	0.2631



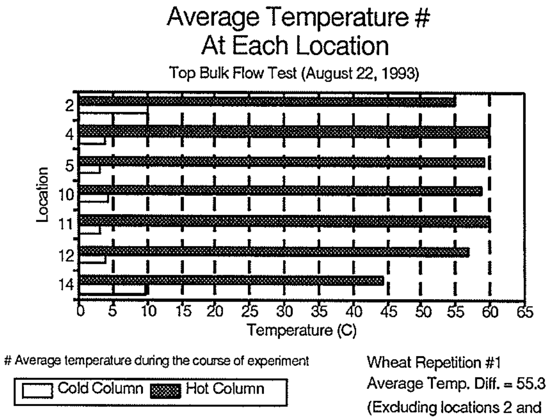
Wheat Repetition #1

Average Temp. Diff. = 55.3 C



Wheat Repetition #1

Average Temp. Diff. = 55.3 C



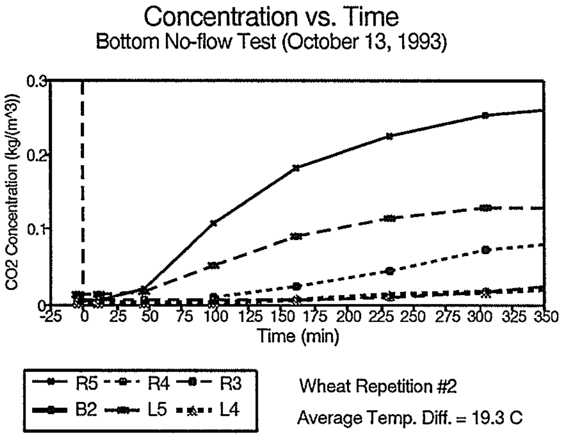
Average temperature during the course of experiment

Wheat Repetition #1
Average Temp. Diff. = 55.3 C
(Excluding locations 2 and 14)

October 13, 1993
Bottom No-flow Test
Temperature Difference = 19.3 C
Wheat Repetition #2

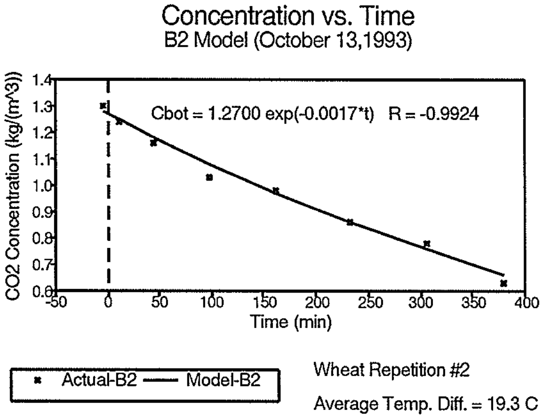
** Note: Blank entries in the table represent missing data.

		Concentration Of CO2															
	Location	R5		R4		R3		B2			L5		L4		L3		
	Temperature (C)	30.05		30.05		30.05		17.00			10.70		10.70		10.70		
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-4	98.81	0.19	0.0033	0.22	0.0038	0.24	0.0042	72.26	1.3025	1.2787	0.66	0.0122	0.09	0.0016	0.07	0.0012	
11	98.81	0.27	0.0046	0.23	0.0040	0.25	0.0043	68.67	1.2376	1.2465	0.65	0.0119	0.10	0.0018	0.08	0.0014	
45	98.87	1.13	0.0196			0.26	0.0045	64.25	1.1587	1.1765	0.95	0.0175	0.11	0.0020	0.07	0.0013	
98	98.73	6.39	0.1101	0.50	0.0086	0.27	0.0046	57.26	1.0312	1.0751	2.82	0.0520	0.14	0.0026	0.08	0.0014	
161	98.68	10.72	0.1847	1.36	0.0235	0.35	0.0060	54.58	0.9825	0.9659	5.05	0.0928	0.37	0.0068	0.09	0.0016	
232	98.62	13.20	0.2272	2.66	0.0457	0.56	0.0096	47.53	0.8551	0.8561	6.39	0.1175	0.64	0.0118	0.12	0.0022	
305	98.50	14.70	0.2528	4.25	0.0731	0.95	0.0164	43.46	0.7809	0.7562	6.97	0.1280	0.92	0.0168	0.17	0.0031	
380	98.32	15.40	0.2644	5.12	0.0879	1.47	0.0252	34.96	0.6269	0.6657	7.21	0.1322	1.15	0.0210	0.24	0.0043	



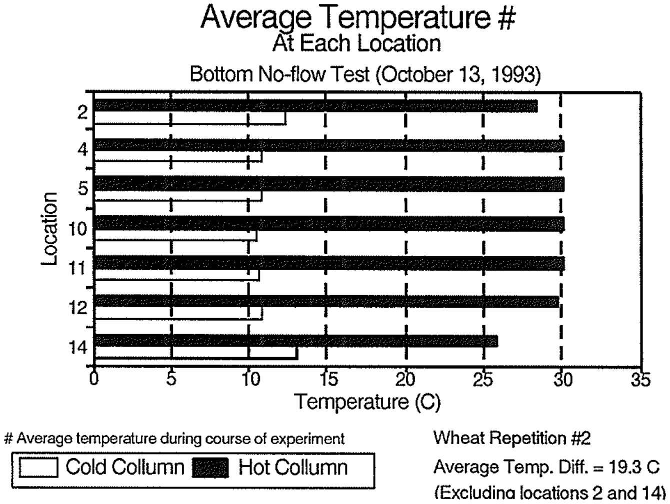
Wheat Repetition #2

Average Temp. Diff. = 19.3 C



Wheat Repetition #2

Average Temp. Diff. = 19.3 C



Wheat Repetition #2

Average Temp. Diff. = 19.3 C

(Excluding locations 2 and 14)

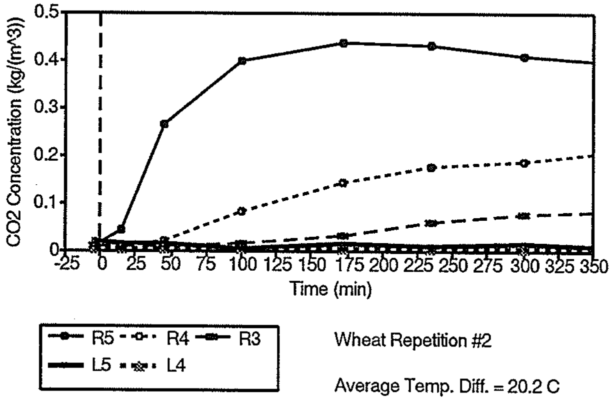
October 14, 1993
Bottom Bulk Flow Test
Temperature Difference = 20.2 C
Wheat Repetition #2

Concentration of CO2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		30.15		30.15		30.15		17.00			9.96		9.96		9.96	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	98.77	0.63	0.0108	0.56	0.0096	0.54	0.0093	75.20	1.3548	1.2197	1.08	0.0200	0.30	0.0056	0.23	0.0043
15	98.80	2.55	0.0440	0.59	0.0102	0.56	0.0096	65.17	1.1745	1.1790	0.87	0.0161	0.29	0.0053	0.20	0.0038
45	98.82	15.39	0.2654	1.17	0.0203	0.60	0.0103	61.69	1.1120	1.1203	0.70	0.0128	0.24	0.0045	0.16	0.0030
100	98.86	23.14	0.3992	4.67	0.0805	0.85	0.0147	48.51	0.8748	1.0203	0.31	0.0058	0.19	0.0035	0.47	0.0087
172	98.94	25.19	0.4349	8.28	0.1430	1.93	0.0333	50.71	0.9151	0.9028	0.78	0.0144	0.19	0.0036	0.16	0.0030
234	98.97	24.96	0.4311	10.29	0.1777	3.47	0.0599	46.35	0.8367	0.8125	0.40	0.0074	0.18	0.0033	0.17	0.0031
300	98.95	23.65	0.4083	10.96	0.1892	4.33	0.0747	41.92	0.7567	0.7262	0.72	0.0134	0.18	0.0034	0.17	0.0032
380	98.92	22.76	0.3928	12.02	0.2075	5.15	0.0890	35.49	0.6404	0.6339	0.56	0.0103	0.19	0.0036	0.19	0.0035

Concentration vs. Time

Bottom Bulk Flow Test(October 14, 1993)

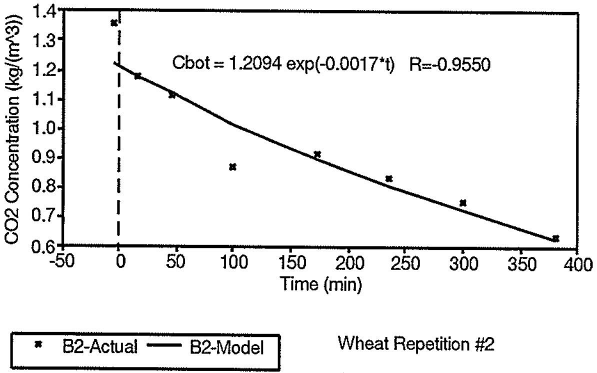


Wheat Repetition #2

Average Temp. Diff. = 20.2 C

Concentration vs. Time

B2 Model (October 14,1993)

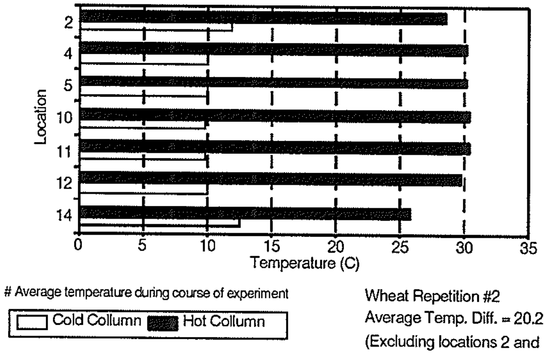


Wheat Repetition #2

Average Temp. Diff. = 20.2 C

Average Temperature #
At Each Location

Bottom Bulk Flow Test (October 14, 1993)



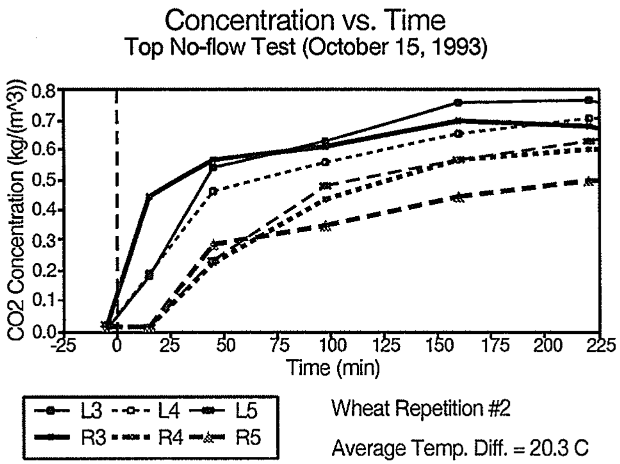
Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 20.2 C
(Excluding locations 2 and 14)

October 15, 1993
Top No-flow Test
Temperature Difference = 20.3 C
Wheat Repetition #2

Concentration of CO2

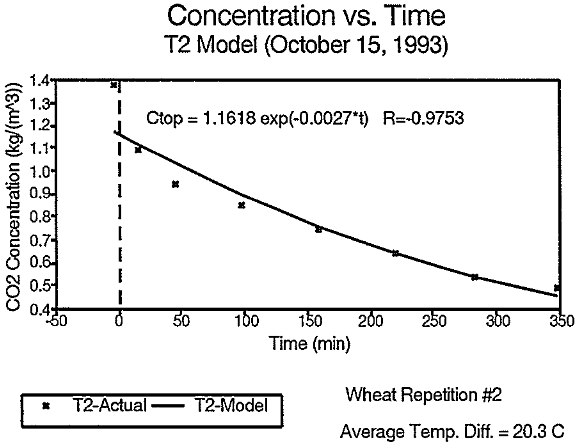
	Location	L3		L4		L5		T2			R3		R4		R5	
	Temperature (C)	10.21		10.21		10.21		19.00			30.52		30.52		30.52	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.48	0.42	0.0076	0.34	0.0062	1.13	0.0207	77.29	1.3788	1.1744	0.68	0.0116	0.72	0.0123	0.84	0.0144
15	98.48	10.10	0.1857	10.46	0.1923	0.81	0.0148	60.78	1.0843	1.1157	25.64	0.4400	0.78	0.0134	0.87	0.0150
45	98.48	29.43	0.5414	25.07	0.4611	12.81	0.2356	52.84	0.9428	1.0289	32.85	0.5639	13.14	0.2256	16.78	0.2879
98	98.46	34.30	0.6308	30.20	0.5555	26.14	0.4808	47.67	0.8503	0.8917	35.57	0.6105	25.29	0.4340	20.48	0.3514
160	98.43	41.07	0.7551	35.38	0.6505	30.51	0.5609	41.84	0.7460	0.7543	40.70	0.6983	32.84	0.5634	25.74	0.4416
220	98.40	41.52	0.7631	38.39	0.7056	34.13	0.6273	35.98	0.6414	0.6414	39.78	0.6823	34.82	0.5971	28.72	0.4925
284	98.36	35.95	0.6605	38.15	0.7009	36.98	0.6794	30.01	0.5348	0.5397	34.21	0.5865	35.87	0.6148	30.32	0.5197
349	98.31	33.00	0.6059	35.13	0.6451	36.59	0.6720	27.58	0.4911	0.4528	30.14	0.5163	33.40	0.5722	32.82	0.5624



Concentration vs. Time
Top No-flow Test (October 15, 1993)

Wheat Repetition #2

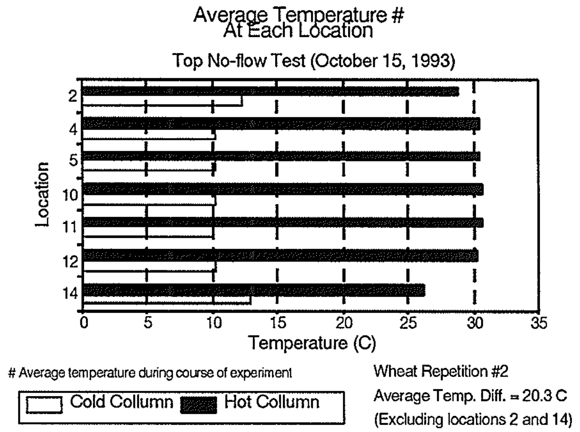
Average Temp. Diff. = 20.3 C



Concentration vs. Time
T2 Model (October 15, 1993)

Wheat Repetition #2

Average Temp. Diff. = 20.3 C



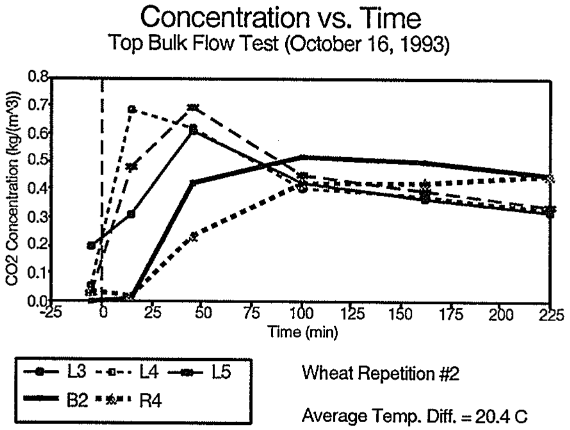
Average Temperature #
At Each Location
Top No-flow Test (October 15, 1993)

Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 20.3 C
(Excluding locations 2 and 14)

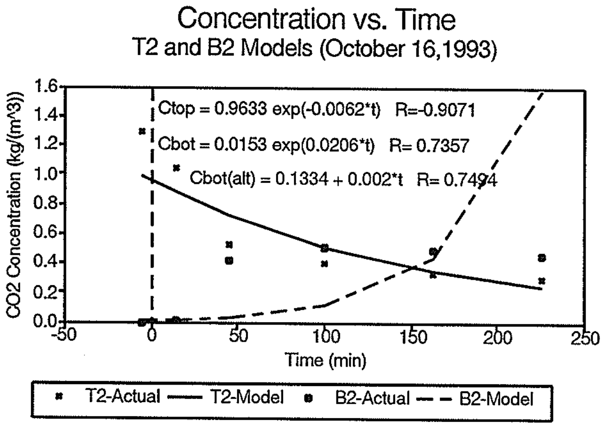
October 16, 1993
Top Bulk Flow Test
Temperature Difference = 20.4 C
Wheat Repetition #2

		Concentration of CO2																
Location		L3		L4		L5		T2			B2			R3		R4		
Temperature (C)		10.17		10.17		10.17		19.00			19.00			30.57		30.57		
Time	Pressure								Actual	Model		Actual	Model					
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-5	98.95	10.36	0.1914	3.23	0.0598	1.46	0.0270	72.18	1.2938	0.9936	0.09	0.0016	0.0138	2.66	0.0458	2.09	0.0360	
15	98.96	16.64	0.3076	37.21	0.6878	26.10	0.4825	57.93	1.0385	0.8778	0.64	0.0114	0.0208	1.75	0.0302	0.91	0.0157	
45	98.97	32.73	0.6051	33.49	0.6192	37.64	0.6959	29.46	0.5281	0.7288	23.51	0.4214	0.0387	11.69	0.2016	13.42	0.2314	
100	99.02	22.68	0.4196	21.90	0.4051	24.27	0.4489	22.05	0.3956	0.5182	28.70	0.5149	0.1200	24.44	0.4217	24.44	0.4218	
162	99.00	19.64	0.3632	20.15	0.3726	21.03	0.3890	18.63	0.3341	0.3528	27.57	0.4945	0.4305	26.33	0.4542	24.65	0.4253	
225	98.97	17.24	0.3188	17.83	0.3297	18.09	0.3345	16.74	0.3001	0.2387	25.27	0.4530	1.5763	26.81	0.4624	26.25	0.4527	

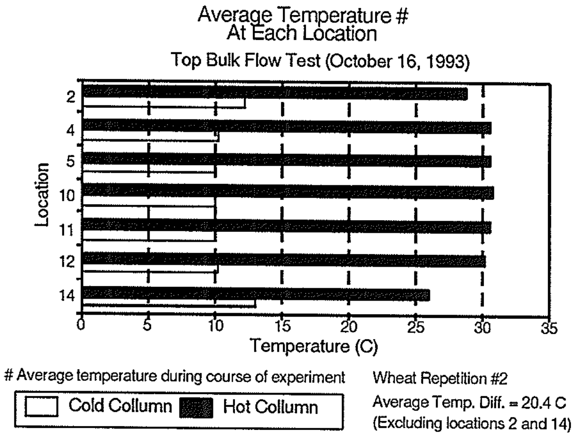


Wheat Repetition #2

Average Temp. Diff. = 20.4 C



Wheat Repetition #2 Average Temp. Diff. = 20.4 C



Average temperature during course of experiment

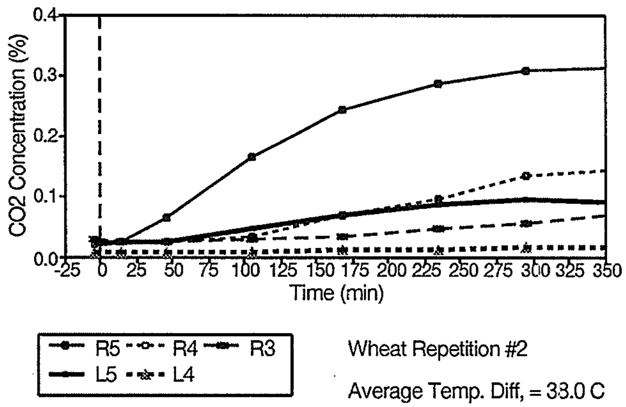
Wheat Repetition #2
Average Temp. Diff. = 20.4 C
(Excluding locations 2 and 14)

October 19, 1993
Bottom No-flow Test
Temperature Difference = 38.0 C
Wheat Repetition #2

Concentration of CO2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		42.42		42.42		42.42		20.00			4.47		4.47		4.47	
Time	Pressure								Actual	Model						
(min.)	(kPa.)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.41	1.42	0.0235	1.74	0.0288	1.84	0.0303	71.63	1.2726	1.2243	1.27	0.0238	0.50	0.0094	0.39	0.0072
15	98.41	1.60	0.0264	1.60	0.0265	1.73	0.0285	64.99	1.1546	1.1899	1.32	0.0247	0.48	0.0091	0.40	0.0075
45	98.39	3.95	0.0652	1.70	0.0281	1.70	0.0281	66.88	1.1879	1.1376	1.48	0.0277	0.44	0.0083	0.38	0.0071
105	98.31	9.89	0.1631	2.24	0.0369	1.88	0.0310	56.94	1.0107	1.0397	2.47	0.0463	0.50	0.0093	0.37	0.0070
167	98.23	14.72	0.2425	4.37	0.0720	2.20	0.0362	51.04	0.9052	0.9473	3.74	0.0701	0.64	0.0121	0.37	0.0070
235	98.13	17.37	0.2859	5.78	0.0952	2.92	0.0480	48.22	0.8543	0.8555	4.51	0.0843	0.81	0.0152	0.36	0.0067
295	98.02	18.60	0.3057	8.04	0.1322	3.54	0.0582	44.45	0.7866	0.7818	5.06	0.0945	0.93	0.0174	0.38	0.0071
370	97.96	19.22	0.3157	8.94	0.1469	4.45	0.0732	40.71	0.7199	0.6986	4.85	0.0906	1.01	0.0189	0.38	0.0070

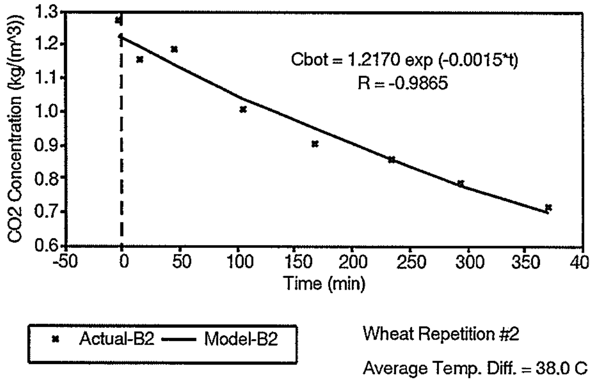
Concentration vs. Time
Bottom No-flow Test (October 19, 1993)



Wheat Repetition #2

Average Temp. Diff, = 33.0 C

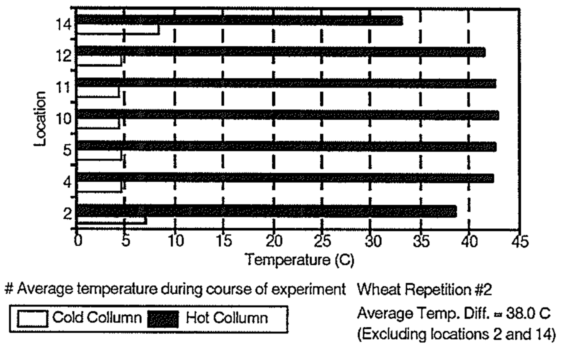
Concentration vs. Time
B2 Model (October 19, 1993)



Wheat Repetition #2

Average Temp. Diff. = 38.0 C

Average Temperature #
At Each Location
Bottom No-flow Test (October 19, 1993)



Average temperature during course of experiment

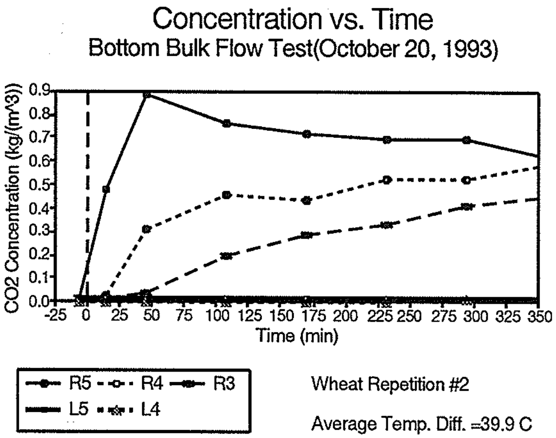
Wheat Repetition #2

Average Temp. Diff. = 38.0 C
(Excluding locations 2 and 14)

October 20, 1993
Bottom Bulk Flow Test
Temperature Difference = 39.9 C
Wheat Repetition #2

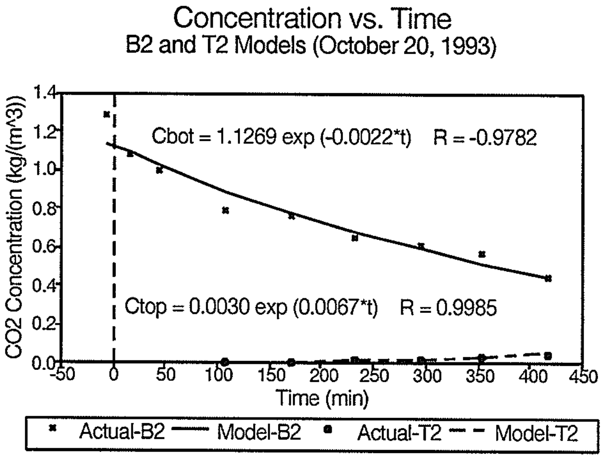
** Note: Blank entries in the table represent missing data.

Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		43.73		43.73		43.73		21.00			4.47		4.47		22.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	98.46	1.09	0.0180	0.99	0.0163	0.94	0.0154	72.92	1.2919	1.1419	0.89	0.0166	0.22	0.0042			
15	98.46	28.86	0.4746	1.59	0.0261	1.07	0.0176	61.15	1.0832	1.0903	0.71	0.0133	0.20	0.0037			
45	98.53	53.83	0.8858	18.86	0.3104	2.55	0.0420	56.08	0.9942	1.0207	0.69	0.0130	0.18	0.0034			
108	98.59	45.85	0.7550	27.30	0.4495	11.96	0.1969	44.72	0.7932	0.8886	0.56	0.0106	0.22	0.0042	0.35	0.0062	0.0062
170	98.61	43.47	0.7160	26.54	0.4371	17.41	0.2868	43.06	0.7639	0.7753	0.56	0.0105	0.27	0.0051	0.50	0.0088	0.0094
232	98.62	41.71	0.6870	31.45	0.5180	19.94	0.3285	36.73	0.6518	0.6764	0.55	0.0103	0.34	0.0064	0.79	0.0140	0.0142
294	98.61	42.31	0.6968	31.84	0.5245	24.46	0.4029	34.63	0.6144	0.5902	0.70	0.0131	0.52	0.0097	1.25	0.0221	0.0215
354	98.57	37.49	0.6172	34.97	0.5758	27.12	0.4465	31.89	0.5656	0.5172	0.83	0.0156	0.82	0.0154	1.88	0.0333	0.0321
417	98.55	34.73	0.5717	32.16	0.5294	28.95	0.4765	25.02	0.4436	0.4503	1.14	0.0213	1.27	0.0238	2.60	0.0460	0.0490

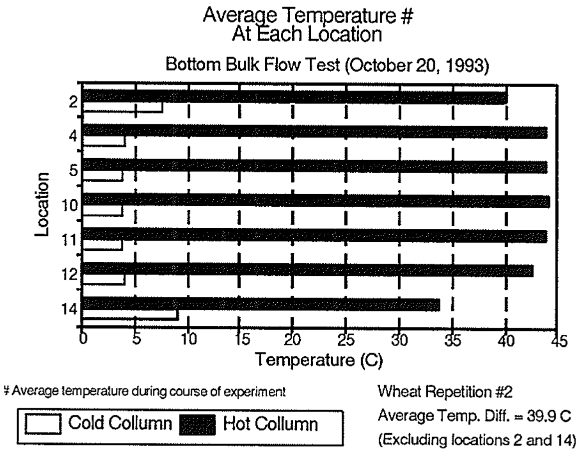


Wheat Repetition #2

Average Temp. Diff. =39.9 C



Wheat Repetition #2 Average Temp. Diff. = 39.9 C

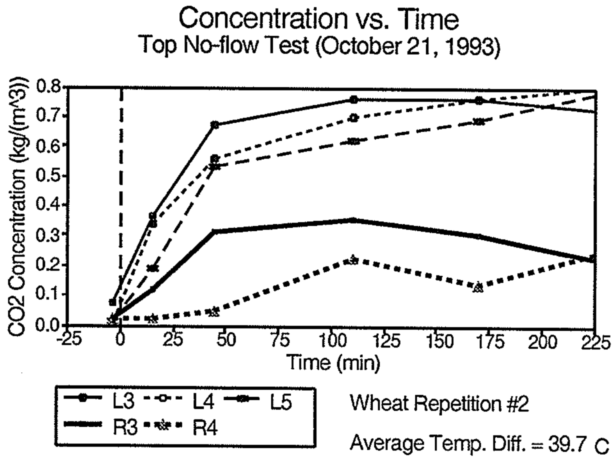


Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 39.9 C
(Excluding locations 2 and 14)

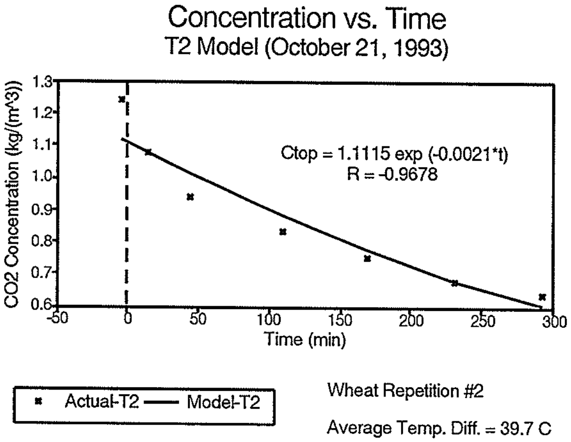
October 21, 1993
Top No-flow Test
Temperature Difference = 39.7 C
Wheat Repetition #2

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		4.16		4.16		4.16		20.00			43.90		43.90		43.90	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.81	3.93	0.0742	0.21	0.0039	0.82	0.0154	69.68	1.2430	1.1209	1.28	0.0210	1.28	0.0211	1.19	0.0196
15	98.83	19.28	0.3636	17.89	0.3374	9.77	0.1843	60.60	1.0813	1.0770	7.15	0.1180	1.38	0.0228	1.34	0.0221
45	98.85	35.50	0.6698	29.61	0.5586	28.53	0.5382	52.68	0.9402	1.0113	19.02	0.3138	2.81	0.0463	1.56	0.0258
110	98.88	40.55	0.7652	36.92	0.6967	32.72	0.6174	46.83	0.8360	0.8822	21.70	0.3581	13.42	0.2216	2.39	0.0395
170	98.92	40.57	0.7658	40.44	0.7634	36.58	0.6905	42.25	0.7546	0.7778	18.48	0.3051	8.00	0.1321	2.23	0.0368
232	98.97	38.57	0.7285	42.69	0.8064	42.05	0.7942	37.78	0.6750	0.6828	13.15	0.2173	15.09	0.2493	1.76	0.0291
292	99.01	39.72	0.7505	41.31	0.7807	43.62	0.8243	35.60	0.6363	0.6020	9.14	0.1511	3.29	0.0543	1.40	0.0232



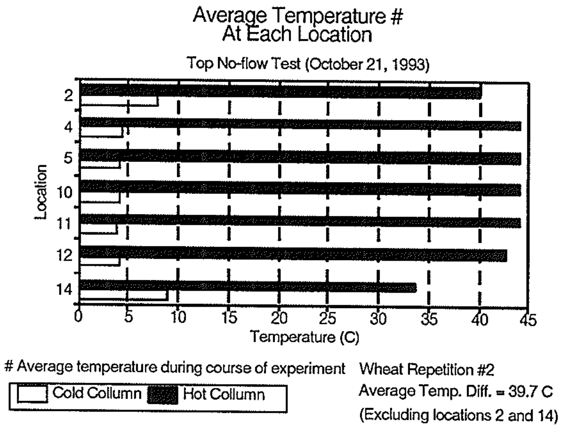
Wheat Repetition #2

Average Temp. Diff. = 39.7 C



Wheat Repetition #2

Average Temp. Diff. = 39.7 C



Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 39.7 C
(Excluding locations 2 and 14)

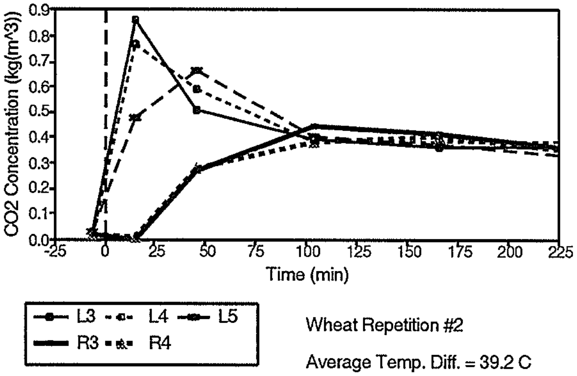
October 22, 1993
Top Bulk Flow Test
Temperature Difference = 39.2 C
Wheat Repetition #2

** Note: Blank entries in the table represent missing data

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		4.65		4.65		4.65		19.00			43.88		43.88		18.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	98.98	1.76	0.0332	0.74	0.0140	1.46	0.0276	65.83	1.1804	0.8435	1.04	0.0172	0.92	0.0151			0.1552
15	98.99	45.42	0.8566	40.63	0.7662	25.05	0.4724	48.67	0.8727	0.7642	0.29	0.0048	0.33	0.0054	4.45	0.0800	0.2065
45	99.00	27.06	0.5104	31.46	0.5934	35.02	0.6606	25.54	0.4580	0.6637	16.16	0.2671	16.91	0.2794	23.16	0.4167	0.3105
104	99.00	20.70	0.3905	20.21	0.3812	21.45	0.4046	20.32	0.3644	0.5030	27.19	0.4493	23.04	0.3808	25.41	0.4573	0.6928
166	99.02	18.92	0.3570	20.51	0.3868	19.87	0.3748	20.76	0.3723	0.3758	25.11	0.4151	24.41	0.4036	23.64	0.4256	1.6099
226	99.05	19.32	0.3646	20.12	0.3797	17.71	0.3342	19.61	0.3519	0.2835	21.81	0.3606	21.12	0.3492	21.90	0.3942	3.6407

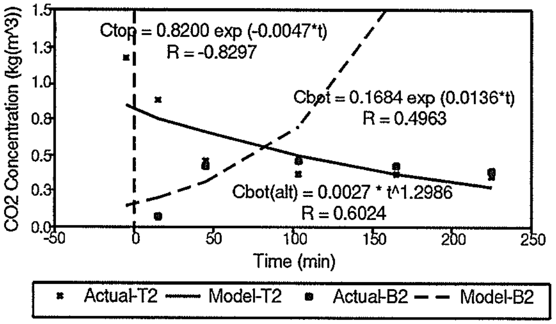
Concentration vs. Time
Top Bulk Flow Test (October 22, 1993)



Wheat Repetition #2

Average Temp. Diff. = 39.2 C

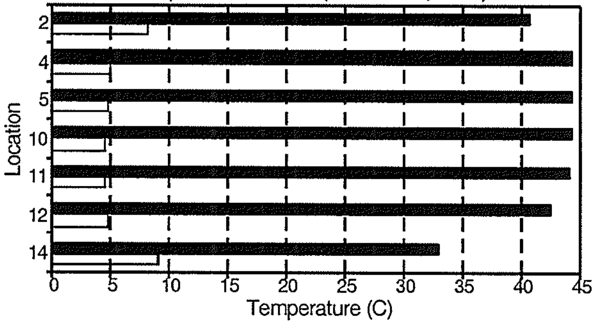
Concentration vs. Time
T2 and B2 Models (October 22, 1993)



Wheat Repetition #2

Average Temp. Diff. = 39.2 C

Average Temperature
At Each Location
Top Bulk Flow Test (October 22, 1993)



Average temperature during course of experiment

Wheat Repetition #2

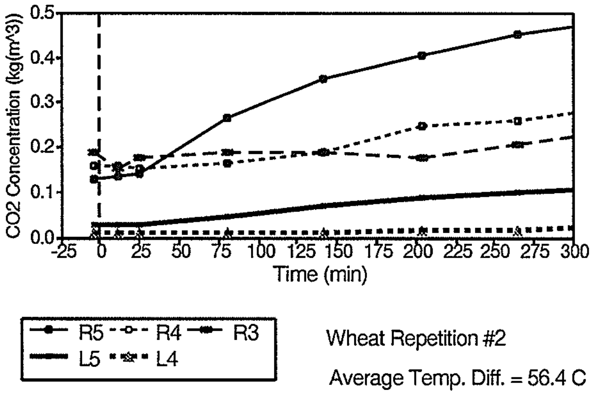
Average Temp. Diff. = 39.2 C

(Excluding locations 2 and 14)

October 26, 1993
Bottom No-flow Test
Temperature Difference = 56.4 C
Wheat Repetition #2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		61.23		61.23		61.23		20.00			4.78		4.78		4.78	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	99.26	8.10	0.1273	9.90	0.1555	11.74	0.1845	74.47	1.3346	1.2609	1.44	0.0271	0.52	0.0098	0.41	0.0078
10	99.28	8.47	0.1331	9.81	0.1541	9.73	0.1529	70.84	1.2697	1.2330	1.29	0.0244	0.54	0.0101	0.37	0.0071
25	99.29	8.86	0.1392	9.38	0.1473	10.95	0.1720	64.97	1.1647	1.2038	1.30	0.0247	0.52	0.0097	0.40	0.0075
81	99.33	16.74	0.2631	10.24	0.1609	11.69	0.1838	58.93	1.0568	1.1006	2.36	0.0447	0.55	0.0104	0.46	0.0088
141	99.42	22.51	0.3542	11.92	0.1876	11.67	0.1837	56.48	1.0137	0.9999	3.55	0.0673	0.63	0.0119	0.44	0.0083
203	99.42	25.69	0.4042	15.44	0.2430	10.94	0.1721	47.88	0.8595	0.9054	4.51	0.0854	0.73	0.0138	0.34	0.0065
265	99.42	28.84	0.4538	16.46	0.2590	13.07	0.2057	45.66	0.8196	0.8199	5.22	0.0988	0.94	0.0178	0.39	0.0073
325	99.43	30.16	0.4746	18.12	0.2852	14.74	0.2319	43.78	0.7859	0.7449	5.54	0.1048	1.04	0.0196	0.40	0.0075
385	99.42	29.37	0.4621	20.82	0.3277	15.98	0.2514	38.71	0.6947	0.6767	5.74	0.1086	1.15	0.0218	0.40	0.0076

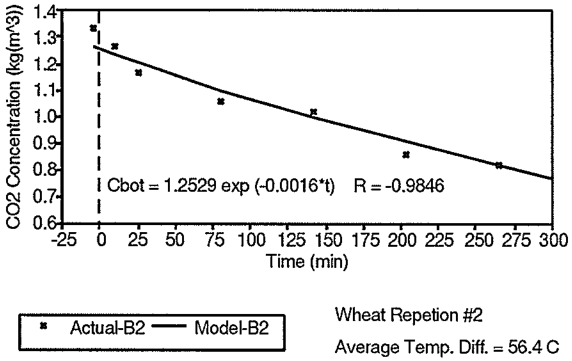
Concentration vs. Time
Bottom No-flow Test (October 26, 1993)



Wheat Repetition #2

Average Temp. Diff. = 56.4 C

Concentration vs. Time
B2 Model (October 26,1993)

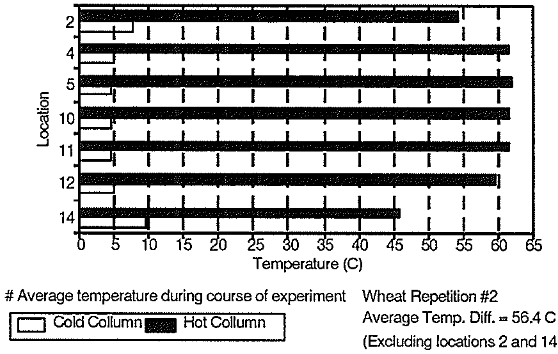


Wheat Repetion #2

Average Temp. Diff. = 56.4 C

Average Temperature #
At Each Location

Bottom No-flow Test (October 26, 1993)

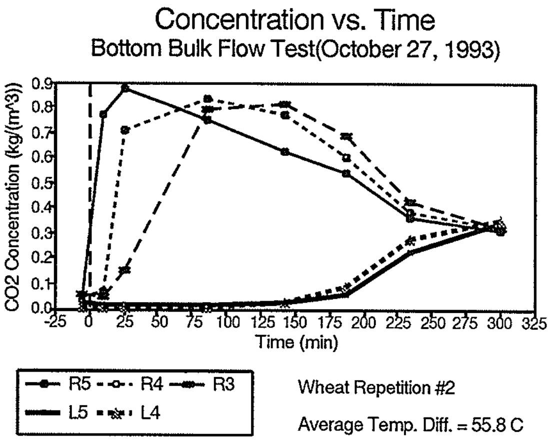


Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 56.4 C
(Excluding locations 2 and 14)

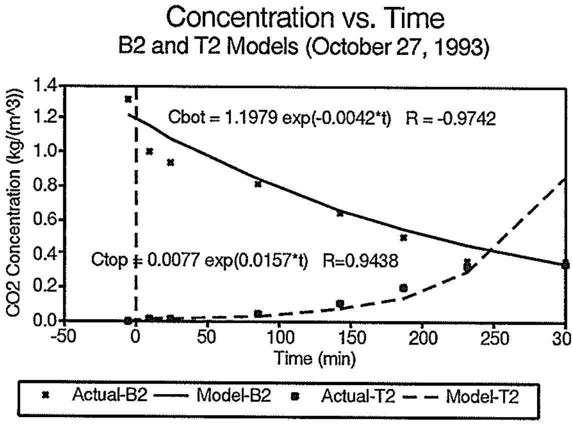
October 27, 1993
Bottom Bulk Flow Test
Temperature Difference = 55.8 C
Wheat Repetition #2

		Concentraton of CO2															
	Location	R5		R4		R3		B2			L5		L4		T2		
	Temperature (C)	60.64		60.64		60.64		18.00			4.78		4.78		19.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	98.67	2.35	0.0367	2.92	0.0457	3.63	0.0569	73.24	1.3136	1.2233	1.24	0.0232	0.27	0.0050	0.12	0.0021	0.0071
10	98.67	49.42	0.7732	4.50	0.0704	2.87	0.0449	55.50	0.9954	1.1486	0.77	0.0144	0.26	0.0048	0.55	0.0097	0.0090
25	98.40	56.03	0.8742	45.85	0.7154	10.21	0.1593	52.61	0.9410	1.0785	0.85	0.0159	0.21	0.0040	0.72	0.0129	0.0114
85	98.21	48.34	0.7527	53.91	0.8395	51.18	0.7969	45.95	0.8203	0.8383	0.95	0.0177	0.63	0.0118	2.32	0.0413	0.0292
143	98.00	40.51	0.6295	49.90	0.7753	52.51	0.8160	36.28	0.6463	0.6570	1.33	0.0248	1.59	0.0297	6.07	0.1077	0.0727
188	97.85	34.94	0.5421	38.98	0.6048	44.15	0.6850	28.25	0.5025	0.5439	3.46	0.0645	4.99	0.0930	11.00	0.1949	0.1474
233	97.78	23.34	0.3619	24.86	0.3855	27.68	0.4292	19.92	0.3541	0.4502	12.32	0.2294	14.75	0.2746	18.66	0.3305	0.2987
300	97.32	20.32	0.3136	20.82	0.3213	20.75	0.3202	20.58	0.3641	0.3398	18.56	0.3440	19.30	0.3577	19.52	0.3441	0.8551



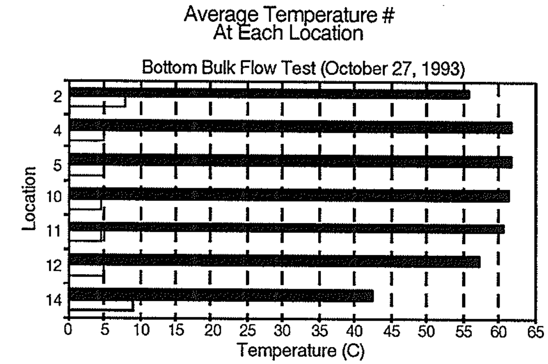
Wheat Repetition #2

Average Temp. Diff. = 55.8 C



Wheat Repetition #2

Average Temp. Diff. = 55.8 C



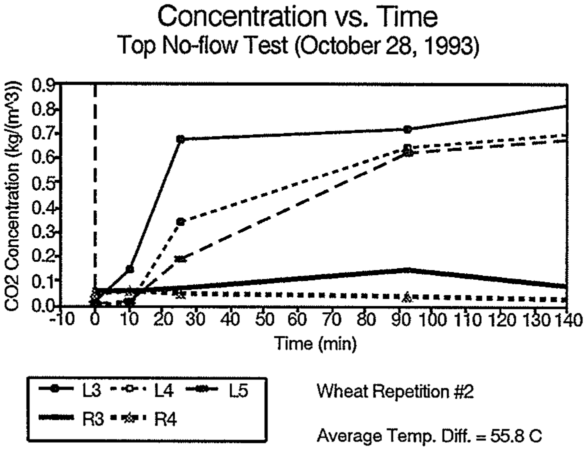
Average temperature during course of experiment

☐ Cold Collumn ■ Hot Collumn

Wheat Repetition #2
Average Temp. Diff = 55.8 C
(Excluding locations 2 and 14)

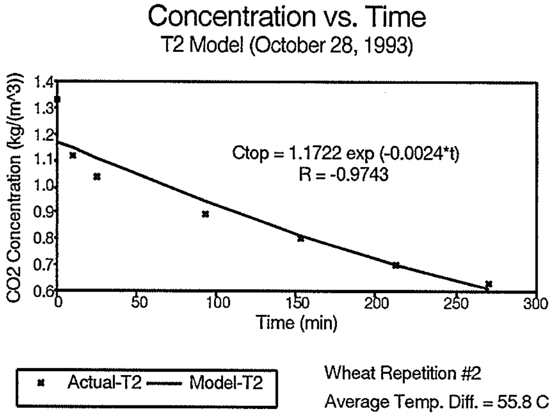
October 28, 1993
Top No-flow Test
Temperature Difference = 55.8 C
Wheat Repetition #2

		Concentration of CO2														
	Location	L3		L4		L5		T2			R3		R4		R5	
	Temperature (C)	5.01		5.01		5.01		20.00			60.84		60.84		60.84	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	96.44	0.81	0.0149	0.43	0.0079	0.46	0.0084	76.39	1.3300	1.1722	4.17	0.0637	3.15	0.0481	2.56	0.0392
10	96.44	7.92	0.1454	0.56	0.0103	1.09	0.0199	64.08	1.1156	1.1444	4.21	0.0643	3.61	0.0552	3.31	0.0506
25	96.48	36.99	0.6790	18.52	0.3399	10.59	0.1943	59.65	1.0390	1.1039	4.56	0.0697	3.18	0.0486	2.37	0.0362
92	96.57	39.23	0.7209	34.96	0.6423	33.56	0.6166	51.22	0.8931	0.9400	9.70	0.1484	2.47	0.0378	2.05	0.0314
152	96.68	45.35	0.8342	38.59	0.7100	37.47	0.6893	45.66	0.7971	0.8139	4.68	0.0717	1.40	0.0214	1.08	0.0166
212	96.81	41.04	0.7559	44.46	0.8189	41.41	0.7627	40.27	0.7039	0.7047	2.53	0.0388	0.91	0.0139	0.72	0.0111
272	96.95	42.52	0.7844	45.30	0.8357	44.34	0.8179	35.78	0.6262	0.6102	1.59	0.0244	0.80	0.0123	0.72	0.0110



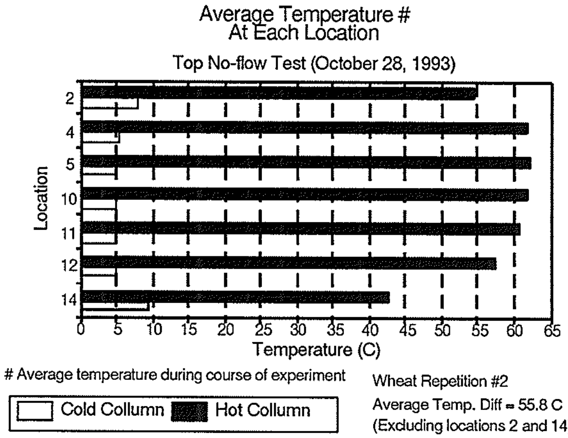
Wheat Repetition #2

Average Temp. Diff. = 55.8 C



Wheat Repetition #2

Average Temp. Diff. = 55.8 C



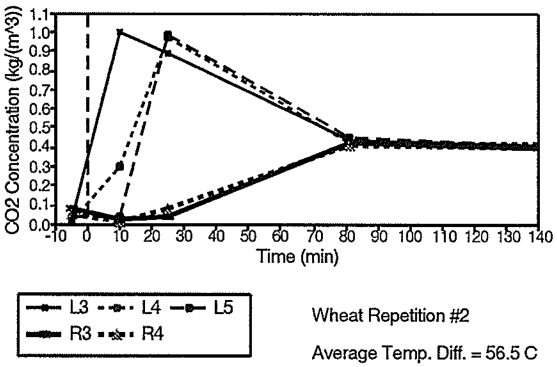
Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff = 55.8 C
(Excluding locations 2 and 14)

October 29, 1993
Top Bulk Flow Test
Temperature Difference = 56.5 C
Wheat Repetition #2

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		5.02		5.02		5.02		20.00			61.49		61.49		19.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	99.05	1.27	0.0240	0.94	0.0177	2.02	0.0380	69.86	1.2492	1.0811	4.77	0.0747	3.40	0.0533	0.08	0.0014	0.0061
10	99.07	53.16	1.0020	15.82	0.2983	2.38	0.0449	60.48	1.0818	0.9588	1.60	0.0250	0.65	0.0101	0.95	0.0171	0.0104
25	99.08	47.46	0.8948	51.73	0.9753	52.28	0.9855	39.80	0.7119	0.8504	2.50	0.0391	4.71	0.0739	1.83	0.0329	0.0178
81	99.16	23.05	0.4348	22.37	0.4221	23.91	0.4511	23.15	0.4144	0.5433	27.31	0.4282	26.43	0.4145	27.53	0.4945	0.1305
141	99.27	22.00	0.4156	22.66	0.4280	21.76	0.4111	22.56	0.4043	0.3362	25.15	0.3948	25.13	0.3946	23.57	0.4238	1.1049

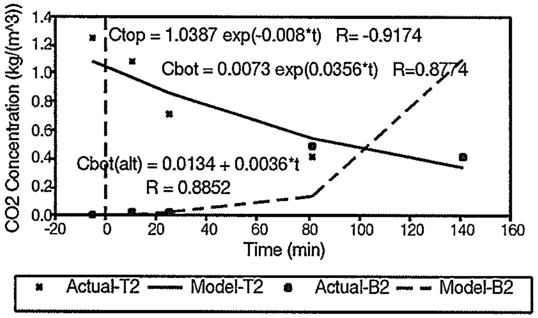
Concentration vs. Time
Top Bulk Flow Test (October 29, 1993)



Wheat Repetition #2

Average Temp. Diff. = 56.5 C

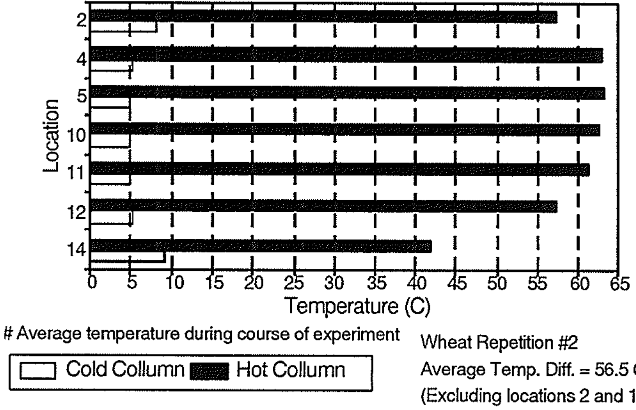
Concentration vs. Time
T2 and B2 Models (October 29, 1993)



Wheat Repetition #2 Average Temp. Diff. = 56.5 C

Average Temperature #
At Each Location

Top Bilk Flow Test (October 29, 1993)

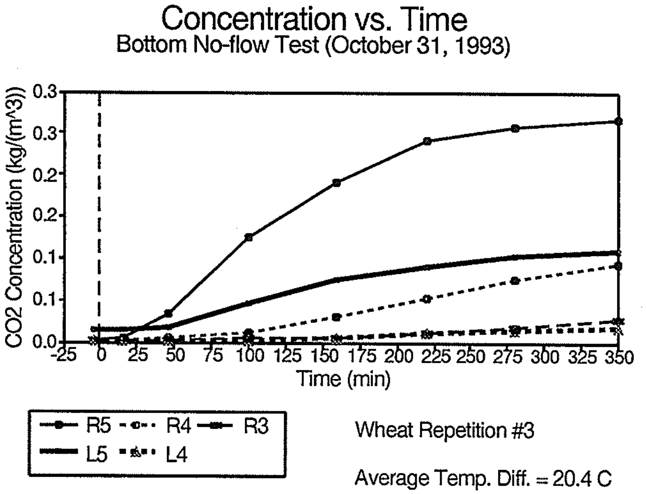


Average temperature during course of experiment

Wheat Repetition #2
Average Temp. Diff. = 56.5 C
(Excluding locations 2 and 14)

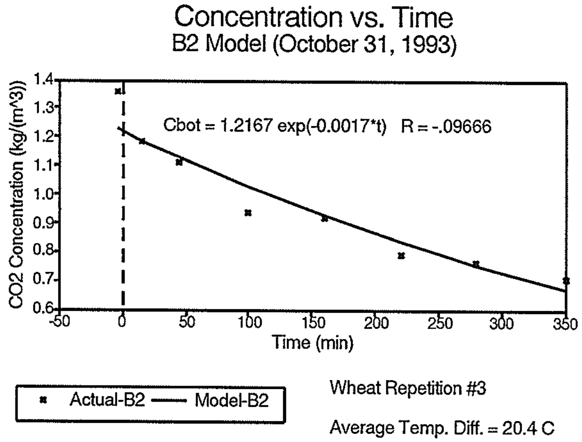
October 31, 1993
Bottom No-flow Test
Temperature Difference = 20.4 C
Wheat Repetition #3

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		31.13		31.13		31.13		20.00			10.72		10.72		10.72	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.57	0.16	0.0027	0.17	0.0028	0.17	0.0029	76.14	1.3550	1.2250	0.76	0.0139	0.12	0.0022	0.09	0.0016
15	98.55	0.30	0.0051	0.17	0.0029	0.17	0.0030	66.39	1.1813	1.1861	0.72	0.0133	0.12	0.0021	0.09	0.0017
45	98.54	1.95	0.0335	0.20	0.0034	0.17	0.0029	62.44	1.1108	1.1271	1.03	0.0189	0.11	0.0020	0.08	0.0014
100	98.53	7.20	0.1233	0.58	0.0100	0.20	0.0035	52.63	0.9361	1.0265	2.56	0.0470	0.18	0.0032	0.09	0.0017
160	98.53	11.24	0.1927	1.73	0.0296	0.32	0.0055	51.36	0.9136	0.9269	4.07	0.0748	0.35	0.0064	0.09	0.0017
220	98.50	14.02	0.2402	2.99	0.0512	0.61	0.0105	44.45	0.7904	0.8371	4.86	0.0893	0.58	0.0106	0.12	0.0021
280	98.47	14.99	0.2568	4.38	0.0750	1.04	0.0178	42.83	0.7613	0.7559	5.54	0.1017	0.82	0.0150	0.15	0.0028
350	98.40	15.54	0.2660	5.46	0.0934	1.64	0.0280	39.60	0.7035	0.6711	5.86	0.1075	1.04	0.0191	0.31	0.0057



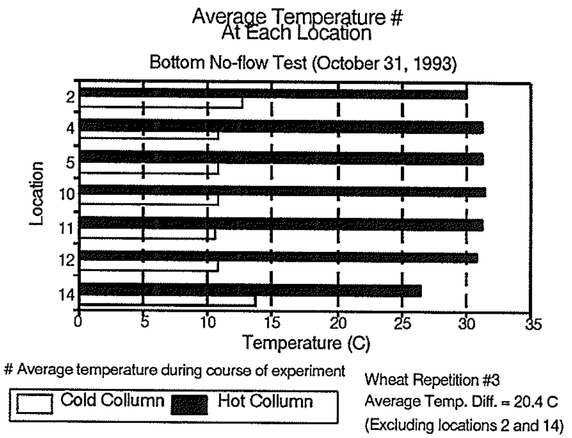
Wheat Repetition #3

Average Temp. Diff. = 20.4 C



Wheat Repetition #3

Average Temp. Diff. = 20.4 C

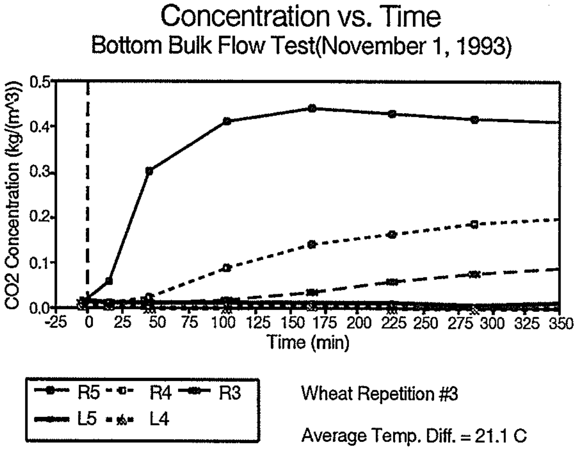


Average temperature during course of experiment

Wheat Repetition #3
Average Temp. Diff. = 20.4 C
(Excluding locations 2 and 14)

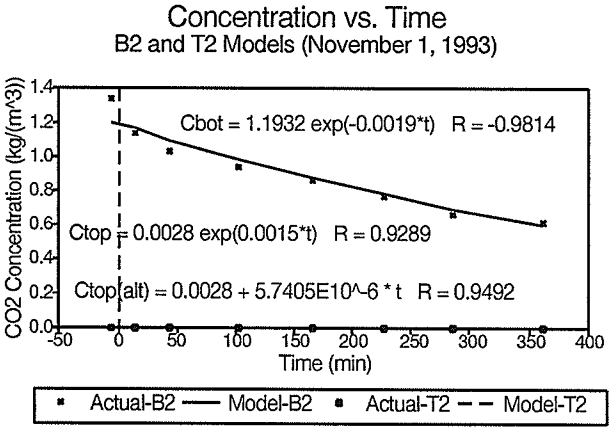
November 1, 1993
Bottom Bulk Flow Test
Temperature Difference = 21.1 C
Wheat Repetition #3

		Concentration of CO2															
	Location	R5		R4		R3		B2			L5		L4		T2		
	Temperature (C)	31.38		31.38		31.38		21.00			10.25		10.25		22.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	97.64	0.77	0.0130	0.67	0.0113	0.59	0.0100	76.00	1.3352	1.2046	1.12	0.0204	0.30	0.0055	0.14	0.0025	0.0028
15	97.63	3.48	0.0590	0.77	0.0131	0.63	0.0107	64.50	1.1331	1.1597	0.87	0.0158	0.25	0.0046	0.17	0.0030	0.0029
45	97.63	17.97	0.3049	1.46	0.0248	0.68	0.0115	58.78	1.0325	1.0954	0.83	0.0152	0.22	0.0040	0.19	0.0033	0.0030
103	97.61	24.41	0.4140	5.28	0.0895	1.11	0.0187	53.67	0.9426	0.9811	0.79	0.0144	0.21	0.0039	0.20	0.0034	0.0033
166	97.60	25.95	0.4402	8.25	0.1399	2.24	0.0380	48.96	0.8598	0.8704	0.80	0.0145	0.28	0.0051	0.21	0.0037	0.0036
226	97.59	25.49	0.4323	9.71	0.1646	3.40	0.0576	44.12	0.7748	0.7767	0.67	0.0121	0.20	0.0036	0.22	0.0038	0.0039
286	97.60	24.67	0.4184	11.02	0.1870	4.41	0.0749	38.11	0.6693	0.6930	0.34	0.0062	0.19	0.0035	0.24	0.0041	0.0043
361	97.57	24.40	0.4137	12.00	0.2035	5.42	0.0919	35.11	0.6164	0.6009	0.67	0.0121	0.23	0.0041	0.30	0.0052	0.0048

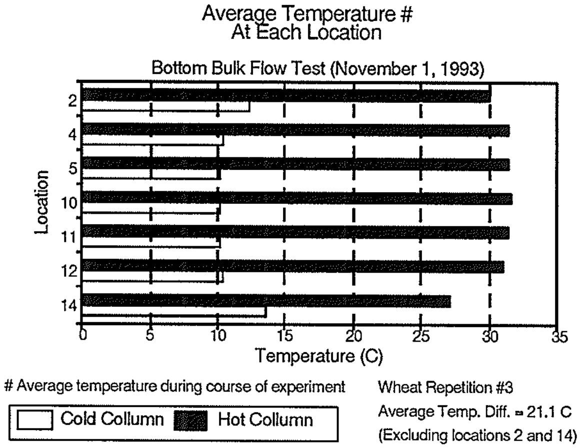


Wheat Repetition #3

Average Temp. Diff. = 21.1 C



Wheat Repetition #3 Average Temp. Diff. = 21.1 C

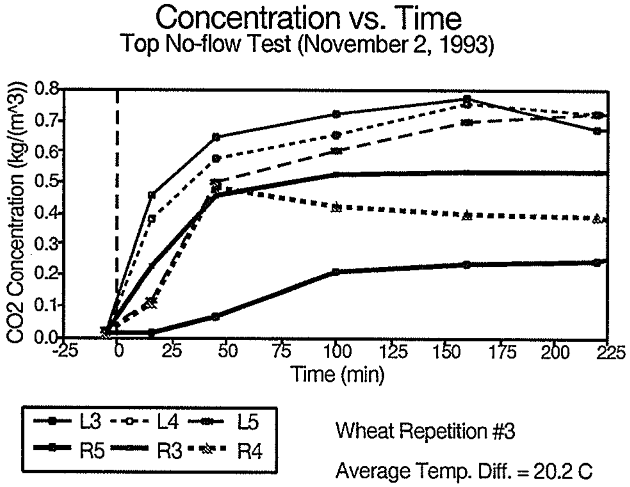


Average temperature during course of experiment

Wheat Repetition #3
Average Temp. Diff. = 21.1 C
(Excluding locations 2 and 14)

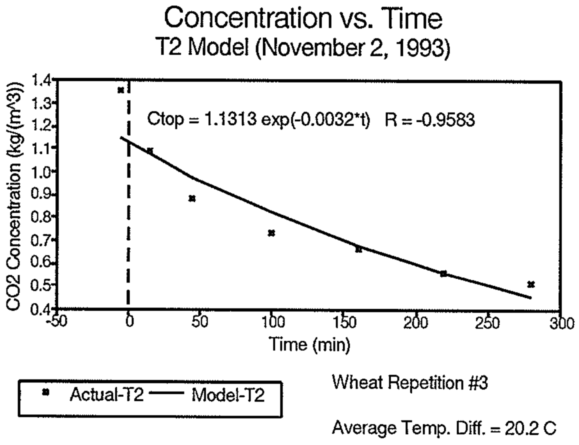
November 2, 1993
Top No-flow Test
Temperature Difference = 20.2 C
Wheat Repetition #3

		Concentration of CO2														
Location		R3		R4		R5		T2			L3		L4		L5	
Temperature (C)		31.61		31.61		31.61		23.00			11.38		11.38		11.38	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	98.04	0.73	0.0125	0.85	0.0144	0.96	0.0163	77.35	1.3553	1.1495	0.61	0.0110	0.32	0.0059	1.00	0.0183
15	98.05	13.19	0.2247	6.40	0.1089	0.98	0.0167	62.47	1.0947	1.0783	24.99	0.4558	20.81	0.3796	6.15	0.1122
45	98.07	26.94	0.4588	28.24	0.4810	3.54	0.0603	50.42	0.8836	0.9796	35.18	0.6418	31.47	0.5741	27.28	0.4976
100	98.09	30.84	0.5254	24.84	0.4231	12.42	0.2116	41.62	0.7296	0.8215	39.47	0.7202	35.82	0.6536	33.02	0.6024
160	98.12	31.58	0.5382	23.20	0.3953	13.68	0.2331	37.80	0.6629	0.6780	42.25	0.7712	41.46	0.7568	38.03	0.6941
220	98.12	31.37	0.5346	22.93	0.3906	14.54	0.2477	32.15	0.5638	0.5595	36.93	0.6741	39.81	0.7267	39.66	0.7238
280	98.04	29.36	0.4999	16.32	0.2779	15.18	0.2585	29.03	0.5087	0.4618	33.07	0.6032	36.24	0.6609	37.57	0.6851



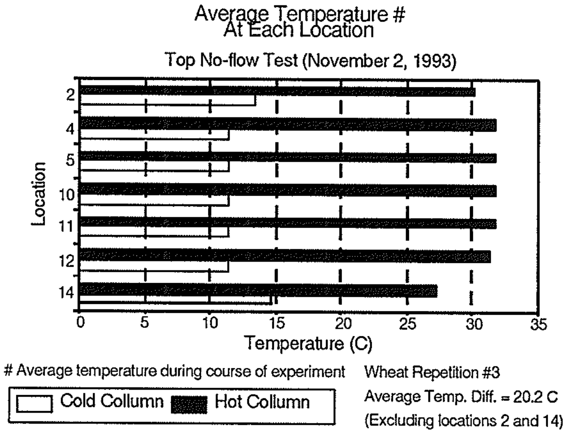
Wheat Repetition #3

Average Temp. Diff. = 20.2 C



Wheat Repetition #3

Average Temp. Diff. = 20.2 C



Average temperature during course of experiment

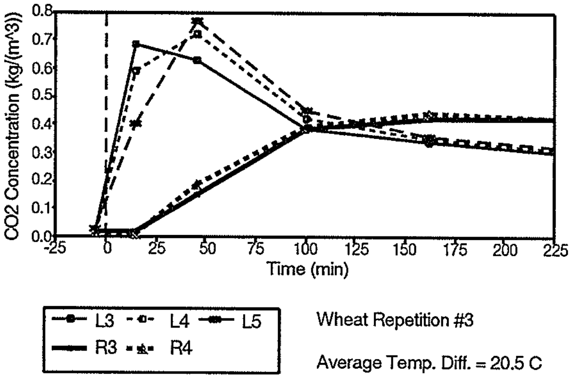
Wheat Repetition #3

Average Temp. Diff. = 20.2 C

(Excluding locations 2 and 14)

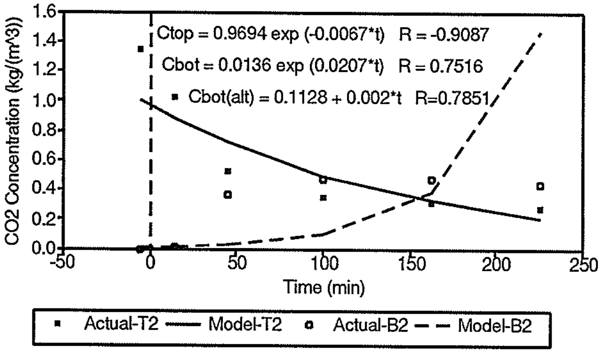
November 3, 1993
Top Bulk Flow Test
Temperature Difference = 20.5 C
Wheat Repetition #3

		Concentration of CO2															
Location		L3		L4		L5		T2			B2			R3		R4	
Temperature (C)		11.52		11.52		11.52		22.00			21.00			32.03		32.03	
Time	Pressure								Actual	Model		Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	97.71	1.11	0.0201	0.61	0.0110	1.38	0.0251	76.62	1.3425	1.0024	0.12	0.0021	0.0123	0.93	0.0157	0.80	0.0135
15	97.71	37.57	0.6825	32.64	0.5929	22.42	0.4073	58.78	1.0299	0.8767	0.38	0.0067	0.0186	0.79	0.0133	0.63	0.0107
45	97.73	34.45	0.6260	39.41	0.7161	42.28	0.7682	30.10	0.5274	0.7171	20.68	0.3637	0.0345	8.90	0.1508	11.14	0.1888
100	97.74	21.00	0.3816	23.31	0.4236	24.63	0.4475	20.39	0.3573	0.4961	26.60	0.4677	0.1078	22.66	0.3841	23.43	0.3972
162	97.72	18.57	0.3374	18.91	0.3435	19.48	0.3539	17.57	0.3078	0.3274	26.64	0.4683	0.3890	24.98	0.4234	25.77	0.4366
226	97.70	16.30	0.2961	16.75	0.3042	17.33	0.3148	15.68	0.2747	0.2133	24.63	0.4329	1.4630	25.09	0.4252	24.98	0.4232


Concentration vs. Time
Top Bulk Flow Test (November 3, 1993)

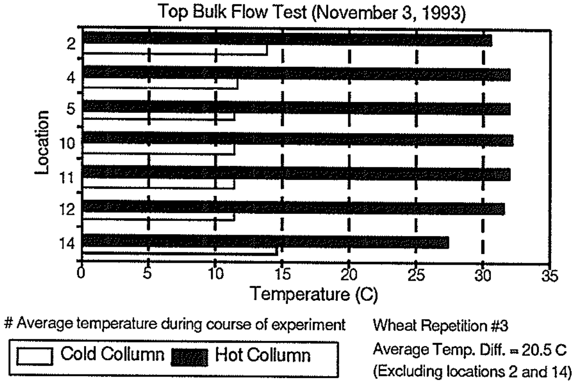
Wheat Repetition #3

Average Temp. Diff. = 20.5 C


Concentration vs. Time
T2 and B2 Models (November 3, 1993)

Wheat Repetition #3

Average Temp. Diff. = 20.5 C


Average Temperature #
At Each Location
Top Bulk Flow Test (November 3, 1993)

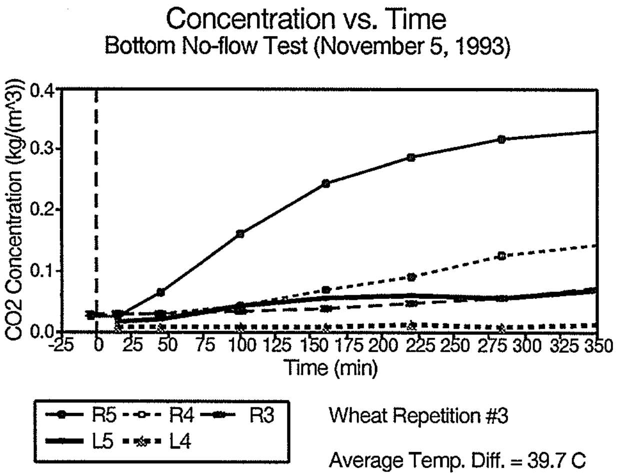
Average temperature during course of experiment

Wheat Repetition #3
Average Temp. Diff. = 20.5 C
(Excluding locations 2 and 14)

November 5, 1993
Bottom No-flow Test
Temperature Difference = 39.7 C
Wheat Repetition #3

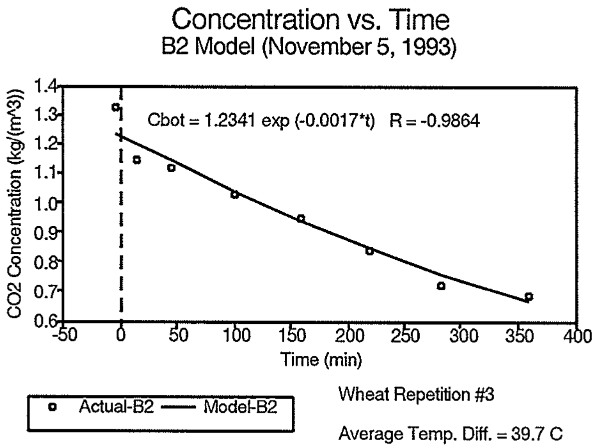
** Note: Blank entries in the table represent missing data

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		44.12		44.12		44.12		21.00			4.44		4.44		4.44	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	99.65	1.42	0.0236	1.58	0.0263	1.89	0.0314	74.13	1.3292	1.2425					0.23	0.0043
15	99.66	1.62	0.0270	1.73	0.0287	1.76	0.0292	63.87	1.1452	1.2030	0.89	0.0170	0.31	0.0058	0.35	0.0066
45	99.66	3.89	0.0646	1.78	0.0295	1.90	0.0315	62.68	1.1240	1.1432	1.16	0.0221	0.31	0.0059	0.23	0.0044
100	99.68	9.64	0.1604	2.42	0.0402	1.97	0.0328	57.41	1.0297	1.0412	2.11	0.0402	0.33	0.0062	0.23	0.0043
160	99.70	14.79	0.2460	4.03	0.0669	2.23	0.0371	52.63	0.9442	0.9402	2.98	0.0566	0.39	0.0073	0.22	0.0041
220	99.68	17.25	0.2869	5.56	0.0924	2.67	0.0443	47.08	0.8444	0.8490	3.06	0.0582	0.60	0.0113	0.21	0.0040
283	99.64	19.26	0.3202	7.46	0.1240	3.22	0.0535	40.39	0.7242	0.7628	2.98	0.0566	0.48	0.0091	0.20	0.0039
360	99.59	19.92	0.3308	8.69	0.1444	4.41	0.0733	38.14	0.6834	0.6692	3.61	0.0685	0.59	0.0112	0.21	0.0040



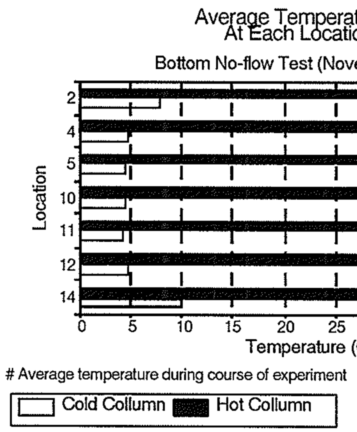
Wheat Repetition #3

Average Temp. Diff. = 39.7 C



Wheat Repetition #3

Average Temp. Diff. = 39.7 C



Average temperature during course of experiment

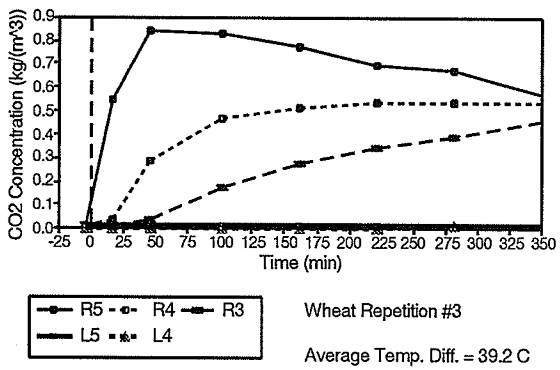
Wheat Repetition #3
Average Temp. Diff. = 39.7 C
(Excluding locations 2 and 14)

November 6, 1993
Bottom Bulk Flow Test
Temperature Difference = 39.2 C
Wheat Repetition #3

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		43.40		43.40		43.40		21.00			4.16		4.16		22.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-4	98.86	0.96	0.0159	0.96	0.0159	0.85	0.0140	72.44	1.2885	1.0812	0.92	0.0173	0.19	0.0036	0.09	0.0016	0.0025
17	98.83	33.06	0.5463	1.91	0.0315	0.98	0.0161	54.49	0.9690	1.0346	0.70	0.0132	0.16	0.0031	0.18	0.0032	0.0021
45	98.80	51.17	0.8453	16.94	0.2797	2.29	0.0378	52.35	0.9307	0.9755	0.68	0.0128	0.17	0.0031	0.23	0.0041	0.0017
101	98.68	49.92	0.8236	28.34	0.4676	10.64	0.1756	43.01	0.7636	0.8673	0.71	0.0133	0.22	0.0040	0.29	0.0052	0.0011
161	98.61	46.82	0.7719	31.29	0.5160	16.48	0.2717	42.90	0.7612	0.7646	0.85	0.0161	0.27	0.0050	0.46	0.0081	0.0007
221	98.49	42.33	0.6971	32.64	0.5375	20.63	0.3398	38.22	0.6773	0.6741	0.82	0.0154	0.32	0.0060	0.73	0.0129	0.0004
281	98.33	40.78	0.6704	32.36	0.5320	23.78	0.3909	33.71	0.5963	0.5943	0.69	0.0129	0.46	0.0086	1.20	0.0211	0.0003
360	98.16	34.09	0.5594	32.87	0.5394	27.92	0.4581	28.58	0.5048	0.5034	0.91	0.0170	0.81	0.0152	1.98	0.0349	0.0002

Concentration vs. Time

Bottom Bulk Flow Test(November 6, 1993)

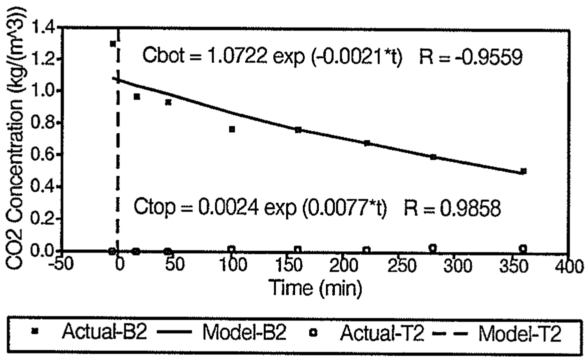


Wheat Repetition #3

Average Temp. Diff. = 39.2 C

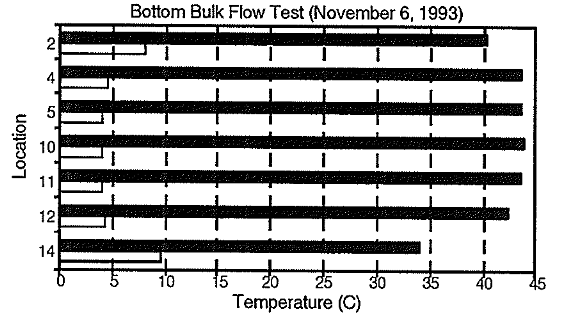
Concentration vs. Time

B2 and T2 Models (November 6, 1993)



Wheat Repetition #3 Average Temp. Diff. = 39.2 C

Average Temperature #
At Each Location



Average temperature during course of experiment

☐ Cold Collumn ■ Hot Collumn

Wheat Repetition #3
Average Temp. Diff. = 39.2 C
(Excluding locations 2 and 14)

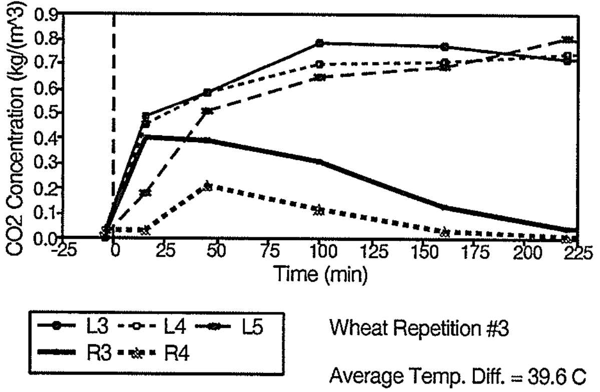
November 7, 1993
Top No-flow Test
Temperature Difference = 39.6 C
Wheat Repetition #3

** Note: Blank entries in the table represent missing data.

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		4.33		4.33		4.33		22.00			43.93		43.93		43.93	
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.05	1.65	0.0309	0.21	0.0040	0.86	0.0161	76.54	1.3458	1.1221	1.51	0.0246	1.75	0.0286	1.64	0.0269
15	98.07	26.14	0.4889	24.17	0.4520	9.57	0.1790	57.19	1.0057	1.0640	24.47	0.4006	1.83	0.0299	1.67	0.0274
45	98.11	31.25	0.5848	31.45	0.5885	27.58	0.5161	49.29	0.8671	0.9782	23.94	0.3921	12.86	0.2106	1.86	0.0304
100	98.21	41.82	0.7833	37.46	0.7016	34.73	0.6506	45.52	0.8017	0.8386	18.92	0.3101	7.01	0.1149	1.67	0.0273
160	98.30	41.62	0.7803	38.05	0.7134	36.48	0.6839	39.94	0.7040	0.7089	7.90	0.1296	2.24	0.0368	0.90	0.0148
220	98.36	38.68	0.7256	39.82	0.7470	42.83	0.8036	33.48	0.5905	0.5993	2.92	0.0480	0.93	0.0153		
280	98.40	35.01	0.6570	36.69	0.6887	38.95	0.7311	29.98	0.5290	0.5066	1.43	0.0235	0.80	0.0131	1.00	0.0163

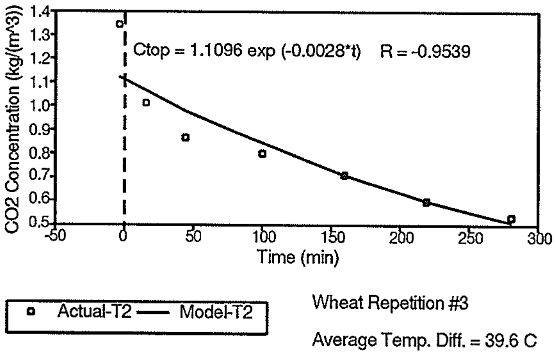
Concentration vs. Time
Top No-flow Test (November 7, 1993)



Wheat Repetition #3

Average Temp. Diff. = 39.6 C

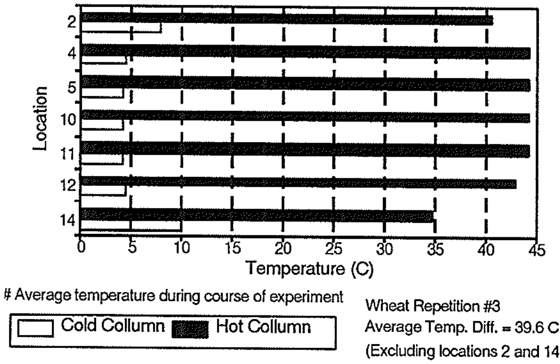
Concentration vs. Time
T2 Model (November 7, 1993)



Wheat Repetition #3

Average Temp. Diff. = 39.6 C

Average Temperature #
At Each Location
Top No-flow Test (November 7, 1993)



Average temperature during course of experiment

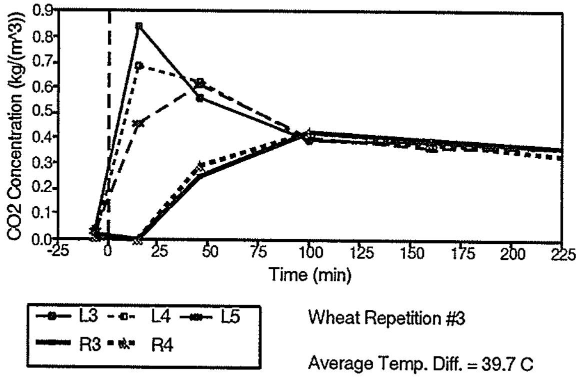
Wheat Repetition #3
Average Temp. Diff. = 39.6 C
(Excluding locations 2 and 14)

November 8, 1993
Top Bulk Flow Test
Temperature Difference = 39.7 C
Wheat Repetition #3

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		4.08		4.08		4.08		22.00			43.77		43.77		20.00		
									Actual	Model						Actual	Model
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	98.94	2.45	0.0462	0.67	0.0126	1.60	0.0302	75.29	1.3358	0.8844	1.01	0.0166	0.83	0.0138	0.07	0.0012	0.0180
15	98.94	44.26	0.8360	36.03	0.6805	24.10	0.4552	48.67	0.8636	0.7945	0.29	0.0047	0.24	0.0039	1.76	0.0315	0.0262
45	98.94	29.48	0.5569	32.72	0.6181	32.39	0.6118	25.81	0.4579	0.6818	15.27	0.2523	17.64	0.2914	23.92	0.4273	0.0450
100	98.95	21.06	0.3979	20.63	0.3896	21.36	0.4034	21.52	0.3818	0.5150	25.62	0.4234	25.68	0.4244	26.35	0.4708	0.1210
161	98.96	20.53	0.3878	19.97	0.3773	19.05	0.3600	20.47	0.3633	0.3773	23.62	0.3903	23.42	0.3871	23.73	0.4240	0.3628
229	98.94	19.43	0.3670	19.28	0.3642	19.34	0.3654	19.20	0.3406	0.2668	21.94	0.3626	20.13	0.3325	21.06	0.3762	1.2336

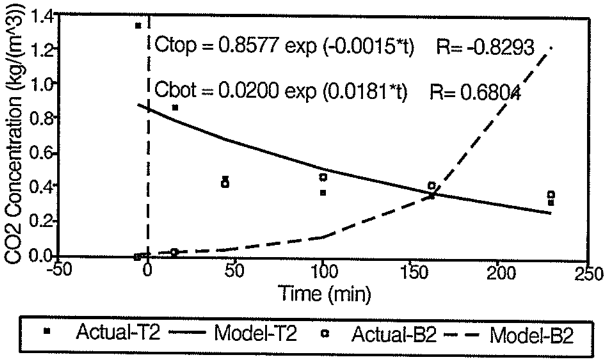
Concentration vs. Time
Top Bulk Flow Test (November 8, 1993)



Wheat Repetition #3

Average Temp. Diff. = 39.7 C

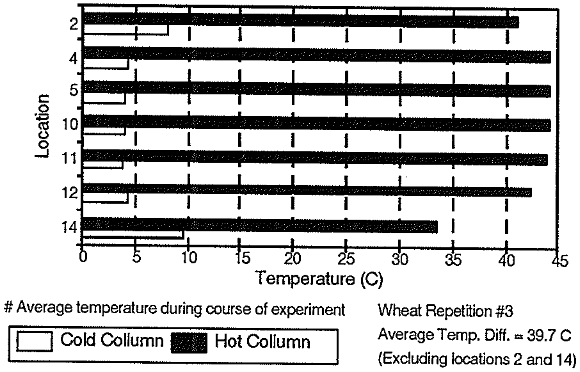
Concentration vs. Time
T2 and B2 Models (November 8, 1993)



Wheat Repetition #3 Average Temp. Diff. = 39.7 C

Average Temperature #
At Each Location

Top Bulk Flow Test (November 8, 1993)



Average temperature during course of experiment

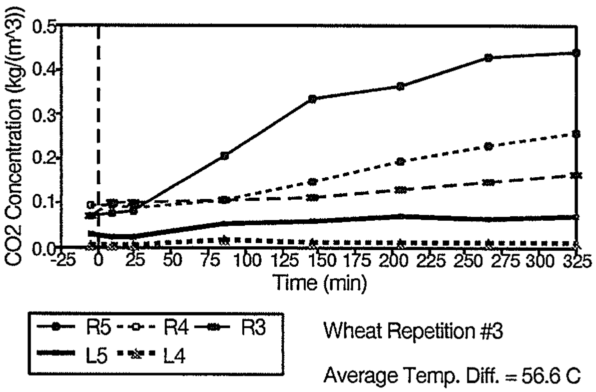
Wheat Repetition #3
Average Temp. Diff. = 39.7 C
(Excluding locations 2 and 14)

November 10, 1993
Bottom No-flow Test
Temperature Difference = 56.6 C
Wheat Repetition #3

Concentration of CO2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		60.68		60.68		60.68		20.00			4.06		4.06		4.06	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	99.00	4.60	0.0722	5.86	0.0919	4.51	0.0708	74.73	1.3356	1.2430	1.45	0.0274	0.45	0.0085	0.34	0.0064
10	99.00	4.78	0.0750	5.86	0.0919	6.44	0.1011	65.00	1.1618	1.2138	1.22	0.0231	0.45	0.0085	0.34	0.0065
25	98.97	5.08	0.0798	5.73	0.0899	6.37	0.0999	64.98	1.1610	1.1832	1.22	0.0231	0.41	0.0077	0.33	0.0063
85	98.88	13.16	0.2063	6.64	0.1041	6.83	0.1070	59.38	1.0601	1.0685	2.82	0.0532	0.93	0.0176	0.35	0.0065
145	98.79	21.46	0.3361	9.36	0.1467	7.24	0.1133	54.14	0.9656	0.9649	3.08	0.0581	0.60	0.0114	0.34	0.0064
205	98.79	23.42	0.3668	12.29	0.1926	8.32	0.1303	47.75	0.8517	0.8713	3.64	0.0686	0.66	0.0125	0.34	0.0064
265	98.67	27.60	0.4318	14.54	0.2274	9.54	0.1493	43.84	0.7810	0.7868	3.54	0.0667	0.66	0.0124	0.32	0.0059
325	98.51	28.10	0.4389	16.73	0.2613	10.71	0.1672	40.23	0.7155	0.7105	3.63	0.0683	0.69	0.0131	0.32	0.0061
380	98.43	28.64	0.4470	17.28	0.2697	12.08	0.1885	36.51	0.6489	0.6471	3.77	0.0709	0.72	0.0135	0.34	0.0063

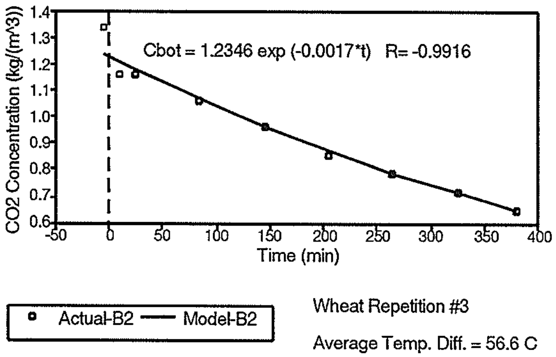
Concentration vs. Time
Bottom No-flow Test (November 10, 1993)



Wheat Repetition #3

Average Temp. Diff. = 56.6 C

Concentration vs. Time
B2 Model (November 10, 1993)

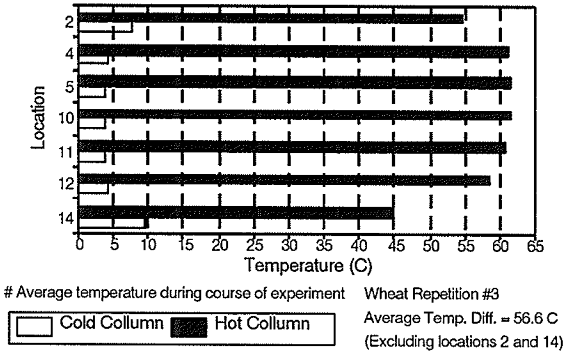


Wheat Repetition #3

Average Temp. Diff. = 56.6 C

Average Temperature #
At Each Location

Bottom No-flow Test (November 10, 1993)

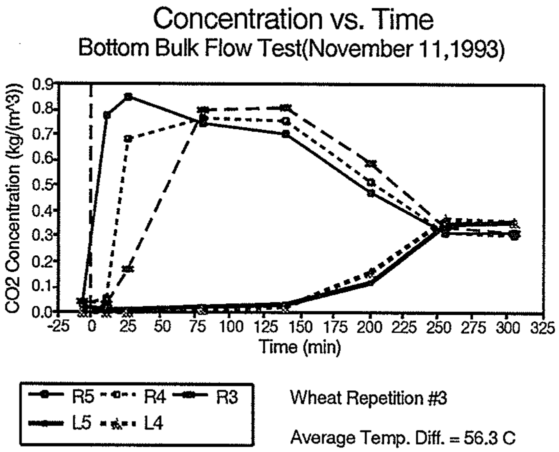


Average temperature during course of experiment

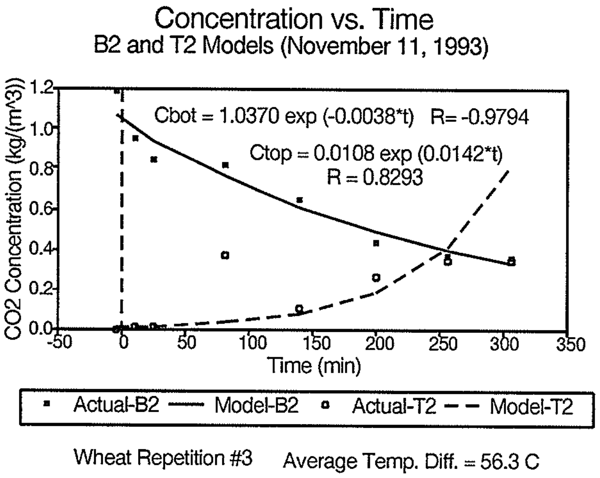
Wheat Repetition #3
Average Temp. Diff. = 56.6 C
(Excluding locations 2 and 14)

November 11, 1993
Bottom Bulk Flow Test
Temperature Difference = 56.3 C
Wheat Repetition #3

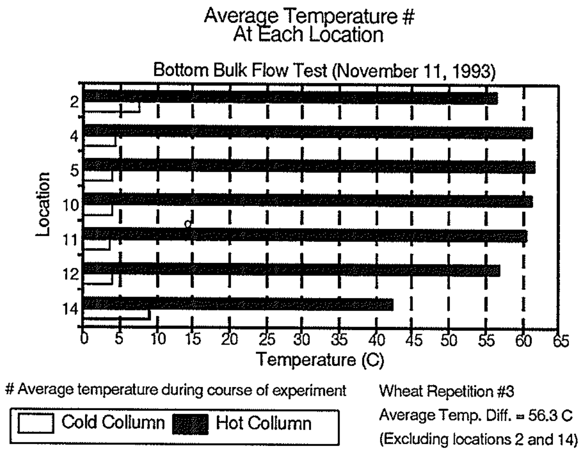
		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		T2	
Temperature (C)		60.33		60.33		60.33		20.00			3.98		3.98		22.00	
Time	Pressure								Actual	Model					Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	98.49	2.00	0.0312	2.39	0.0374	2.91	0.0455	66.79	1.1877	1.0609	1.18	0.0222	0.26	0.0050	0.14	0.0025	0.0099
10	98.50	49.88	0.7797	3.80	0.0595	2.44	0.0382	53.64	0.9538	0.9983	0.84	0.0157	0.22	0.0042	0.49	0.0086	0.0124
25	98.52	53.91	0.8430	43.51	0.6804	10.79	0.1687	47.33	0.8419	0.9430	0.77	0.0145	0.30	0.0057	0.65	0.0115	0.0154
80	98.57	47.50	0.7431	49.02	0.7669	51.13	0.7999	46.00	0.8186	0.7652	1.54	0.0290	0.60	0.0113	20.94	0.3701	0.0336
140	98.59	44.54	0.6969	47.86	0.7489	51.55	0.8065	36.54	0.6504	0.6092	1.59	0.0300	1.58	0.0297	6.13	0.1083	0.0788
200	98.60	29.79	0.4662	32.53	0.5090	37.31	0.5839	24.47	0.4356	0.4850	6.04	0.1137	8.30	0.1563	14.80	0.2617	0.1849
255	98.59	20.53	0.3212	20.18	0.3157	21.49	0.3362	21.10	0.3756	0.3935	18.18	0.3423	19.36	0.3645	19.63	0.3471	0.4036
305	98.56	19.94	0.3119	19.49	0.3048	20.26	0.3170	20.11	0.3578	0.3254	18.76	0.3531	19.12	0.3600	19.24	0.3401	0.8210


Concentration vs. Time
Bottom Bulk Flow Test(November 11,1993)

Wheat Repetition #3
Average Temp. Diff. = 56.3 C


Concentration vs. Time
B2 and T2 Models (November 11, 1993)

Wheat Repetition #3 Average Temp. Diff. = 56.3 C


Average Temperature #
At Each Location

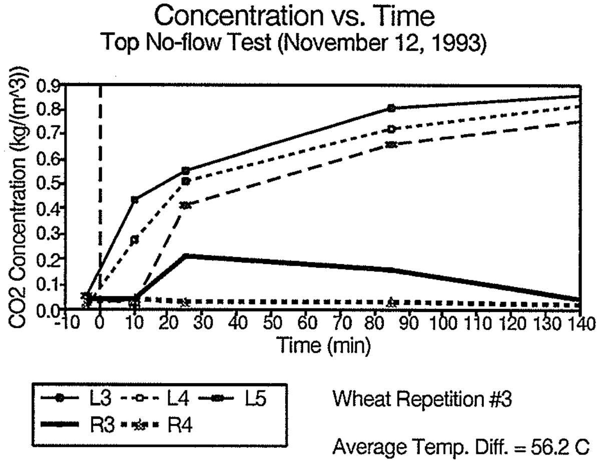
Average temperature during course of experiment

Wheat Repetition #3
Average Temp. Diff. = 56.3 C
(Excluding locations 2 and 14)

November 12, 1993
Top No-flow Test
Temperature Difference = 56.2 C
Wheat Repetition #3

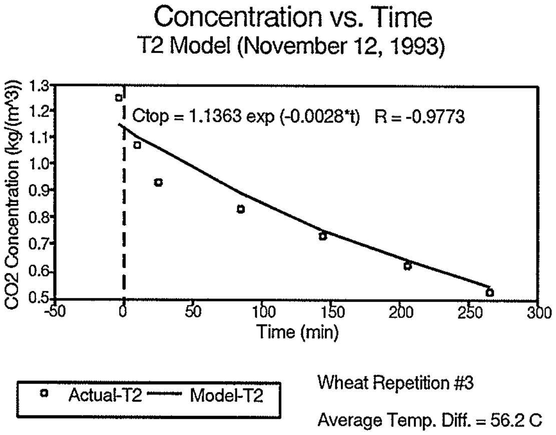
Concentration of CO2

		L3		L4		L5		T2			R3		R4		R5	
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		4.08		4.08		4.08		22.00			60.31		60.31		60.31	
Time	Pressure								Actual	Model						
(min.)	(KPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	98.43	2.63	0.0495	0.37	0.0069	2.75	0.0516	71.05	1.2540	1.1491	3.09	0.0483	2.35	0.0368	1.74	0.0272
10	98.52	23.33	0.4388	14.45	0.2718	1.05	0.0198	60.42	1.0674	1.1049	2.97	0.0465	2.42	0.0378	1.83	0.0286
25	98.52	29.19	0.5490	27.17	0.5111	21.87	0.4114	52.83	0.9334	1.0595	13.37	0.2090	2.19	0.0343	2.00	0.0312
85	98.57	42.71	0.8037	38.17	0.7182	35.04	0.6594	47.37	0.8372	0.8956	10.49	0.1641	2.28	0.0357	1.59	0.0248
145	98.59	45.67	0.8595	43.98	0.8277	40.46	0.7614	41.24	0.7290	0.7571	2.19	0.0342	1.61	0.0251	1.68	0.0263
205	98.60	40.03	0.7535	42.38	0.7977	43.75	0.8236	35.33	0.6246	0.6400	2.97	0.0464	1.13	0.0177	0.86	0.0135
265	98.59	34.60	0.6512	36.71	0.6910	40.11	0.7550	29.88	0.5282	0.5411	2.00	0.0313	0.92	0.0144	0.63	0.0098


Concentration vs. Time
Top No-flow Test (November 12, 1993)

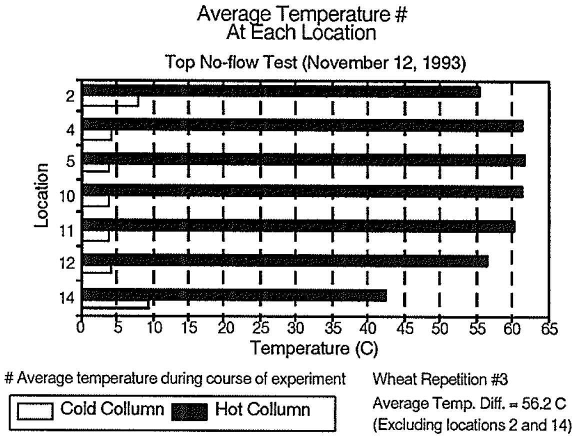
Wheat Repetition #3

Average Temp. Diff. = 56.2 C


Concentration vs. Time
T2 Model (November 12, 1993)

Wheat Repetition #3

Average Temp. Diff. = 56.2 C

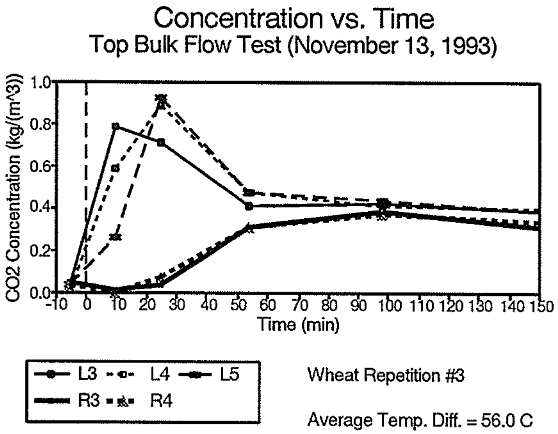

Average Temperature #
At Each Location
Top No-flow Test (November 12, 1993)

Average temperature during course of experiment

Wheat Repetition #3
Average Temp. Diff. = 56.2 C
(Excluding locations 2 and 14)

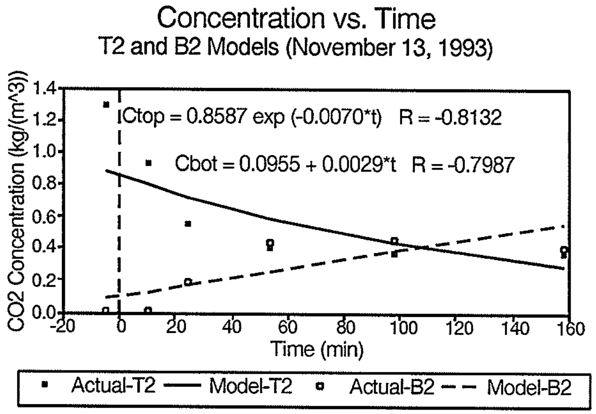
November 13, 1993
Top Bulk Flow Test
Temperature Difference = 56.0 C
Wheat Repetition #3

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		4.23		4.23		4.23		21.00			60.24		60.24		20.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	97.77	1.93	0.0359	0.63	0.0118	1.91	0.0355	73.41	1.2915	0.8893	3.06	0.0475	2.43	0.0378	0.10	0.0018	0.0810
10	97.79	42.25	0.7883	31.27	0.5835	13.73	0.2561	53.20	0.9361	0.8006	0.85	0.0132	0.27	0.0042	0.32	0.0056	0.1245
25	97.82	38.29	0.7147	47.23	0.8816	49.23	0.9189	31.62	0.5565	0.7208	2.48	0.0385	4.46	0.0692	10.53	0.1859	0.1680
54	97.85	21.95	0.4098	25.53	0.4767	25.49	0.4760	22.63	0.3984	0.5884	19.91	0.3093	19.79	0.3075	25.14	0.4442	0.2521
98	98.87	22.52	0.4248	22.13	0.4174	22.96	0.4332	20.88	0.3714	0.4324	24.90	0.3909	23.93	0.3756	25.32	0.4519	0.3797
158	97.94	20.78	0.3884	21.34	0.3988	20.76	0.3879	21.08	0.3714	0.2841	19.74	0.3069	21.66	0.3368	23.11	0.4087	0.5537

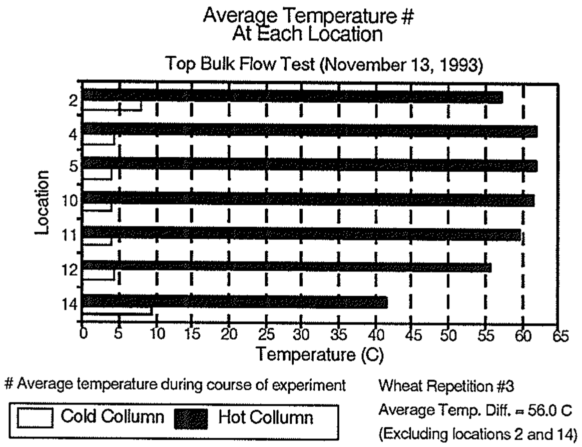


Wheat Repetition #3

Average Temp. Diff. = 56.0 C



Wheat Repetition #3 Average Temp. Diff. = 56.0 C



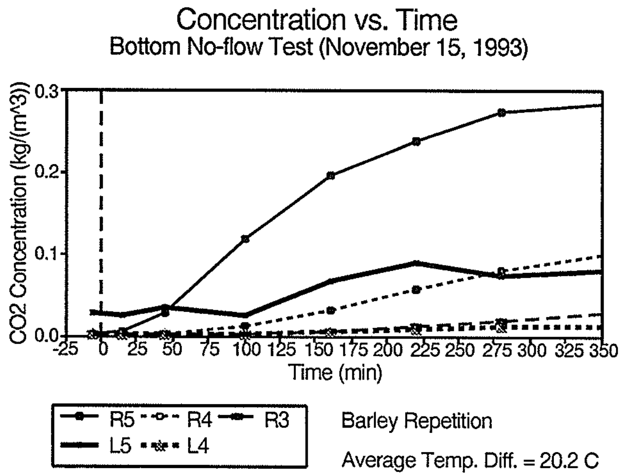
Average temperature during course of experiment

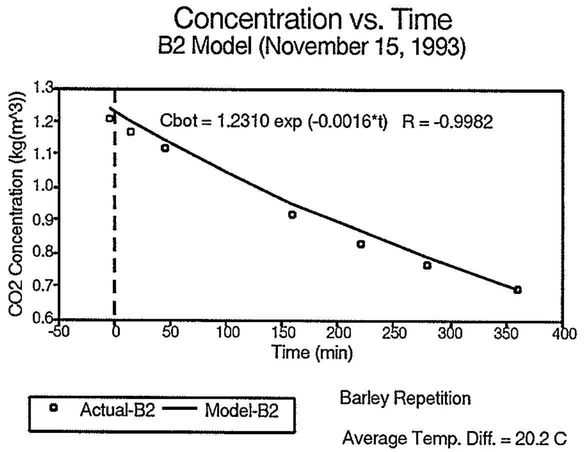
Wheat Repetition #3
Average Temp. Diff. = 56.0 C
(Excluding locations 2 and 14)

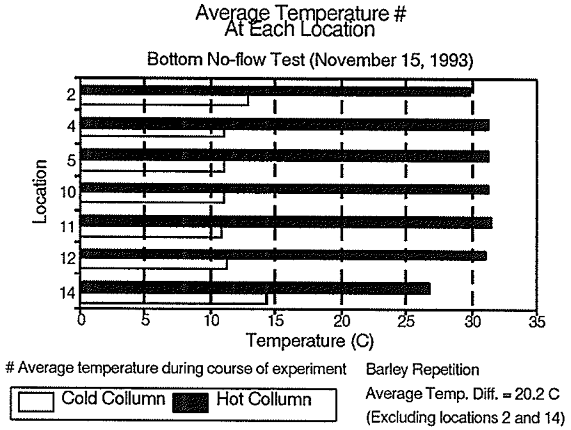
November 15, 1993
Bottom No-flow Test
Temperence Difference = 20.2 C
Barley Repetition

** Note: Blank entries in the table represent missing data.

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		L3		
Temperature (C)		31.29		31.29		31.29		20.00			11.08		11.08		11.08		
Time	Pressure								Actual	Model							
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-5	98.02	0.09	0.0015	0.10	0.0017	0.11	0.0019	68.35	1.2095	1.2409	1.57	0.0286	0.15	0.0027	0.10	0.0018	
15	98.01	0.22	0.0037	0.12	0.0020	0.12	0.0020	65.90	1.1660	1.2018	1.25	0.0228	0.17	0.0032	0.11	0.0020	
45	97.99	1.55	0.0263	0.16	0.0027	0.12	0.0020	63.15	1.1172	1.1455	1.84	0.0335	0.17	0.0031	0.11	0.0020	
100	98.00	7.07	0.1204	0.65	0.0111	0.14	0.0024			1.0490	1.23	0.0224	0.18	0.0032	0.08	0.0015	
160	97.98	11.61	0.1978	1.73	0.0294	0.22	0.0038	51.69	0.9144	0.9530	3.56	0.0649	0.34	0.0062	0.11	0.0020	
220	97.99	14.06	0.2394	3.29	0.0560	0.56	0.0096	47.04	0.8321	0.8657	4.94	0.0900	0.42	0.0076	0.11	0.0020	
280	97.97	16.08	0.2738	4.65	0.0792	1.02	0.0173	43.15	0.7633	0.7865	4.00	0.0730	0.51	0.0093	0.15	0.0027	
360	97.92	16.88	0.2873	6.01	0.1023	1.75	0.0299	39.20	0.6930	0.6920	4.51	0.0823	0.64	0.0116	0.15	0.0027	

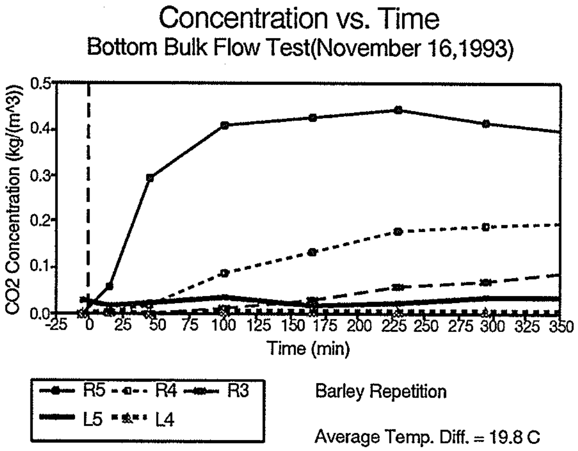






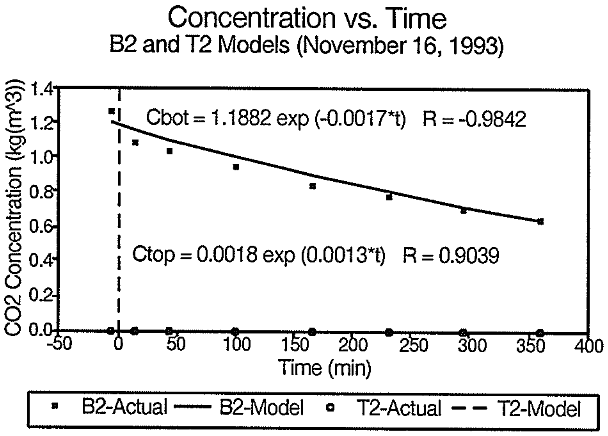
November 16, 1993
Bottom Bulk Flow Test
Temperature Difference = 19.8 C
Barley Repetition

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		T2	
Temperature (C)		30.98		30.98		30.98		19.00			11.14		11.14		21.00	
Time	Pressure								Actual	Model					Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	97.55	0.11	0.0019	0.10	0.0017	0.10	0.0018	71.25	1.2592	1.1983	1.48	0.0269	0.13	0.0023	0.10	0.0018	0.0018
15	97.54	3.57	0.0606	0.26	0.0045	0.12	0.0021	61.00	1.0778	1.1583	0.86	0.0155	0.17	0.0031	0.11	0.0019	0.0018
45	97.52	17.34	0.2943	1.11	0.0188	0.15	0.0025	58.61	1.0355	1.1007	1.15	0.0209	0.15	0.0027	0.11	0.0020	0.0019
100	97.52	24.13	0.4095	5.06	0.0858	0.51	0.0087	53.29	0.9415	1.0024	1.76	0.0319	0.16	0.0029	0.11	0.0019	0.0020
165	97.49	25.27	0.4286	7.73	0.1311	1.55	0.0264	47.80	0.8443	0.8976	0.97	0.0175	0.17	0.0031	0.12	0.0021	0.0022
230	97.49	26.06	0.4422	10.52	0.1785	3.28	0.0556	43.64	0.7708	0.8037	1.35	0.0244	0.18	0.0033	0.12	0.0021	0.0024
295	97.46	24.52	0.4159	11.09	0.1881	4.01	0.0679	39.18	0.6917	0.7196	1.82	0.0331	0.18	0.0033	0.14	0.0025	0.0026
360	97.51	23.11	0.3921	11.68	0.1983	5.00	0.0848	36.42	0.6434	0.6443	2.02	0.0367	0.18	0.0032	0.19	0.0033	0.0029

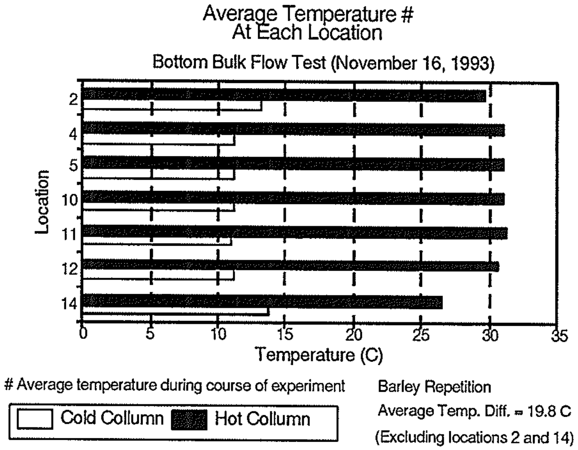


Barley Repetition

Average Temp. Diff. = 19.8 C



Barley Repetition Average Temp. Diff. = 19.8 C

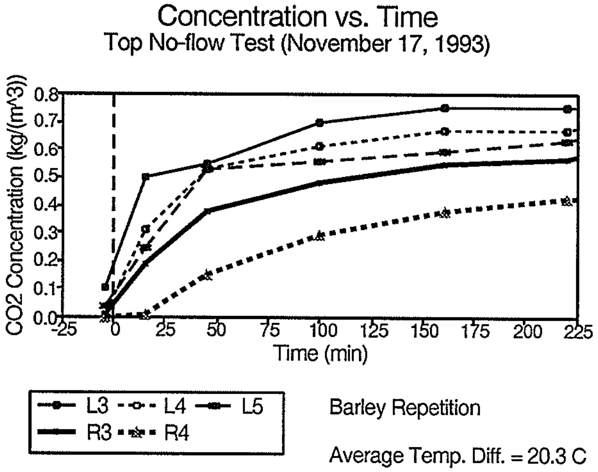


Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 19.8 C
(Excluding locations 2 and 14)

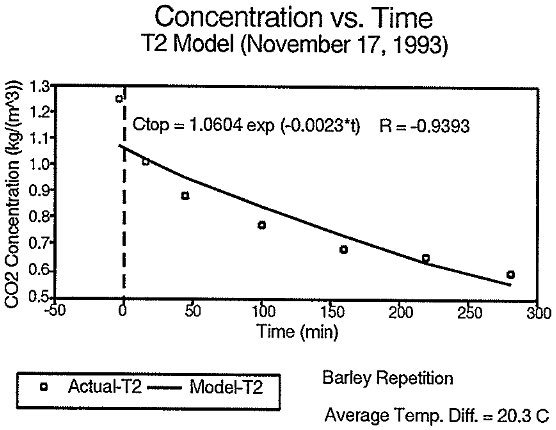
November 17, 1993
Top No-flow Test
Temperature Difference = 20.3 C
Barley Repetition

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		11.07		11.07		11.07		22.00			31.41		31.41		31.41	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	99.26	5.77	0.1067	0.55	0.0101	1.84	0.0340	70.41	1.2532	1.0702	0.34	0.0059	0.15	0.0026	0.16	0.0027
15	99.25	27.16	0.5020	17.12	0.3163	13.50	0.2496	56.84	1.0116	1.0244	11.07	0.1909	0.57	0.0098	0.31	0.0053
45	99.23	29.74	0.5496	28.36	0.5241	28.49	0.5265	49.42	0.8793	0.9561	21.99	0.3792	8.73	0.1505	5.68	0.0979
100	99.19	37.63	0.6950	32.93	0.6083	30.35	0.5605	43.61	0.7757	0.8425	27.90	0.4808	16.84	0.2903	10.60	0.1826
160	99.16	41.05	0.7580	36.31	0.6704	32.05	0.5918	38.36	0.6820	0.7339	31.52	0.5431	22.15	0.3817	13.74	0.2368
220	99.10	41.06	0.7578	36.38	0.6714	34.36	0.6340	37.03	0.6580	0.6393	33.18	0.5715	24.65	0.4245	16.57	0.2853
280	98.98	39.86	0.7347	39.78	0.7331	35.99	0.6634	33.44	0.5936	0.5569	33.70	0.5796	23.93	0.4117	17.48	0.3006



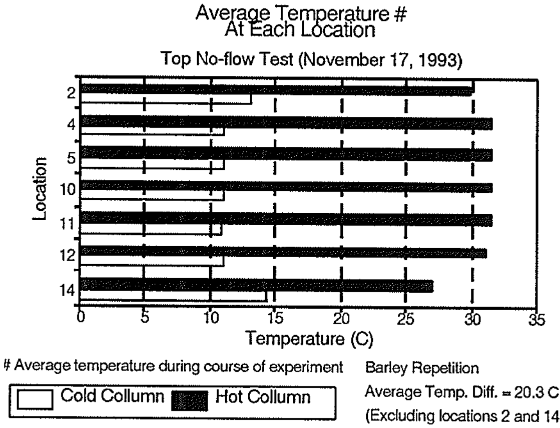
Barley Repetition

Average Temp. Diff. = 20.3 C



Barley Repetition

Average Temp. Diff. = 20.3 C

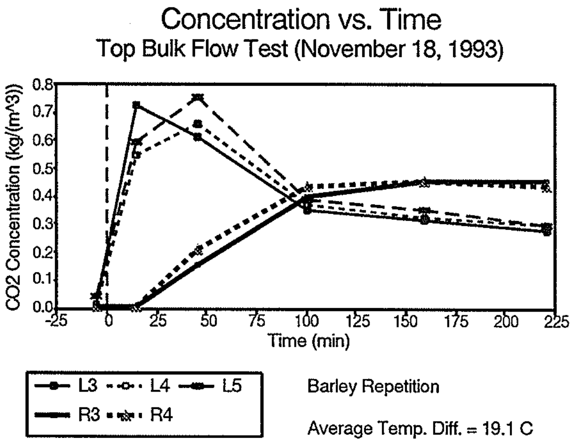


Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 20.3 C
(Excluding locations 2 and 14)

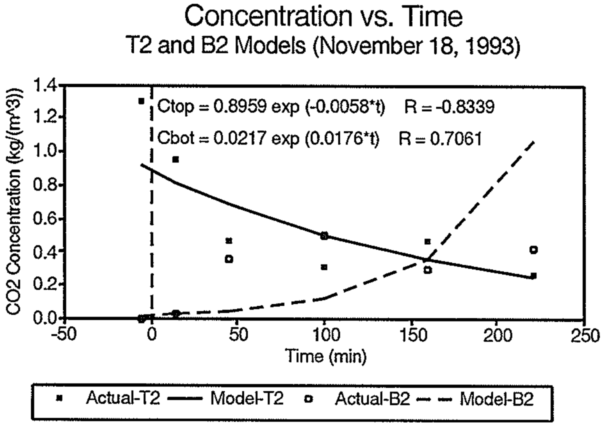
November 18, 1993
Top Bulk Flow Test
Temperature Difference = 19.1 C
Barley Repetition

		Concentration of CO2															
Location		L3		L4		L5		T2			B2			R3		R4	
Temperature (C)		11.68		11.68		11.68		21.00			20.00			30.73		30.73	
Time	Pressure								Actual	Model		Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	97.88	0.66	0.0121	0.35	0.0063	2.43	0.0441	73.24	1.2899	0.9223	0.12	0.0020	0.0199	0.20	0.0034	0.18	0.0031
15	98.87	39.64	0.7283	29.60	0.5438	32.38	0.5948	53.41	0.9501	0.8213	1.69	0.0301	0.0283	0.18	0.0031	0.19	0.0032
45	97.86	33.72	0.6132	36.01	0.6549	41.38	0.7525	26.77	0.4714	0.6901	20.25	0.3578	0.0479	8.88	0.1514	12.48	0.2127
100	97.82	19.29	0.3506	20.28	0.3687	21.52	0.3911	18.21	0.3205	0.5016	28.05	0.4954	0.1261	23.37	0.3981	25.39	0.4325
160	97.77	17.44	0.3168	17.79	0.3232	19.07	0.3465	26.49	0.4660	0.3542	16.80	0.2966	0.3626	26.83	0.4569	26.66	0.4540
221	97.73	15.45	0.2806	16.01	0.2908	16.46	0.2989	15.56	0.2736	0.2486	23.63	0.4170	1.0609	26.60	0.4527	25.75	0.4383

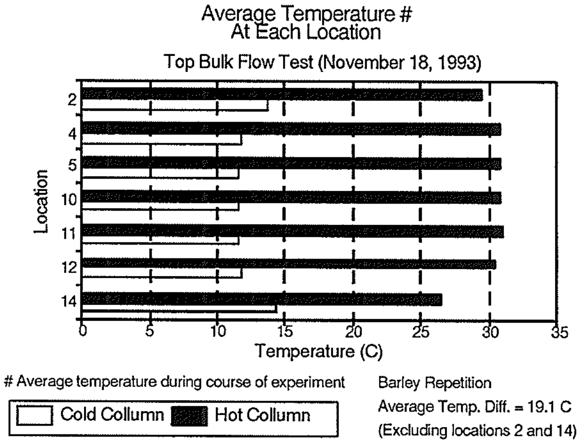


Barley Repetition

Average Temp. Diff. = 19.1 C



Barley Repetition Average Temp. Diff. = 19.1 C



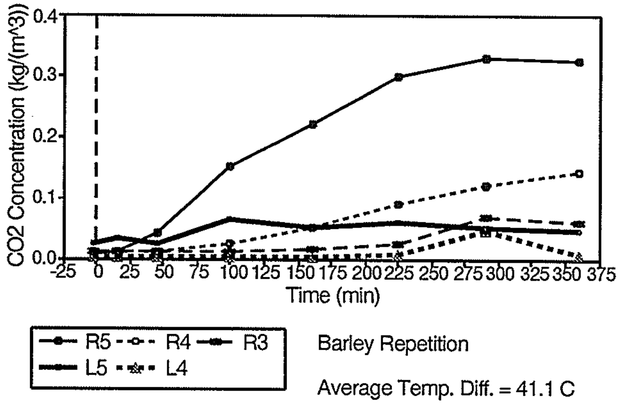
Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 19.1 C
(Excluding locations 2 and 14)

November 23, 1993
Bottom No-flow Test
Temperature Difference = 41.1 C
Barley Repetition

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		44.70		44.70		44.70		20.00			3.61		3.61		3.61	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	100.46	0.54	0.0090	0.63	0.0105	0.60	0.0100	69.48	1.2602	1.2087	1.43	0.0274	0.23	0.0045	0.10	0.0019
15	100.49	0.72	0.0120	0.61	0.0102	0.73	0.0122	65.07	1.1805	1.1765	1.68	0.0323	0.18	0.0035	0.15	0.0028
45	100.5	2.59	0.0434	0.83	0.0138	0.70	0.0116	61.69	1.1194	1.1248	1.29	0.0247	0.17	0.0032	0.11	0.0021
100	100.55	9.16	0.1533	1.58	0.0264	0.79	0.0132	57.82	1.0496	1.0357	3.44	0.0662	0.22	0.0042	0.12	0.0024
160	100.59	13.36	0.2238	3.18	0.0532	1.00	0.0167	50.57	0.9183	0.9465	2.65	0.0509	0.28	0.0054	0.11	0.0021
225	100.56	17.93	0.3002	5.43	0.0908	1.61	0.0270	43.45	0.7889	0.8586	3.06	0.0589	0.40	0.0077	0.11	0.0021
290	100.51	19.68	0.3293	7.10	0.1188	4.02	0.0673	44.82	0.8134	0.7789	2.58	0.0495	2.43	0.0467	0.11	0.0022
360	100.46	19.41	0.3247	8.49	0.1421	3.50	0.0585	40.79	0.7397	0.7012	2.52	0.0484	0.37	0.0072	0.12	0.0022

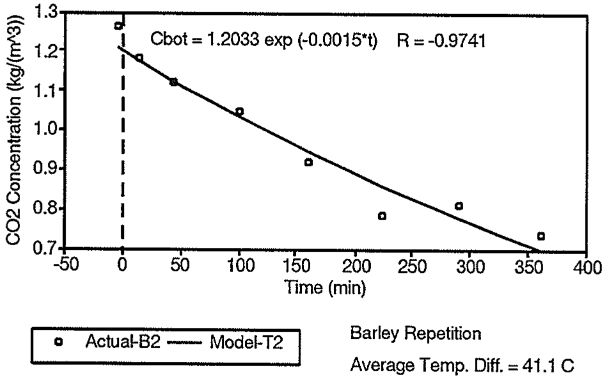
Concentration vs. Time
Bottom No-flow Test (November 23, 1993)



Barley Repetition

Average Temp. Diff. = 41.1 C

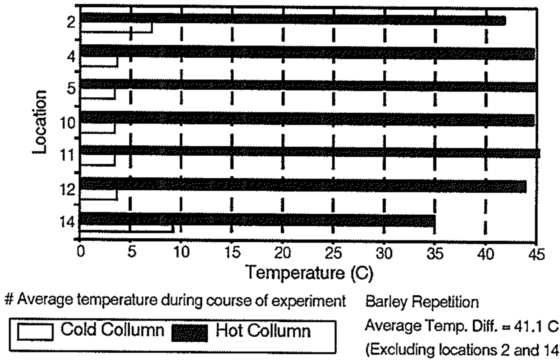
Concentration vs. Time
B2 Model (November 23, 1993)



Barley Repetition

Average Temp. Diff. = 41.1 C

Average Temperature #
At Each Location
Bottom No-flow Test (November 23, 1993)



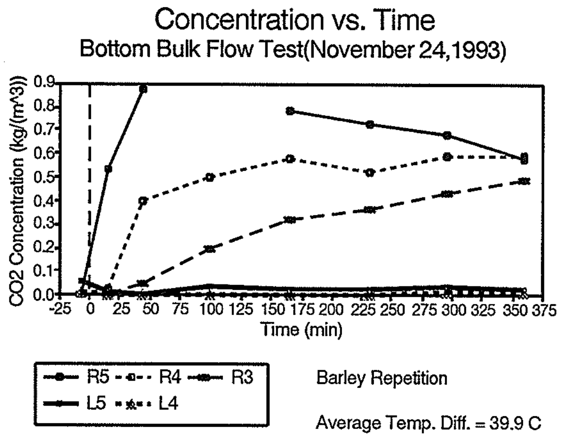
Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 41.1 C
(Excluding locations 2 and 14)

November 24, 1993
Bottom Bulk Flow Test
Temperature Difference = 39.9 C
Barley Repetition

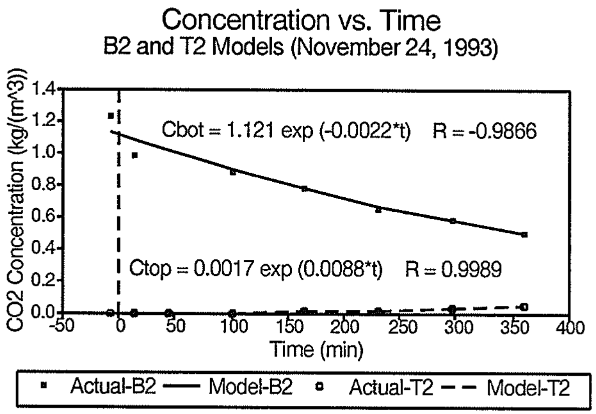
** Note: Blank entries in the table represent missing data.

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		43.95		43.95		43.95		20.00			4.05		4.05		22.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	100.73	0.21	0.0035	0.24	0.0041	0.26	0.0043	67.54	1.2283	1.1269	3.18	0.0612	0.81	0.0156	0.08	0.0015	0.0016
15	100.71	32.12	0.5399	1.49	0.0250	0.30	0.0051	54.27	0.9868	1.0760	0.94	0.0180	0.13	0.0025	0.12	0.0021	0.0019
45	100.70	51.99	0.8738	23.71	0.3986	2.99	0.0503			1.0073	0.18	0.0034	0.11	0.0021	0.13	0.0023	0.0025
100	100.72			29.98	0.5039	11.59	0.1949	48.08	0.8743	0.8925	1.58	0.0303	0.28	0.0053	0.22	0.0040	0.0041
166	100.70	46.34	0.7788	34.53	0.5804	19.05	0.3202	42.68	0.7760	0.7719	1.09	0.0210	0.23	0.0044	0.38	0.0068	0.0073
231	100.80	42.93	0.7223	31.37	0.5278	21.78	0.3664	36.02	0.6555	0.6690	1.26	0.0242	0.26	0.0050	0.72	0.0131	0.0130
296	100.76	40.27	0.6772	34.76	0.5846	25.85	0.4347	32.20	0.5857	0.5799	2.15	0.0413	0.43	0.0082	1.25	0.0227	0.0230
360	100.77	34.68	0.5834	34.98	0.5883	29.32	0.4931	27.07	0.4924	0.5037	1.04	0.0200	0.70	0.0135	2.11	0.0381	0.0404

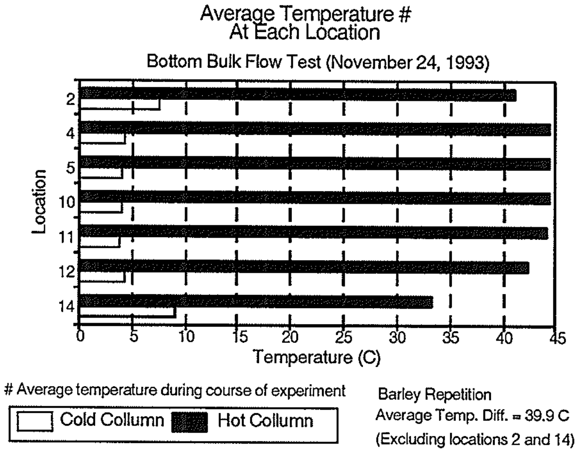


Barley Repetition

Average Temp. Diff. = 39.9 C



Barley Repetition Average Temp. Diff. = 39.9 C



Average temperature during course of experiment

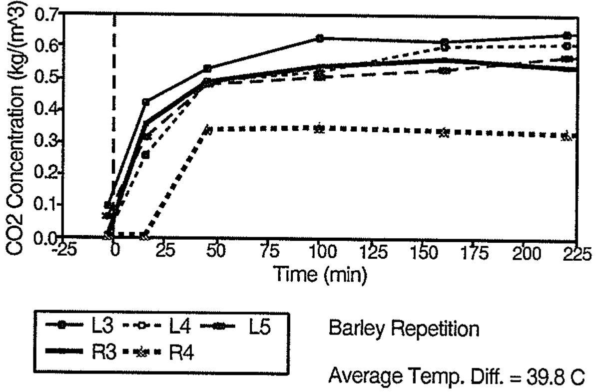
Barley Repetition
Average Temp. Diff. = 39.9 C
(Excluding locations 2 and 14)

November 25, 1993
Top No-flow Test
Temperurature Difference = 39.8 C
Barley Repetition

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		44.13		44.13		44.13		21.00			4.30		4.30		4.30	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	100.24	5.94	0.0994	0.42	0.0070	3.82	0.0639	69.47	1.2530	1.0326	0.62	0.0119	0.40	0.0076	0.30	0.0058
15	100.21	25.17	0.4207	15.18	0.2538	18.61	0.3110	55.00	0.9916	0.9979	18.74	0.3581	0.46	0.0087	0.48	0.0093
45	100.19	31.58	0.5278	29.14	0.4870	28.44	0.4753	44.63	0.8046	0.9426	25.45	0.4864	17.92	0.3426	6.02	0.1151
100	100.14	37.54	0.6271	30.90	0.5161	30.11	0.5030	42.76	0.7705	0.8490	28.01	0.5350	18.37	0.3509	9.96	0.1902
160	100.02	37.19	0.6206	35.92	0.5992	31.80	0.5306	41.42	0.7454	0.7576	29.21	0.5574	17.54	0.3347	9.20	0.1754
220	100.00	38.81	0.6474	36.46	0.6082	34.13	0.5693	37.85	0.6809	0.6759	28.26	0.5391	17.41	0.3321	9.35	0.1783
280	99.88	38.61	0.6432	37.82	0.6301	35.53	0.5919	34.86	0.6265	0.6031	26.58	0.5064	17.53	0.3341	9.41	0.1793

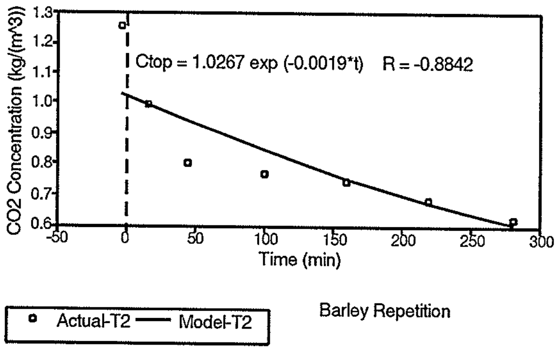
Concentration vs. Time
Top No-flow Test (November 25, 1993)



Barley Repetition

Average Temp. Diff. = 39.8 C

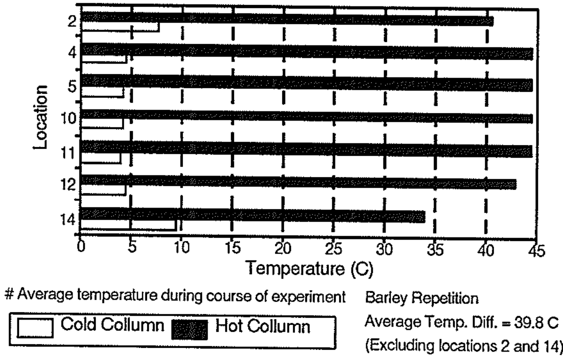
Concentration vs. Time
T2 Model (November 25, 1993)



Barley Repetition

Average Temp. Diff. = 39.8 C

Average Temperature #
At Each Location
Top No-flow Test (November 25, 1993)



Average temperature during course of experiment

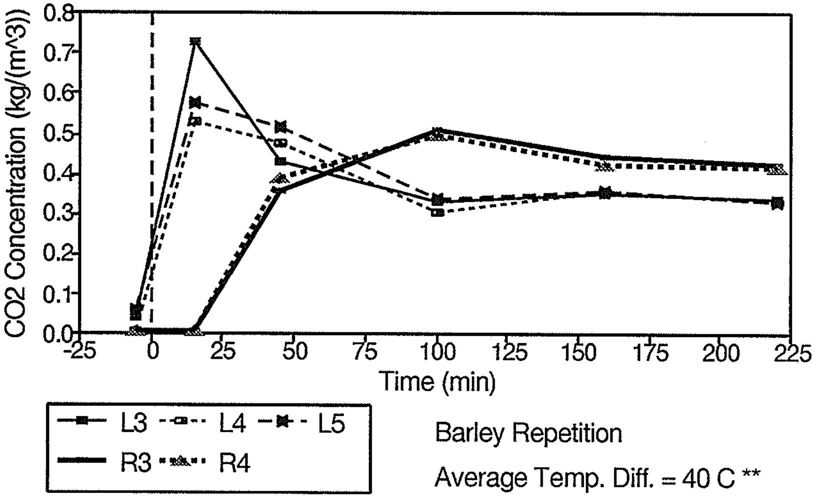
Barley Repetition
Average Temp. Diff. = 39.8 C
(Excluding locations 2 and 14)

November 26, 1993
Top Bulk Flow Test
Temperature Difference = 40.0** C
Barley Repetition

** -- Temperature data on computer disk was lost and unretrievable due to bad disk.
-- Temperatures during experiment were regularly inspected and maitained at a difference very close to 40 C.

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		44.00		44.00		44.00		21.00			4.00		4.00		20.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	99.20	2.32	0.0384	0.54	0.0089	3.86	0.0639	78.44	1.4000	0.8587	0.49	0.0094	0.38	0.0071	0.08	0.0014	0.1465
15	99.19	44.15	0.7308	32.11	0.5316	34.86	0.5770	47.33	0.8447	0.7785	0.29	0.0054	0.27	0.0050	4.72	0.0845	0.1765
45	99.17	26.07	0.4315	28.75	0.4758	31.08	0.5144	21.87	0.3901	0.6721	18.87	0.3573	20.72	0.3923	23.25	0.4163	0.2215
100	99.11	20.03	0.3313	18.23	0.3015	20.29	0.3357	22.01	0.3924	0.5133	26.98	0.5107	26.41	0.4999	25.09	0.4489	0.3040
160	99.00	21.22	0.3506	21.48	0.3548	21.52	0.3556	21.63	0.3853	0.3826	23.53	0.4448	22.59	0.4270	23.19	0.4144	0.3940
220	98.92	20.59	0.3399	19.99	0.3300	20.21	0.3337	20.16	0.3589	0.2851	22.57	0.4263	22.03	0.4162	21.34	0.3812	0.4840

Concentration vs. Time
Top Bulk Flow Test (November 26, 1993)

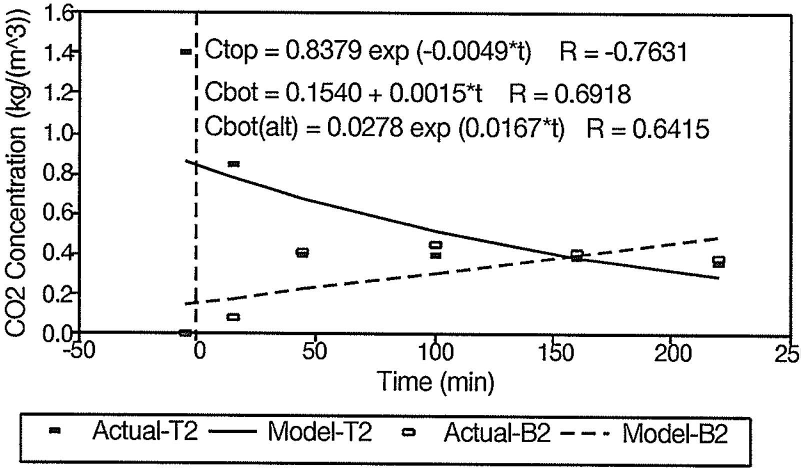


Barley Repetition

Average Temp. Diff. = 40 C **

** Data is not available due to technical difficulties. Temperature difference was maintaned at 40 C.

Concentration vs. Time
T2 and B2 Models (November 26, 1993)



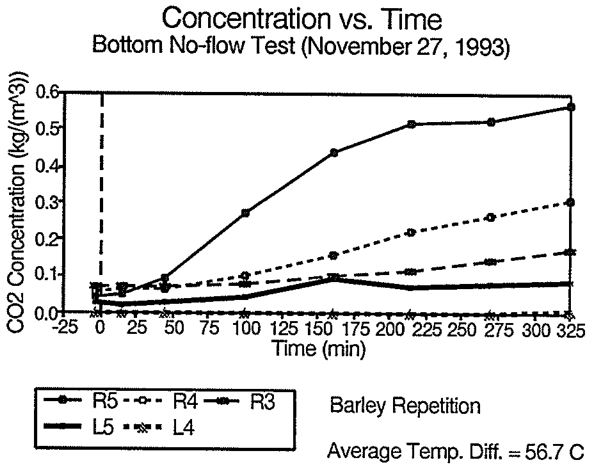
Barley Repetition

Average Temp. Diff. = 40 C **

** Due to technical difficulties this data is not available. Temperature difference was maintained at 40 C.

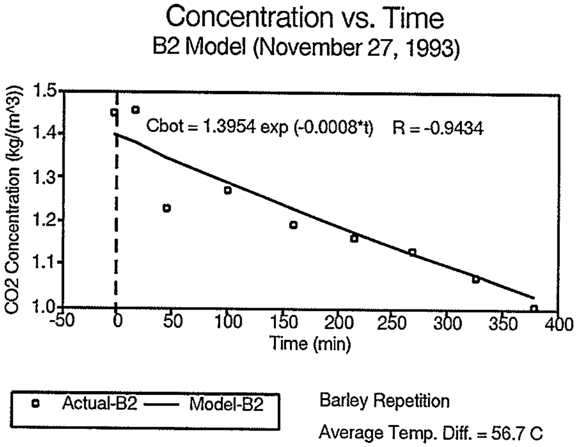
November 27, 1993
Bottom No-flow Test
Temperature Difference = 56.7 C
Barley Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		60.41		60.41		60.41		20.00			3.71		3.71		3.71	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.11	2.71	0.0422	3.612	0.0562	4.656	0.0725	81.82	1.4492	1.3988	1.729	0.0324	0.082	0.0015	0.039	0.0007
15	98.13	3.06	0.0477	3.938	0.0613	4.576	0.0712	82.27	1.4575	1.3788	1.32	0.0248	0.072	0.0014	0.039	0.0007
45	98.13	6.06	0.0944	4.238	0.0660	4.86	0.0757	69.26	1.2271	1.3461	1.415	0.0265	0.072	0.0014	0.037	0.0007
100	98.13	17.52	0.2728	6.567	0.1022	5.212	0.0812	71.73	1.2707	1.2881	2.367	0.0444	0.07	0.0013	0.039	0.0007
160	98.15	28.22	0.4394	10.25	0.1595	6.353	0.0989	67.31	1.1928	1.2277	5.045	0.0947	0.103	0.0019	0.039	0.0007
215	98.16	33.40	0.5203	14.57	0.2269	7.403	0.1153	65.65	1.1635	1.1749	3.716	0.0697	0.124	0.0023	0.044	0.0008
270	98.14	33.87	0.5274	17.15	0.2670	9.439	0.1470	63.97	1.1335	1.1243	4.323	0.0811	0.143	0.0027	0.051	0.0010
325	98.08	36.56	0.5690	20.13	0.3133	10.93	0.1702	60.61	1.0733	1.0759	4.52	0.0847	0.365	0.0068	0.049	0.0009
380	97.99	37.76	0.5871	21.15	0.3289	12.77	0.1985	56.70	1.0031	1.0296	4.155	0.0778	0.289	0.0054	0.055	0.0010



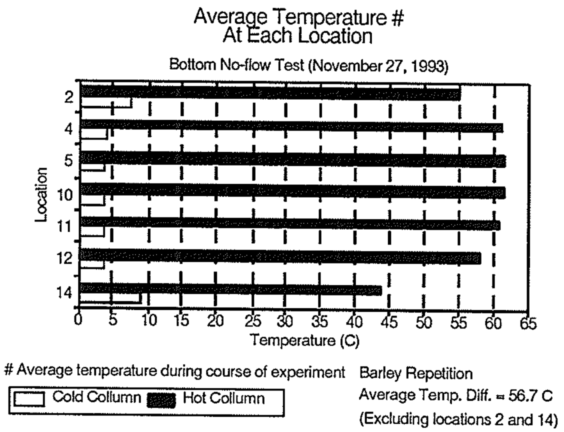
Barley Repetition

Average Temp. Diff. = 56.7 C



Barley Repetition

Average Temp. Diff. = 56.7 C

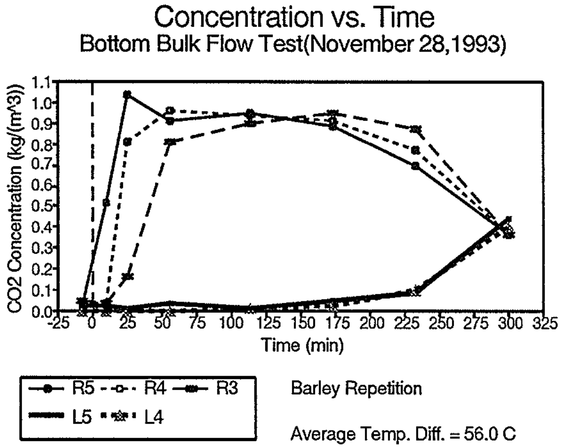


Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 56.7 C
(Excluding locations 2 and 14)

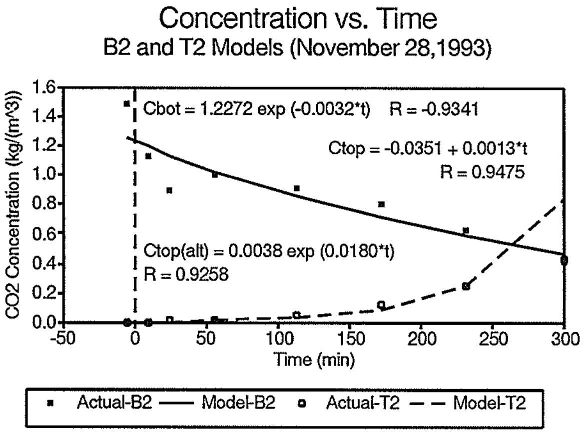
November 28, 1993
Bottom Bulk Flow Test
Temperature Difference = 56.0 C
Barley Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		59.96		59.96		59.96		20.00			3.93		3.93		22.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	97.60	1.69	0.0262	2.73	0.0424	3.03	0.0470	83.87	1.4778	1.2510	1.15	0.0214	0.04	0.0008	0.04	0.0006	0.0034
10	97.60	33.15	0.5140	2.62	0.0406	2.53	0.0393	63.52	1.1192	1.1886	1.31	0.0245	0.05	0.0008	0.31	0.0054	0.0045
25	97.61	66.72	1.0348	52.56	0.8152	10.45	0.1620	51.05	0.8997	1.1328	0.63	0.0117	0.06	0.0012	0.62	0.0109	0.0060
56	97.63	59.05	0.9159	62.23	0.9653	52.33	0.8117	56.93	1.0035	1.0259	2.00	0.0372	0.14	0.0026	1.02	0.0179	0.0104
113	97.66	61.18	0.9492	60.15	0.9333	57.79	0.8967	51.61	0.9099	0.8548	0.87	0.0162	0.47	0.0087	3.44	0.0602	0.0290
173	97.66	57.05	0.8853	58.90	0.9139	61.36	0.9521	45.94	0.8099	0.7055	2.65	0.0494	1.52	0.0283	7.08	0.1240	0.0855
233	97.71	44.97	0.6981	49.93	0.7751	56.39	0.8755	35.64	0.6288	0.5822	4.58	0.0854	5.62	0.1049	14.12	0.2474	0.2519
300	97.79	23.56	0.3660	23.41	0.3637	24.02	0.3732	23.12	0.4081	0.4699	23.58	0.4405	21.95	0.4101	24.91	0.4368	0.8413

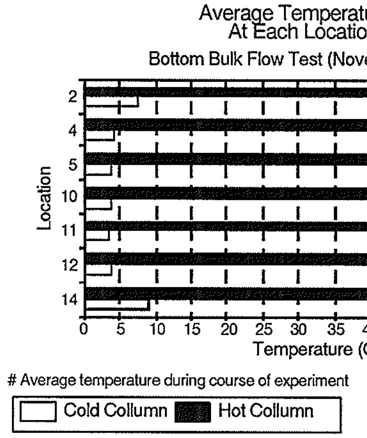


Barley Repetition

Average Temp. Diff. = 56.0 C



Barley Repetition Average Temp. Diff. = 56.0 C

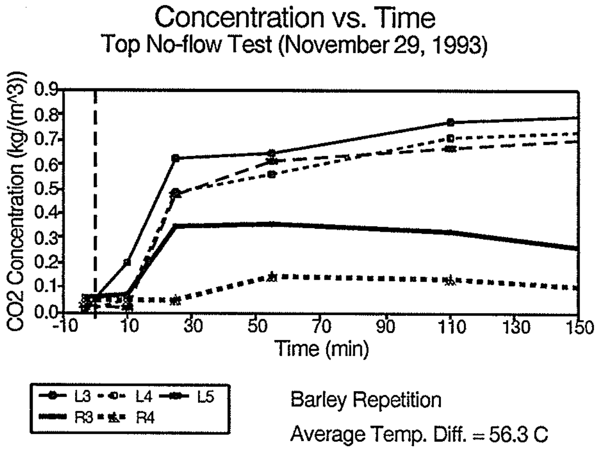


Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 56.0 C
(Excluding locations 2 and 14)

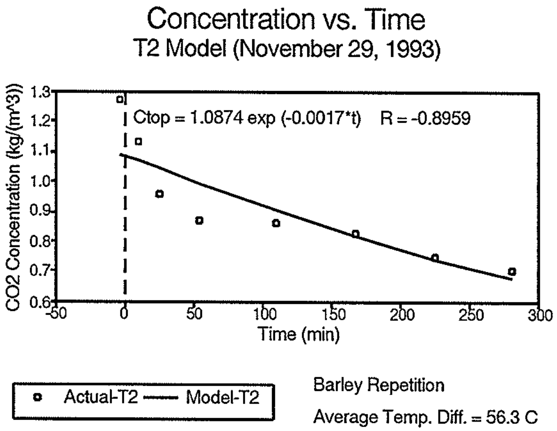
November 29, 1993
Top No-flow Test
Temperature Difference = 56.3 C
Barley Repetition

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		R5		
Temperature (C)		3.87		3.87		3.87		22.00			60.22		60.22		60.22		
Time	Pressure								Actual	Model							
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-3	99.39	0.45	0.0086	0.06	0.0011	1.44	0.0274	71.28	1.2704	1.0930	3.556	0.0561	2.68	0.0422	1.32	0.0209	
10	99.39	10.41	0.1976	2.59	0.0492	0.96	0.0182	63.64	1.1342	1.0691	4.385	0.0692	2.63	0.0415	1.55	0.0245	
25	99.40	32.90	0.6247	25.19	0.4784	24.74	0.4697	53.48	0.9532	1.0422	22.23	0.3508	2.84	0.0449	1.69	0.0267	
55	99.44	33.96	0.6452	29.63	0.5629	32.30	0.6136	48.70	0.8683	0.9903	22.69	0.3583	9.13	0.1442	2.04	0.0323	
110	99.48	40.39	0.7676	37.16	0.7063	35.20	0.6691	48.48	0.8648	0.9019	20.69	0.3268	8.41	0.1329	2.42	0.0382	
168	99.49	42.26	0.8033	39.09	0.7429	37.00	0.7033	46.27	0.8255	0.8172	14.83	0.2343	5.16	0.0815	1.60	0.0253	
225	99.45	43.81	0.8323	41.56	0.7897	39.33	0.7473	41.95	0.7481	0.7418	9.419	0.1487	2.85	0.0450	0.76	0.0120	
280	99.43	44.01	0.8359	42.60	0.8093	41.79	0.7939	39.55	0.7051	0.6756	9.252	0.1460	2.179	0.0344	1.522	0.0240	



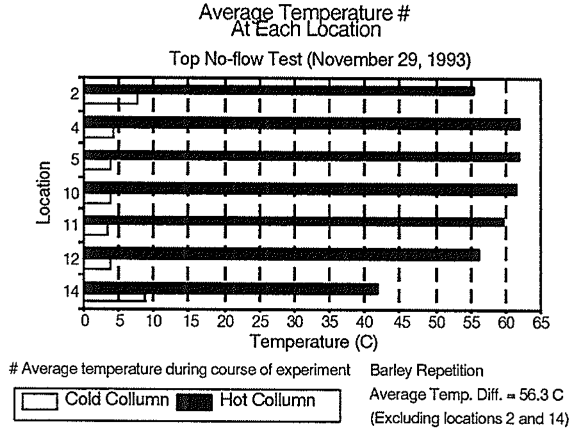
Barley Repetition

Average Temp. Diff. = 56.3 C



Barley Repetition

Average Temp. Diff. = 56.3 C



Average temperature during course of experiment

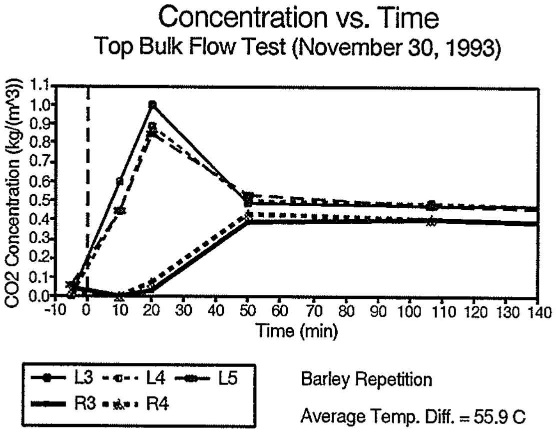
Barley Repetition

Average Temp. Diff. = 56.3 C

(Excluding locations 2 and 14)

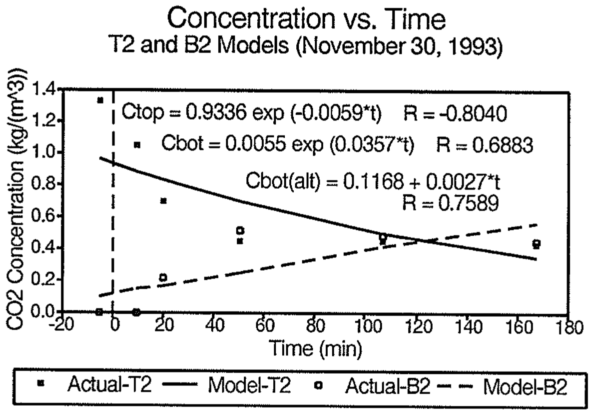
November 30, 1993
Top Bulk Flow Test
Temperature Difference = 55.9 C
Barley Repetition

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		4.00		4.00		4.00		22.00			59.85		59.85		20.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	98.42	0.36	0.0068	0.07	0.0014	3.16	0.0593	75.70	1.3359	0.9616	2.65	0.0414	1.85	0.0289	0.01	0.0002	0.1033
10	98.42	32.04	0.6022	23.62	0.4439	23.87	0.4486	58.91	1.0397	0.8801	0.55	0.0086	0.04	0.0007	0.09	0.0016	0.1438
20	98.42	53.24	1.0007	46.93	0.8821	45.02	0.8461	39.82	0.7027	0.8297	1.68	0.0262	4.56	0.0714	11.84	0.2104	0.1708
50	98.42	25.72	0.4835	26.85	0.5047	27.95	0.5254	25.07	0.4424	0.6951	24.53	0.3837	27.87	0.4359	28.65	0.5090	0.2518
107	98.40	25.46	0.4784	25.66	0.4823	25.30	0.4755	25.66	0.4528	0.4966	25.92	0.4053	25.54	0.3994	26.57	0.4721	0.4057
167	98.33	24.61	0.4621	24.94	0.4682	23.95	0.4498	24.44	0.4310	0.3485	24.09	0.3765	24.61	0.3847	25.15	0.4465	0.5677

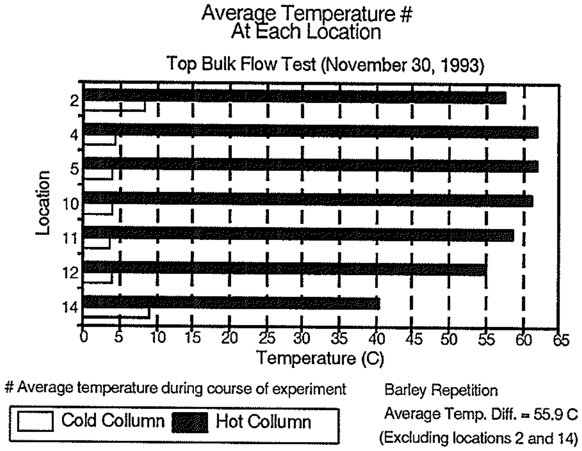


Barley Repetition

Average Temp. Diff. = 55.9 C



Barley Repetition Average Temp. Diff. = 55.9 C



Average temperature during course of experiment

Barley Repetition
Average Temp. Diff. = 55.9 C
(Excluding locations 2 and 14)

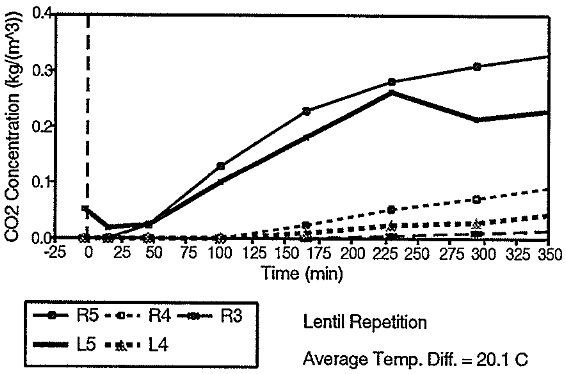
December 1, 1993
Bottom No-flow Test
Temperature Difference = 20.1 C
Lentil Repetition

Concentration of CO2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		31.40		31.40		31.40		20.00			11.26		11.26		11.26	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.09	0.02	0.0004	0.02	0.0004	0.02	0.0003	75.38	1.3350	1.3465	2.84	0.0518	0.04	0.0007	0.02	0.0004
15	98.10	0.04	0.0007	0.03	0.0005	0.03	0.0004	77.50	1.3725	1.3345	1.06	0.0194	0.03	0.0005	0.02	0.0004
45	98.11	1.31	0.0224	0.03	0.0005	0.03	0.0005	70.05	1.2408	1.3146	1.37	0.0250	0.03	0.0006	0.02	0.0003
100	98.15	7.42	0.1266	0.16	0.0028	0.03	0.0005	74.20	1.3148	1.2789	5.41	0.0988	0.08	0.0014	0.02	0.0004
165	98.15	13.28	0.2265	1.45	0.0248	0.06	0.0010	71.72	1.2709	1.2380	9.91	0.1810	0.47	0.0085	0.03	0.0005
230	98.16	16.46	0.2807	3.06	0.0521	0.23	0.0038	66.18	1.1728	1.1984	14.27	0.2607	1.25	0.0229	0.05	0.0009
295	98.18	18.11	0.3090	4.23	0.0722	0.63	0.0108	65.44	1.1599	1.1601	11.56	0.2112	1.68	0.0307	0.06	0.0010
360	98.12	19.18	0.3271	5.51	0.0939	1.08	0.0183	62.51	1.1073	1.1230	12.52	0.2286	2.52	0.0461	0.14	0.0025

Concentration vs. Time

Bottom No-flow Test (December 1, 1993)

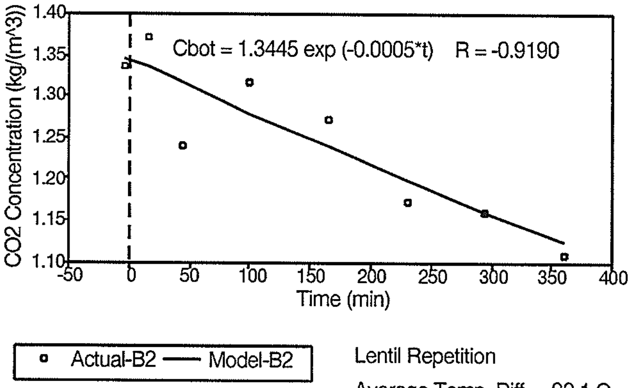


Lentil Repetition

Average Temp. Diff. = 20.1 C

Concentration vs. Time

B2 Model (December 1, 1993)

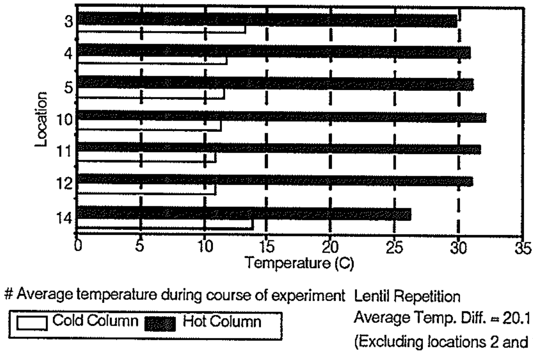


Lentil Repetition

Average Temp. Diff. = 20.1 C

Average Temperature #
At Each Location

Bottom No-flow Test (December 1, 1993)



Average temperature during course of experiment

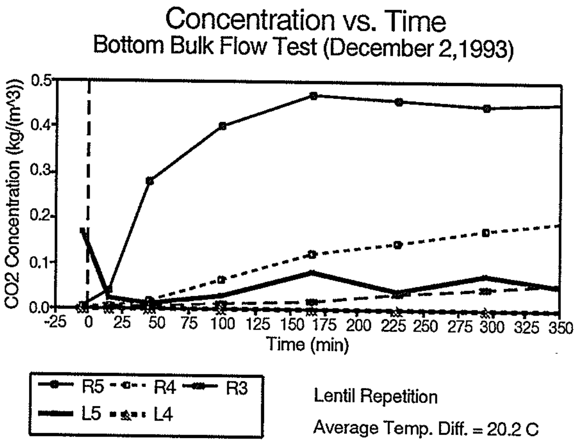
Lentil Repetition

Average Temp. Diff. = 20.1 C

(Excluding locations 2 and 14)

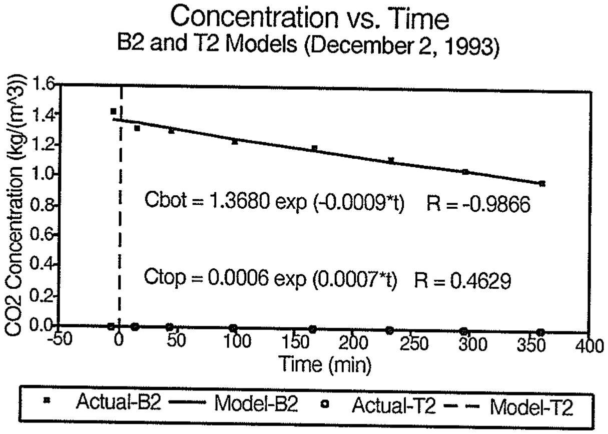
December 2, 1993
Bottom Bulk Flow Test
Temperature Difference = 20.2 C
Lentil Repetition

Location		Concentration of CO2 R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		31.83		31.83		31.83		20.00			11.61		11.61		21.00		
									Actual	Model						Actual	Model
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	98.52	0.30	0.0051	0.26	0.0044	0.17	0.0029	80.16	1.4258	1.3742	9.36	0.1714	0.10	0.0018	0.03	0.0006	0.0006
15	98.56	2.28	0.0390	0.42	0.0072	0.30	0.0052	73.82	1.3135	1.3497	1.31	0.0241	0.06	0.0010	0.03	0.0005	0.0006
45	98.57	16.23	0.2776	1.04	0.0177	0.30	0.0051	72.73	1.2943	1.3137	0.74	0.0136	0.06	0.0010	0.03	0.0006	0.0006
99	98.62	23.62	0.4042	3.80	0.0650	0.63	0.0107	69.52	1.2379	1.2514	1.65	0.0303	0.07	0.0012	0.06	0.0010	0.0006
165	98.70	27.48	0.4706	7.09	0.1214	1.29	0.0221	66.93	1.1927	1.1792	4.59	0.0842	0.06	0.0011	0.04	0.0006	0.0007
230	98.76	26.73	0.4581	8.64	0.1481	2.12	0.0364	63.33	1.1293	1.1122	2.21	0.0405	0.07	0.0012	0.04	0.0007	0.0007
295	98.81	26.14	0.4483	10.27	0.1761	2.95	0.0507	58.64	1.0460	1.0490	4.20	0.0772	0.05	0.0009	0.04	0.0007	0.0007
360	98.87	26.49	0.4545	11.29	0.1937	3.56	0.0611	55.32	0.9875	0.9894	2.84	0.0523	0.06	0.0012	0.04	0.0008	0.0008

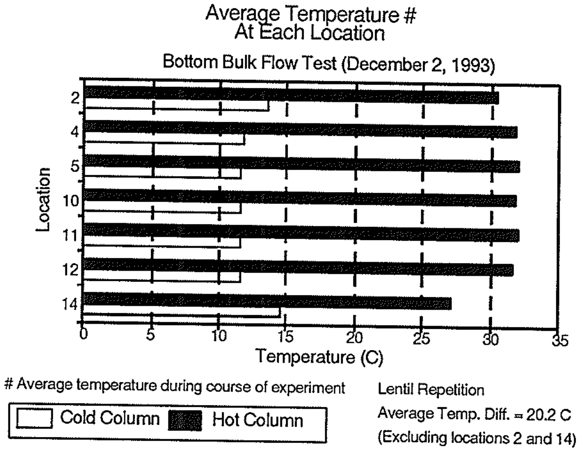

Concentration vs. Time
Bottom Bulk Flow Test (December 2,1993)

Lentil Repetition

Average Temp. Diff. = 20.2 C


Concentration vs. Time
B2 and T2 Models (December 2, 1993)

Lentil Repetition Average Temp. Diff. = 20.2 C


Average Temperature #
At Each Location
Bottom Bulk Flow Test (December 2, 1993)

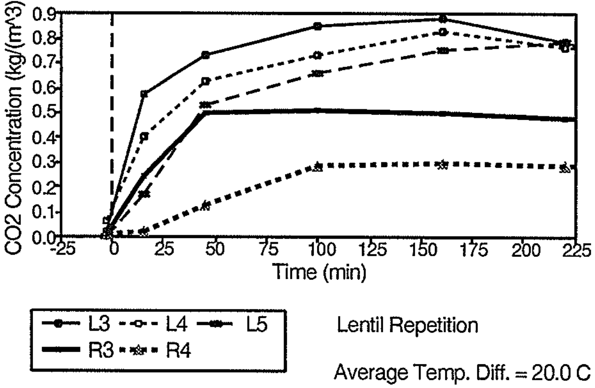
Average temperature during course of experiment

Lentil Repetition
Average Temp. Diff. = 20.2 C
(Excluding locations 2 and 14)

December 3, 1993
Top No-flow Test
Temperature Difference = 20.0 C
Lentil Repetition

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		11.36		11.36		11.36		22.00			31.32		31.32		31.32	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	99.11	1.21	0.0223	3.36	0.0619	0.08	0.0015	81.05	1.4405	1.2849	0.70	0.0121	0.74	0.0127	0.92	0.0159
15	99.10	31.06	0.5726	22.02	0.4059	9.25	0.1705	69.20	1.2296	1.2196	14.33	0.2469	0.95	0.0163	0.98	0.0169
45	99.08	39.86	0.7347	33.88	0.6245	28.90	0.5327	58.56	1.0405	1.1180	29.19	0.5027	7.62	0.1313	1.40	0.0241
100	99.06	46.31	0.8534	39.95	0.7361	35.43	0.6528	49.52	0.8796	0.9531	29.40	0.5062	16.39	0.2823	8.26	0.1423
160	99.07	48.09	0.8862	44.81	0.8258	40.71	0.7503	44.33	0.7875	0.8009	29.00	0.4994	17.13	0.2950	7.37	0.1268
220	99.00	42.50	0.7827	41.78	0.7694	42.52	0.7831	38.26	0.6792	0.6730	27.72	0.4770	16.59	0.2854	7.17	0.1234
280	98.93	38.74	0.7129	39.97	0.7356	40.76	0.7500	33.81	0.5998	0.5655	26.19	0.4504	14.93	0.2568	7.02	0.1208

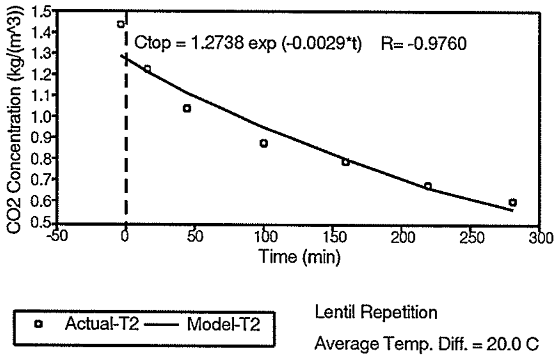
Concentration vs. Time
Top No-flow Test (December 3, 1993)



Lentil Repetition

Average Temp. Diff. = 20.0 C

Concentration vs. Time
T2 Model (December 3, 1993)

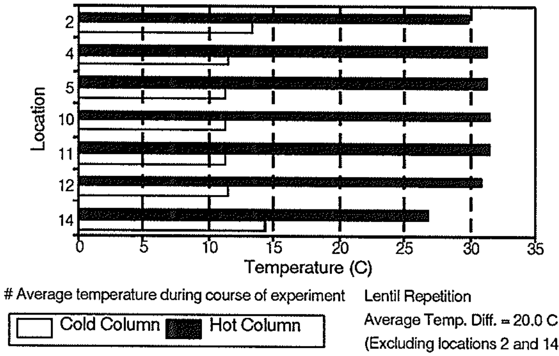


Lentil Repetition

Average Temp. Diff. = 20.0 C

Average Temperature #
At Each Location

Top No-flow Test (December 3, 1993)



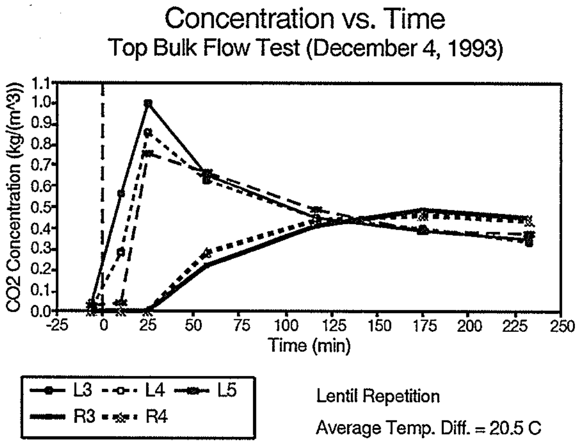
Average temperature during course of experiment

Lentil Repetition
Average Temp. Diff. = 20.0 C
(Excluding locations 2 and 14)

December 4, 1993
Top Bulk Flow Test
Temperature Difference = 20.5 C
Lentil Repetition

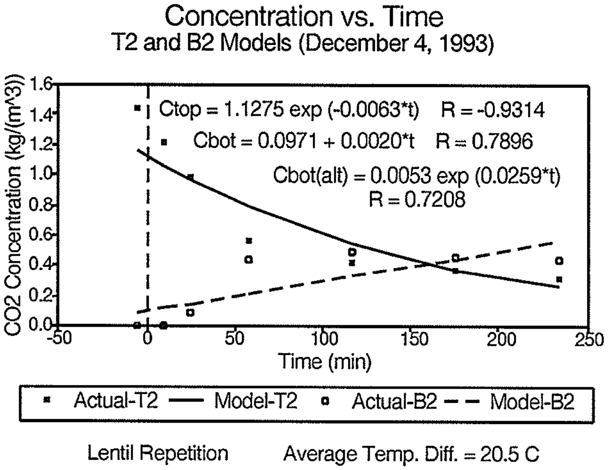
Concentration of CO2

Time	Pressure	L3		L4		L5		T2			B2			R3		R4	
Location		L3		L4		L5		T2			B2			R3		R4	
Temperature (C)		11.14		11.14		11.14		21.00			20.00			31.62		31.62	
									Actual	Model		Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	97.70	2.13	0.0387	0.81	0.0147	1.89	0.0343	82.42	1.4489	1.1636	0.02	0.0003	0.0871	0.49	0.0083	0.27	0.0045
10	97.69	31.16	0.5666	15.46	0.2811	2.20	0.0399	69.40	1.2198	1.0587	0.04	0.0008	0.1171	0.35	0.0060	0.17	0.0030
25	97.68	54.58	0.9925	46.97	0.8540	41.86	0.7613	56.46	0.9923	0.9632	4.84	0.0853	0.1471	0.06	0.0009	0.07	0.0012
57	97.65	35.82	0.6511	34.58	0.6286	36.82	0.6693	32.24	0.5665	0.7873	24.87	0.4384	0.2111	12.67	0.2149	16.39	0.2779
116	97.56	25.13	0.4565	24.62	0.4471	26.92	0.4890	23.82	0.4181	0.5429	28.10	0.4949	0.3291	24.00	0.4066	25.37	0.4298
175	97.52	20.99	0.3811	21.67	0.3934	21.49	0.3902	20.91	0.3668	0.3744	26.39	0.4647	0.4471	28.65	0.4852	27.10	0.4590
233	97.49	19.02	0.3453	18.2	0.3303	20.81	0.3777	18.55	0.3253	0.2598	24.58	0.4326	0.5631	26.89	0.4552	25.63	0.4339

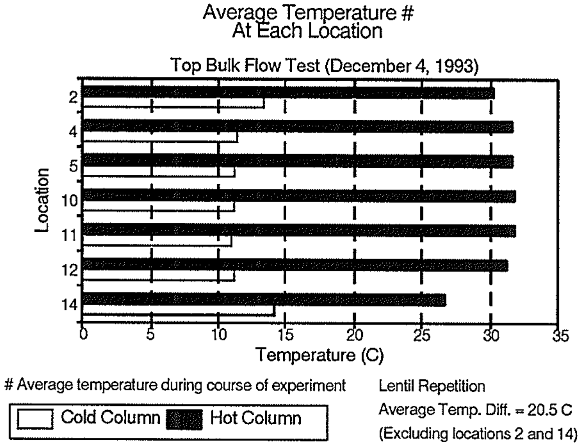

Concentration vs. Time
Top Bulk Flow Test (December 4, 1993)

Lentil Repetition

Average Temp. Diff. = 20.5 C


Concentration vs. Time
T2 and B2 Models (December 4, 1993)

Lentil Repetition Average Temp. Diff. = 20.5 C

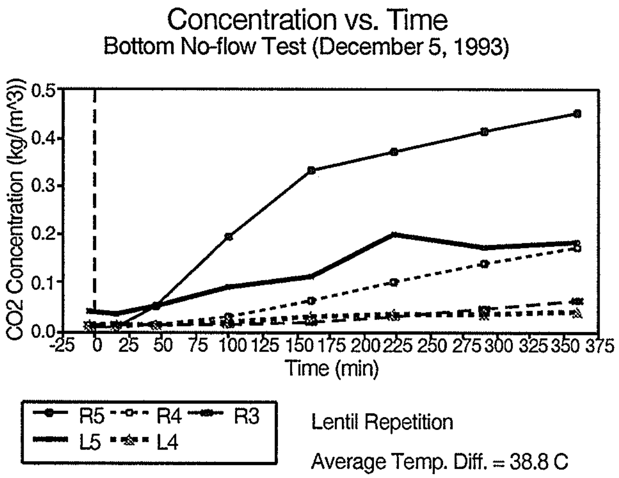

Average Temperature #
At Each Location
Top Bulk Flow Test (December 4, 1993)

Average temperature during course of experiment

Lentil Repetition
Average Temp. Diff. = 20.5 C
(Excluding locations 2 and 14)

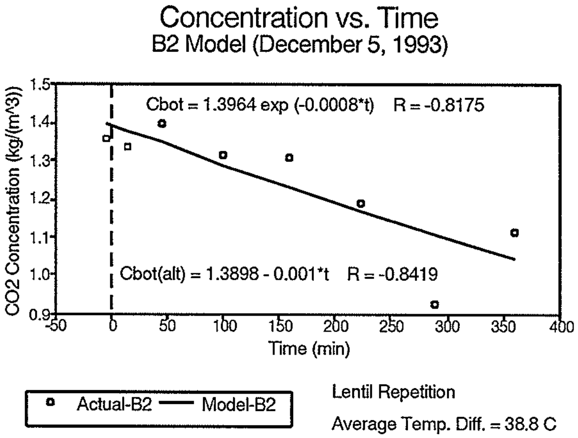
December 5, 1993
Bottom No-flow Test
Temperature Difference = 38.8 C
Lentil Repetition

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		44.14		44.14		44.14		20.00			5.34		5.34		5.34	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	97.15	0.62	0.0100	0.73	0.0119	0.78	0.0127	77.32	1.3562	1.4009	2.31	0.0427	0.91	0.0168	0.73	0.0134
15	97.17	0.68	0.0111	0.73	0.0118	0.80	0.0129	76.07	1.3346	1.3797	2.06	0.0381	0.95	0.0175	0.84	0.0156
45	97.23	3.39	0.0550	0.81	0.0131	0.82	0.0133	79.50	1.3956	1.3470	2.94	0.0544	0.96	0.0177	0.74	0.0137
100	97.37	12.03	0.1954	1.86	0.0302	0.87	0.0142	74.68	1.3128	1.2890	4.86	0.0899	1.20	0.0222	0.76	0.0141
160	97.48	20.41	0.3319	3.75	0.0610	1.15	0.0188	74.34	1.3083	1.2286	6.15	0.1139	1.60	0.0296	0.82	0.0151
222	97.54	22.79	0.3708	6.40	0.1041	1.84	0.0299	67.62	1.1907	1.1692	10.95	0.2029	1.91	0.0355	0.88	0.0163
290	97.58	25.53	0.4155	8.63	0.1404	2.86	0.0465	52.62	0.9271	1.1073	9.20	0.1707	2.08	0.0385	0.84	0.0155
360	97.71	27.62	0.4502	10.78	0.1758	3.94	0.0642	63.29	1.1165	1.0470	10.00	0.1856	2.26	0.0419	0.98	0.0182



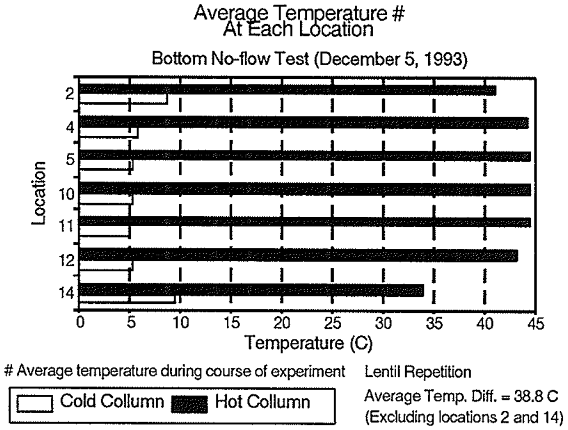
Lentil Repetition

Average Temp. Diff. = 38.8 C



Lentil Repetition

Average Temp. Diff. = 38.8 C

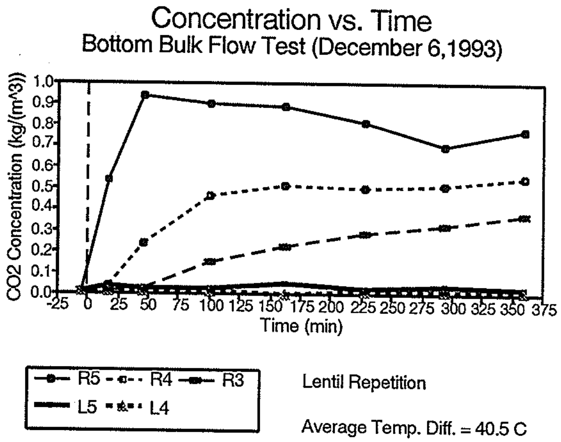


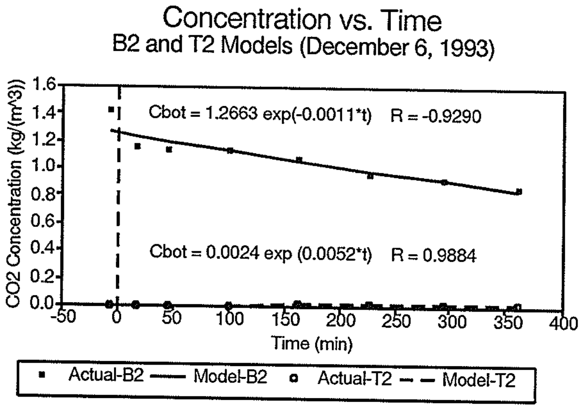
Average temperature during course of experiment

Lentil Repetition
Average Temp. Diff. = 38.8 C
(Excluding locations 2 and 14)

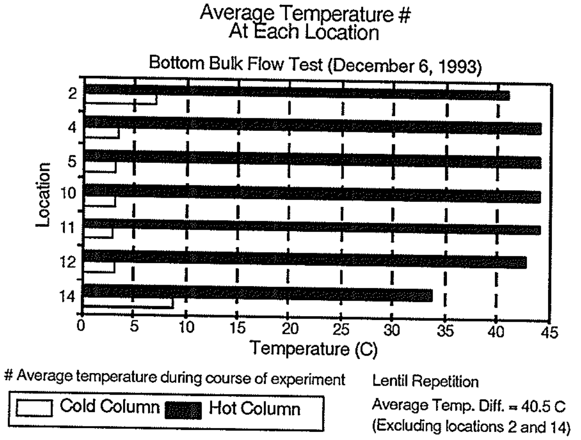
December 6, 1993
Bottom Bulk Flow Test
Temperature Difference = 40.5 C
Lentil Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		43.76		43.76		43.76		20.00			3.21		3.21		23.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	98.78	0.62	0.0103	0.63	0.0104	0.59	0.0097	80.42	1.4342	1.2747	0.78	0.0147	0.51	0.0096	0.12	0.0020	0.0023
17	98.78	32.26	0.5321	2.51	0.0415	0.71	0.0118	65.21	1.1630	1.2428	1.67	0.0316	0.37	0.0071	0.17	0.0031	0.0026
45	98.77	56.27	0.9281	14.70	0.2424	1.70	0.0281	63.34	1.1294	1.2051	1.50	0.0284	0.36	0.0068	0.19	0.0034	0.0030
101	98.76	54.15	0.8931	27.49	0.4535	8.59	0.1417	63.75	1.1367	1.1331	1.33	0.0252	0.44	0.0084	0.22	0.0038	0.0041
162	98.82	53.54	0.8836	31.06	0.5126	13.63	0.2250	60.22	1.0744	1.0596	2.30	0.0435	0.31	0.0059	0.30	0.0053	0.0056
228	98.84	49.46	0.8163	30.51	0.5037	17.09	0.2821	54.34	0.9697	0.9854	1.01	0.0191	0.39	0.0073	0.41	0.0073	0.0079
293	98.85	42.48	0.7013	30.58	0.5048	19.64	0.3243	52.01	0.9282	0.9174	1.64	0.0310	0.52	0.0099	0.66	0.0117	0.0110
360	98.84	46.39	0.7658	33.27	0.5491	22.52	0.3717	48.79	0.8706	0.8522	1.53	0.0290	0.45	0.0086	0.90	0.0160	0.0156





Lentil Repetition Average Temp. Diff. = 40.5 C

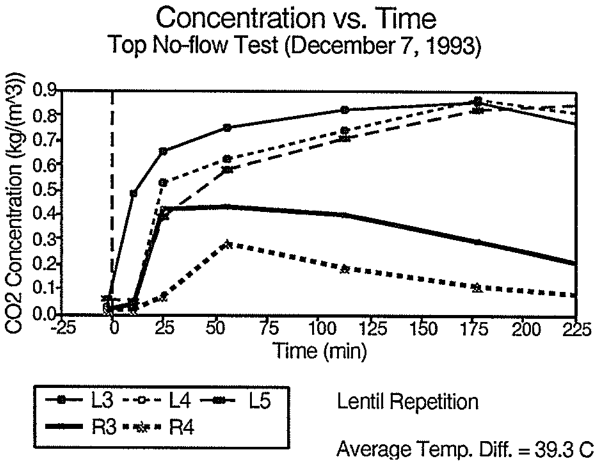


Lentil Repetition
Average Temp. Diff. = 40.5 C
(Excluding locations 2 and 14)

December 7, 1993
Top No-flow Test
Temperature Difference = 39.3 C
Lentil Repetition

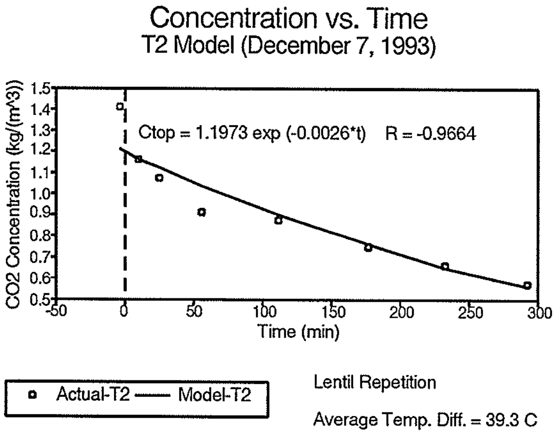
Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		3.69		3.69		3.69		22.00			43.02		43.02		43.02	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.29	1.43	0.0269	0.52	0.0098	2.90	0.0544	79.66	1.4040	1.2067	1.01	0.0166	1.02	0.0168	0.91	0.0150
10	98.28	25.74	0.4836	1.38	0.0259	2.50	0.0470	66.19	1.1664	1.1666	2.16	0.0355	1.11	0.0182	1.03	0.0169
25	98.27	34.99	0.6574	28.31	0.5319	20.45	0.3842	60.64	1.0685	1.1220	25.34	0.4168	3.89	0.0640	1.71	0.0282
56	98.27	39.79	0.7476	32.96	0.6192	31.12	0.5847	51.95	0.9154	1.0351	26.08	0.4290	16.78	0.2761	1.83	0.0300
112	98.27	44.16	0.8296	39.47	0.7416	37.93	0.7126	49.40	0.8706	0.8948	24.37	0.4010	11.19	0.1841	2.60	0.0428
177	98.28	45.40	0.8530	46.26	0.8691	44.04	0.8275	42.83	0.7547	0.7557	17.47	0.2874	6.79	0.1116	5.37	0.0883
232	98.24	40.47	0.7602	43.20	0.8113	45.13	0.8476	37.69	0.6639	0.6550	12.31	0.2025	4.50	0.0740	2.78	0.0456
292	98.18	36.59	0.6867	36.68	0.6885	40.92	0.7681	32.33	0.5692	0.5604	8.106	0.1332	3.025	0.0497	0.951	0.0156



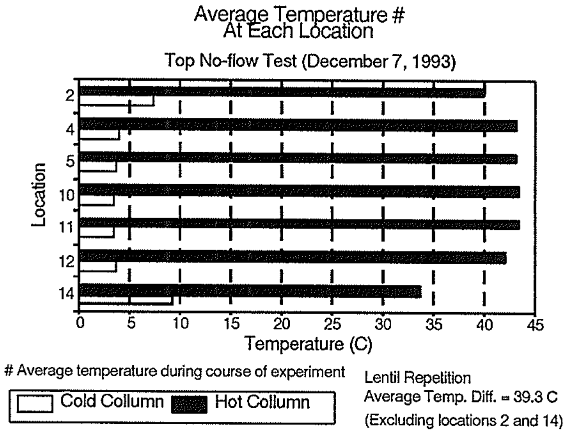
Lentil Repetition

Average Temp. Diff. = 39.3 C



Lentil Repetition

Average Temp. Diff. = 39.3 C

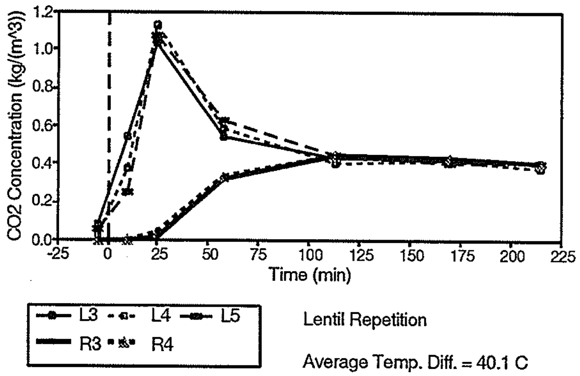


Lentil Repetition
Average Temp. Diff. = 39.3 C
(Excluding locations 2 and 14)

December 8, 1993
Top Bulk Flow Test
Temperature Difference = 40.1 C
Lentil Repetition

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		3.74		3.74		3.74		22.00			43.89		43.89		20.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	97.49	4.64	0.0865	1.84	0.0342	3.31	0.0616	82.52	1.4425	0.9523	0.56	0.0092	0.51	0.0083	0.11	0.0019	0.1067
10	97.47	29.58	0.5511	20.61	0.3840	13.99	0.2606	66.90	1.1693	0.8809	0.42	0.0068	0.33	0.0053	0.47	0.0083	0.1382
25	97.46	55.83	1.0401	60.39	1.1250	57.63	1.0735	32.31	0.5646	0.8148	1.19	0.0194	3.04	0.0494	9.95	0.1751	0.1697
57	97.46	29.61	0.5516	31.31	0.5833	34.14	0.6359	27.36	0.4781	0.6899	19.75	0.3213	21.20	0.3449	26.19	0.4608	0.2369
113	97.46	23.61	0.4399	21.43	0.3993	24.35	0.4537	23.65	0.4133	0.5156	27.52	0.4477	27.57	0.4486	27.69	0.4873	0.3545
169	97.43	22.34	0.4159	22.76	0.4238	22.28	0.4149	23.03	0.4023	0.3853	26.76	0.4352	26.96	0.4386	26.94	0.4738	0.4721
214	97.40	22.27	0.4146	20.15	0.3752	21.98	0.4092	22.14	0.3866	0.3049	24.95	0.4057	25.36	0.4124	25.07	0.4409	0.5666

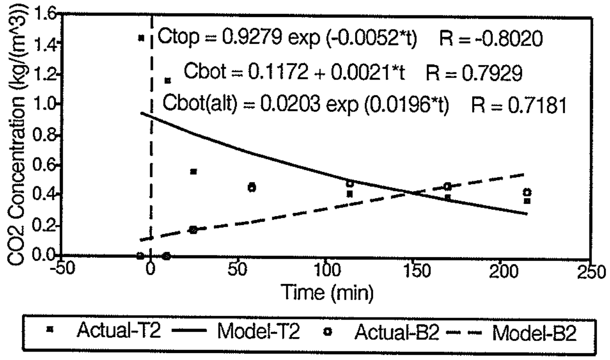
Concentration vs. Time
Top Bulk Flow Test (December 8, 1993)



Lentil Repetition

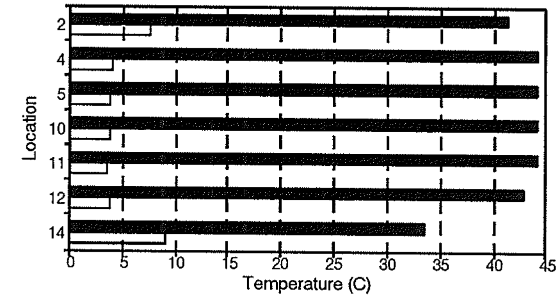
Average Temp. Diff. = 40.1 C

Concentration vs. Time
T2 and B2 Models (December 8, 1993)



Lentil Repetition Average Temp. Diff. = 40.1 C

Average Temperature #
At Each Location
Top Bulk Flow Test (December 8, 1993)



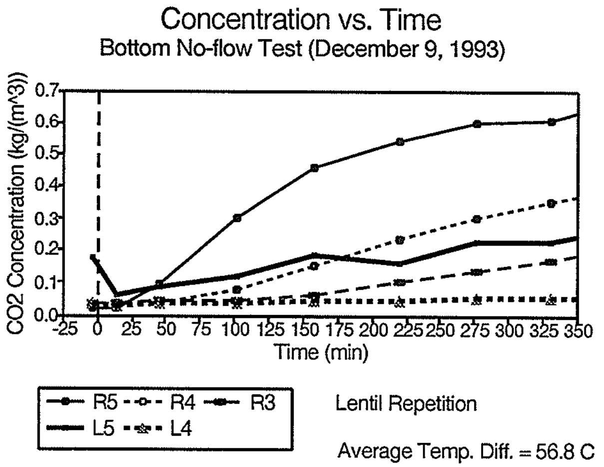
Average temperature during course of experiment

☐ Cold Column ■ Hot Column

Lentil Repetition
Average Temp. Diff. = 40.1 C
(Excluding locations 2 and 14)

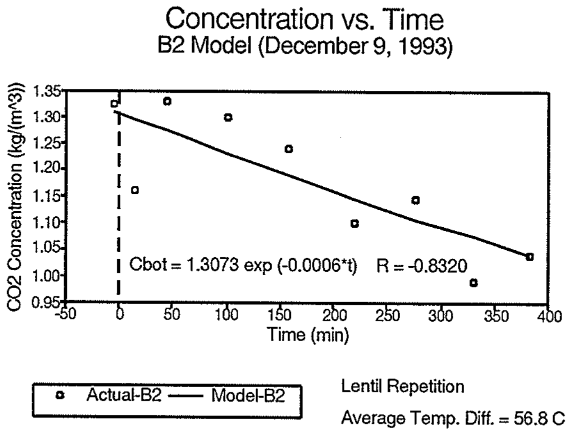
December 9, 1993
Bottom No-flow Test
Temperature Difference = 56.8 C
Lentil Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		L3		
Temperature (C)		60.14		60.14		60.14		21.00			3.32		3.32		3.32		
Time	Pressure								Actual	Model							
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	
-4	97.55	1.24	0.0192	1.96	0.0303	2.15	0.0333	75.36	1.3228	1.3104	9.66	0.1803	1.74	0.0324	1.40	0.0262	
15	97.58	1.59	0.0246	2.07	0.0321	2.39	0.0371	65.92	1.1573	1.2956	3.08	0.0575	1.63	0.0305	1.23	0.0229	
45	97.60	6.20	0.0960	2.12	0.0329	2.60	0.0403	75.73	1.3299	1.2725	4.83	0.0903	1.85	0.0346	1.44	0.0269	
102	97.62	19.76	0.3063	5.06	0.0784	2.75	0.0426	74.05	1.3006	1.2297	6.23	0.1165	1.97	0.0368	1.39	0.0259	
159	97.62	29.53	0.4577	10.05	0.1558	4.19	0.0650	70.57	1.2395	1.1883	10.00	0.1869	2.28	0.0427	1.41	0.0263	
220	97.68	35.02	0.5431	15.31	0.2375	6.49	0.1007	62.54	1.0991	1.1456	8.85	0.1654	2.55	0.0477	1.35	0.0252	
277	97.73	38.50	0.5974	19.43	0.3016	8.63	0.1339	65.04	1.1437	1.1071	12.33	0.2306	2.68	0.0502	1.34	0.0251	
330	97.74	39.39	0.6113	22.41	0.3477	11.01	0.1709	56.38	0.9915	1.0725	12.15	0.2273	2.61	0.0489	1.48	0.0277	
382	97.71	42.92	0.6659	25.40	0.3942	13.03	0.2021	59.15	1.0400	1.0395	14.47	0.2706	2.85	0.0532	1.39	0.0259	



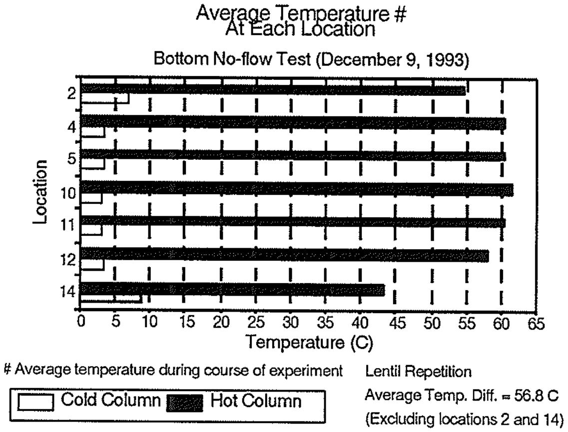
Lentil Repetition

Average Temp. Diff. = 56.8 C



Lentil Repetition

Average Temp. Diff. = 56.8 C



Average temperature during course of experiment

Lentil Repetition

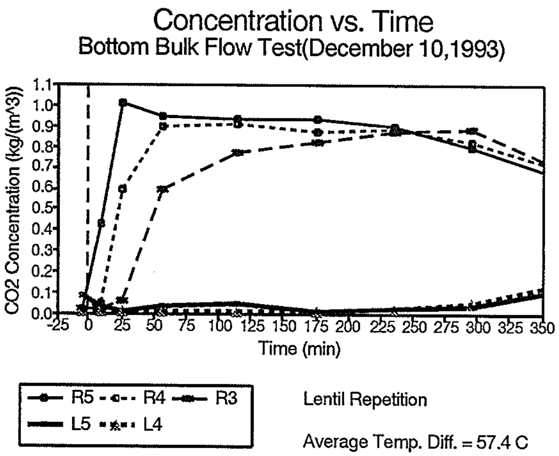
Average Temp. Diff. = 56.8 C

(Excluding locations 2 and 14)

December 10, 1993
Bottom Bulk Flow Test
Temperature Difference = 57.4 C
Lentil Repetition

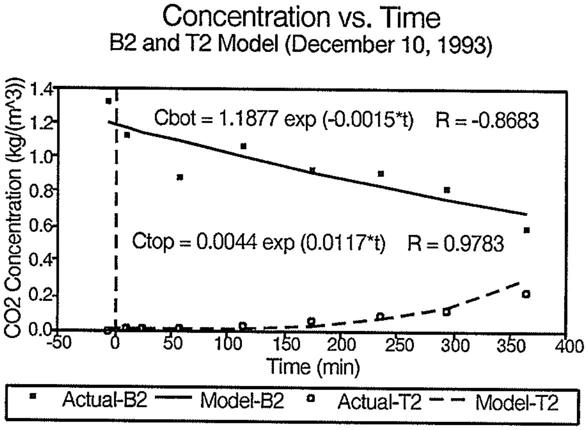
** Note: Blank entries in the table represent missing data.

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		60.84		60.84		60.84		21.00			3.47		3.47		24.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-6	99.52	0.95	0.0150	1.31	0.0206	1.35	0.0214	73.86	1.3225	1.1984	4.49	0.0856	0.64	0.0122	0.13	0.0023	0.0041
10	99.58	26.94	0.4251	2.96	0.0467	1.19	0.0188	63.20	1.1324	1.1700	1.92	0.0366	0.48	0.0091	0.25	0.0045	0.0049
25	99.60	64.45	1.0172	37.26	0.5881	3.86	0.0608			1.1440	0.51	0.0096	0.37	0.0071	0.47	0.0083	0.0059
57	99.67	59.88	0.9457	56.99	0.9000	37.61	0.5940	49.06	0.8798	1.0904	2.02	0.0385	0.38	0.0072	0.44	0.0078	0.0086
114	99.77	59.56	0.9416	58.14	0.9191	49.27	0.7790	59.61	1.0701	1.0010	2.55	0.0487	0.57	0.0109	1.25	0.0223	0.0167
175	99.81	59.72	0.9445	55.15	0.8723	52.11	0.8242	51.45	0.9239	0.9135	0.65	0.0125	0.58	0.0112	2.85	0.0507	0.0341
235	99.88	57.00	0.9022	56.16	0.8889	54.95	0.8697	51.01	0.9167	0.8349	1.43	0.0274	1.31	0.0250	4.88	0.0868	0.0688
295	99.88	50.43	0.7982	51.73	0.8187	55.64	0.8807	46.08	0.8280	0.7630	2.19	0.0418	2.89	0.0551	6.97	0.1239	0.1388
363	99.98	41.65	0.6598	43.91	0.6957	44.69	0.7080	33.02	0.5940	0.6890	5.42	0.1036	7.01	0.1340	12.47	0.2220	0.3076



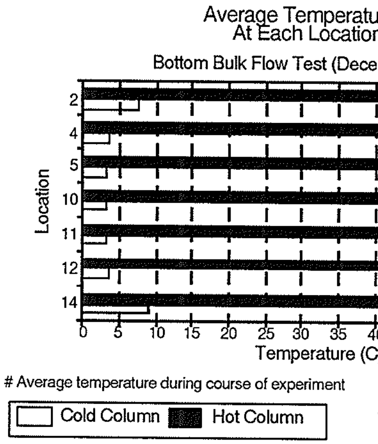
Lentil Repetition

Average Temp. Diff. = 57.4 C



Lentil Repetition

Average Temp. Diff. = 57.4 C



Average temperature during course of experiment

Lentil Repetition

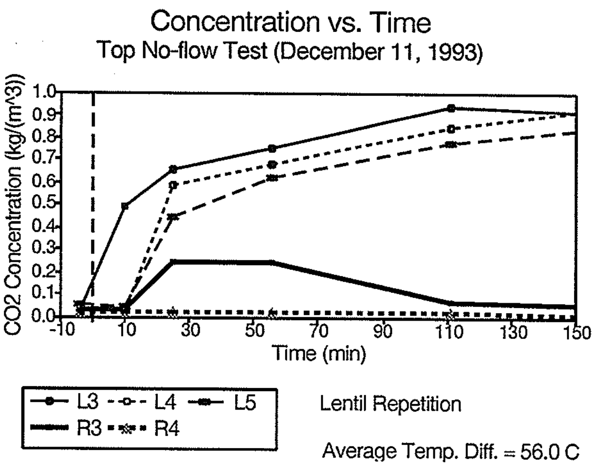
Average Temp. Diff. = 57.4 C

(Excluding locations 2 and 14)

December 11, 1993
Top No-flow Test
Temperature Difference = 56.0 C
Lentil Repetition

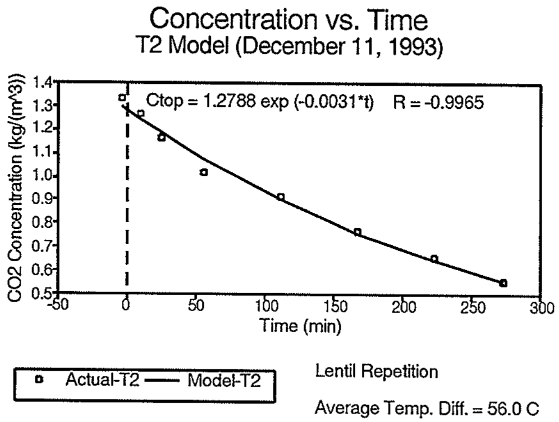
** Note: Blank entries in the table represent missing data.

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		3.75		3.75		3.75		22.00			59.75		59.75		59.75	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-4	99.74	0.91	0.0173	0.60	0.0115	2.80	0.0535	74.50	1.3324	1.2948	1.70	0.0269	1.45	0.0230	0.96	0.0152
10	99.76	25.59	0.4879	1.04	0.0199	1.98	0.0378	70.89	1.2682	1.2398	1.55	0.0246	1.29	0.0205	0.94	0.0150
25	99.78	34.49	0.6579	30.49	0.5814	23.31	0.4446	65.04	1.1637	1.1834	15.12	0.2398	1.29	0.0204	1.17	0.0185
56	99.81	39.10	0.7459	35.40	0.6753	32.51	0.6203	56.90	1.0184	1.0750	15.09	0.2394	1.27	0.0201	1.20	0.0191
111	99.87	49.40	0.9430	44.51	0.8496	40.63	0.7757	51.21	0.9171	0.9065	4.32	0.0686	0.85	0.0136	1.06	0.0168
167	99.87	47.19	0.9008	49.41	0.9431	44.97	0.8585	43.14	0.7725	0.7620	2.90	0.0461	0.58	0.0093	0.73	0.0117
222	99.91	40.57	0.7748	45.33	0.8656	47.57	0.9084	36.47	0.6534	0.6426	1.14	0.0181	0.46	0.0074	0.61	0.0096
272	99.97	35.43	0.6769	40.10	0.7662	43.63	0.8337	30.87	0.5534	0.5503	0.81	0.0128	0.43	0.0069		



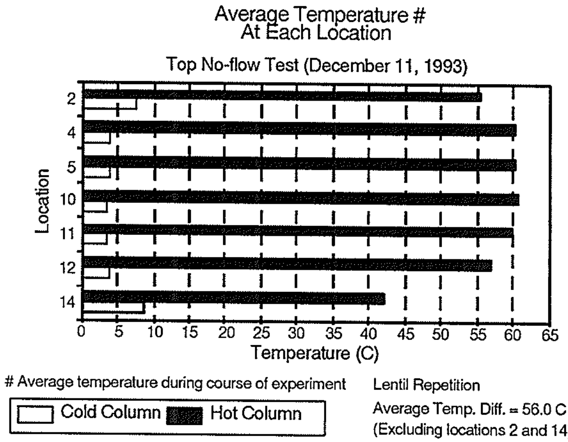
Lentil Repetition

Average Temp. Diff. = 56.0 C



Lentil Repetition

Average Temp. Diff. = 56.0 C



Average temperature during course of experiment

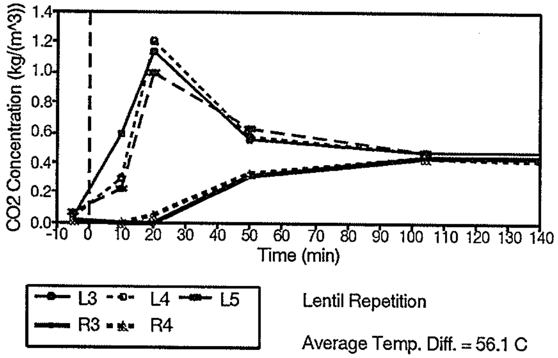
Lentil Repetition

Average Temp. Diff. = 56.0 C
(Excluding locations 2 and 14)

December 12, 1993
Top Bulk Flow Test
Temperature Difference = 56.1 C
Lentil Repetition

		Concentration of CO2															
Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		3.84		3.84		3.84		21.00			59.95		59.95		20.00		
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))
-5	96.73	2.20	0.0407	1.84	0.0340	3.65	0.0675	73.16	1.2734	1.0564	1.03	0.0158	0.81	0.0124	0.07	0.0013	0.0111
10	96.70	32.31	0.5970	15.48	0.2860	12.68	0.2343	65.00	1.1309	0.9582	0.48	0.0074	0.25	0.0038	0.41	0.0071	0.0173
20	96.69	61.17	1.1302	65.44	1.2090	53.99	0.9974	52.09	0.9062	0.8979	0.48	0.0073	3.32	0.0510	6.10	0.1064	0.0232
50	96.65	30.36	0.5606	31.27	0.5775	33.97	0.6273	27.49	0.4781	0.7389	20.16	0.3096	21.94	0.3369	27.44	0.4788	0.0558
104	96.60	25.84	0.4769	25.61	0.4727	25.90	0.4781	25.88	0.4498	0.5201	28.66	0.4399	28.49	0.4373	29.22	0.5096	0.2716
164	96.56	25.50	0.4705	24.91	0.4596	25.02	0.4615	25.26	0.4389	0.3522	27.58	0.4231	25.85	0.3965	26.09	0.4548	1.5757

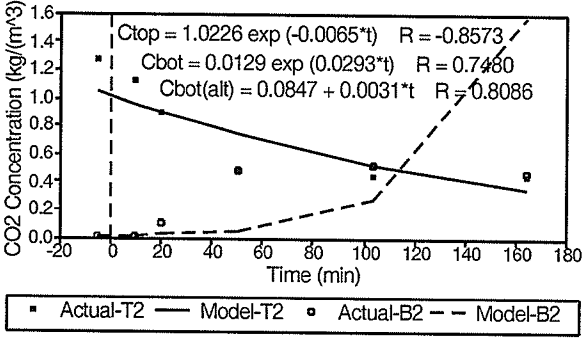
Concentration vs. Time
Top Bulk Flow Test (December 12, 1993)



Lentil Repetition

Average Temp. Diff. = 56.1 C

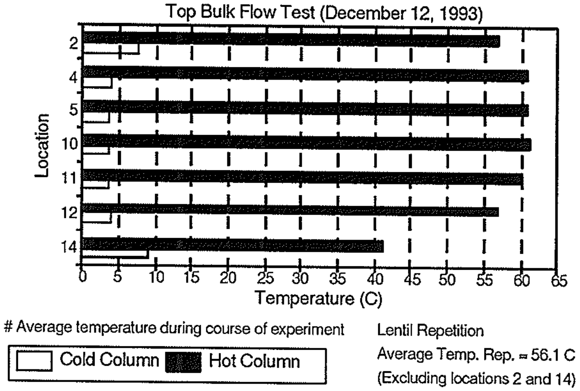
Concentration vs. Time
T2 and B2 Models (December 12, 1993)



Lentil Repetition Average Temp. Diff. = 56.1 C

Average Temperature #
At Each Location

Top Bulk Flow Test (December 12, 1993)



Average temperature during course of experiment

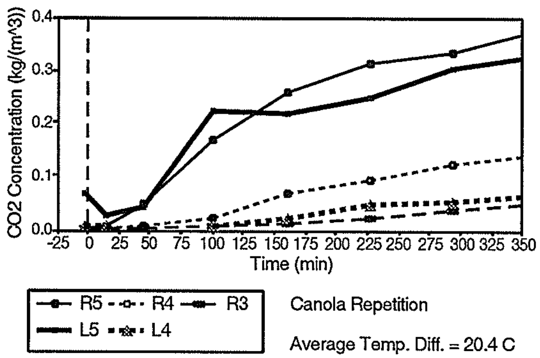
Lentil Repetition
Average Temp. Rep. = 56.1 C
(Excluding locations 2 and 14)

December 13, 1993
Bottom No-flow Test
Temperature Difference = 20.4 C
Canola Repetition

** Note: Blank entries in the table represent missing data.

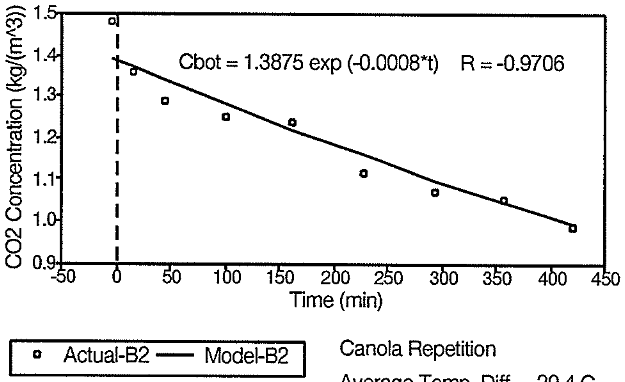
Concentration of CO2

Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		31.28		31.28		31.28		20.00			10.92		10.92		10.92	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	97.62	0.19	0.0032	0.23	0.0039	0.21	0.0035	84.12	1.4826	1.3908	3.69	0.0672	0.27	0.0048	0.09	0.0016
15	97.65	0.35	0.0059	0.22	0.0038	0.22	0.0038	76.96	1.3567	1.3709	1.39	0.0253	0.25	0.0045		
45	97.70	2.92	0.0496	0.31	0.0053	0.23	0.0039	72.92	1.2861	1.3384	2.46	0.0448				
101	97.82	9.95	0.1692	1.30	0.0221	0.31	0.0052	70.65	1.2477	1.2798	12.09	0.2204	0.54	0.0099	0.20	0.0036
161	97.98	15.19	0.2587	3.88	0.0662	0.78	0.0133	69.80	1.2348	1.2198	11.84	0.2160	1.14	0.0208	0.15	0.0028
228	98.14	18.33	0.3128	5.47	0.0933	1.21	0.0206	62.85	1.1135	1.1562	13.46	0.2460	2.54	0.0464	0.39	0.0071
293	98.20	19.55	0.3337	7.24	0.1236	2.12	0.0361	60.26	1.0683	1.0976	16.44	0.3007	2.90	0.0530	0.53	0.0098
356	98.24	21.67	0.3701	8.15	0.1391	2.94	0.0502	59.28	1.0513	1.0436	17.72	0.3243	3.37	0.0617	0.56	0.0103
420	98.37	21.58	0.3690	9.87	0.1688	3.74	0.0640	55.71	0.9894	0.9915	13.70	0.2511	4.65	0.0852	0.87	0.0159


Concentration vs. Time
Bottom No-flow Test (December 13, 1993)

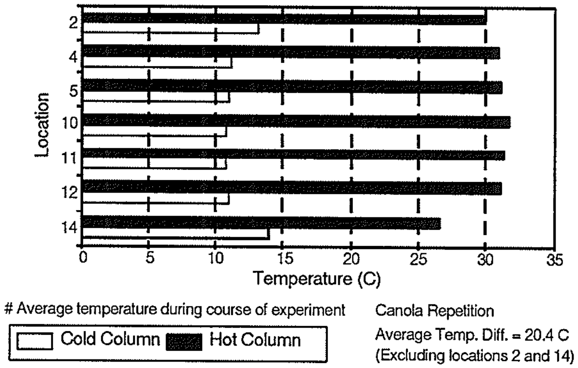
Canola Repetition

Average Temp. Diff. = 20.4 C


Concentration vs. Time
B2 Model (December 13, 1993)

Canola Repetition

Average Temp. Diff. = 20.4 C


Average Temperature #
At Each Location
Bottom No-flow Test (December 13, 1993)

Average temperature during course of experiment

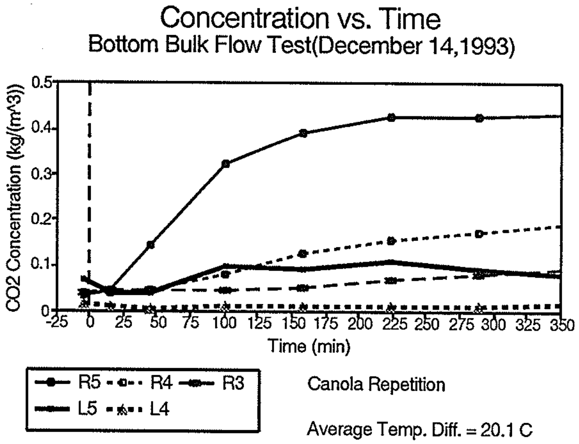
Canola Repetition

Average Temp. Diff. = 20.4 C

(Excluding locations 2 and 14)

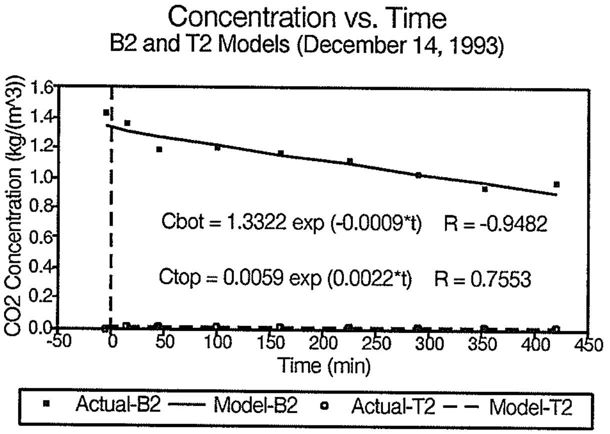
December 14, 1993
Bottom Bulk Flow Test
Temperature Difference = 20.1 C
Canola Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		31.53		31.53		31.53		20.00			11.38		11.38		21.00		
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))
-5	99.45	2.14	0.0369	2.26	0.0391	2.29	0.0396	79.35	1.4247	1.3382	3.77	0.0698	0.80	0.0148	0.24	0.0044	0.0058
15	99.47	2.57	0.0444	2.24	0.0387	2.60	0.0449	75.11	1.3489	1.3143	2.24	0.0414	0.54	0.0099	0.33	0.0059	0.0061
45	99.50	8.35	0.1443	2.56	0.0443	2.54	0.0439	66.32	1.1913	1.2793	2.30	0.0425	0.40	0.0075	0.35	0.0062	0.0065
100	99.51	18.53	0.3203	4.68	0.0809	2.50	0.0432	66.42	1.1933	1.2175	5.36	0.0992	0.50	0.0092	0.44	0.0078	0.0074
159	99.53	22.61	0.3910	7.16	0.1238	3.12	0.0540	64.48	1.1586	1.1546	4.82	0.0893	0.73	0.0134	0.44	0.0078	0.0084
224	99.59	24.79	0.4289	9.12	0.1578	3.89	0.0672	61.77	1.1107	1.0890	5.91	0.1094	0.58	0.0108	0.86	0.0154	0.0097
289	99.63	24.77	0.4287	10.15	0.1757	4.76	0.0823	56.96	1.0246	1.0271	4.88	0.0905	0.72	0.0134	0.96	0.0171	0.0111
354	99.58	25.01	0.4326	11.01	0.1904	5.18	0.0895	51.89	0.9330	0.9687	4.23	0.0784	0.80	0.0149	0.58	0.0103	0.0129
420	99.54	24.33	0.4206	11.4	0.1972	5.766	0.0997	54.33	0.9764	0.9129	4.669	0.0865	0.788	0.0146	0.571	0.0102	0.0149

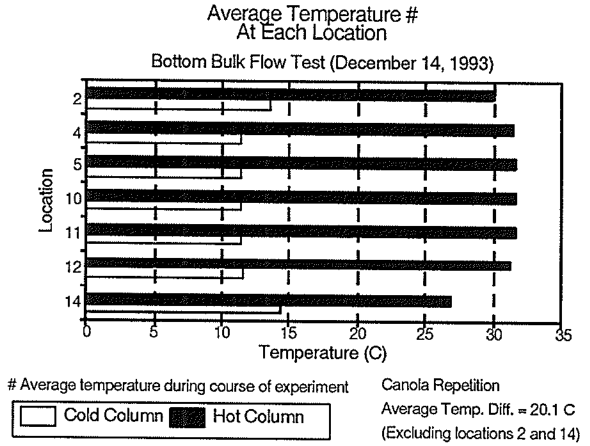


Canola Repetition

Average Temp. Diff. = 20.1 C



Canola Repetition Average Temp. Diff. = 20.1 C

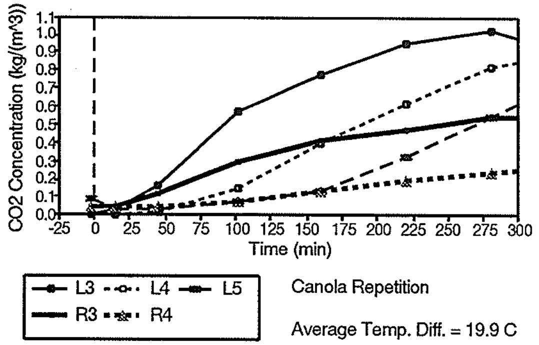


Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 20.1 C
(Excluding locations 2 and 14)

December 15, 1993
Top No-flow Test
Temperature Difference = 19.9 C
Canola Repetition

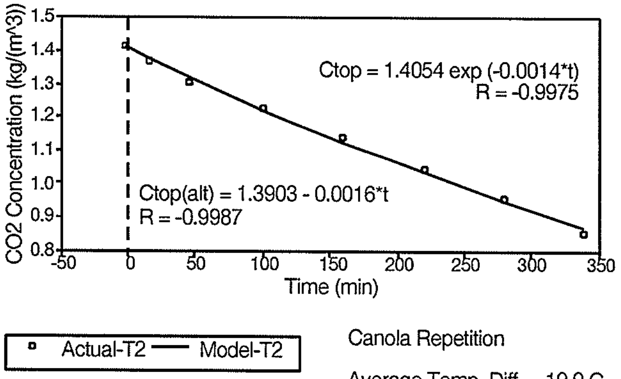
Location		Concentration of CO2 L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		11.47		11.47		11.47		21.00			31.40		31.40		31.40	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	99.50	0.53	0.0098	0.57	0.0106	5.32	0.0984	78.90	1.4125	1.4113	2.58	0.0446	2.67	0.0462	2.48	0.0428
15	99.51	1.44	0.0266	0.58	0.0107	2.13	0.0394	76.32	1.3664	1.3762	3.05	0.0528	2.73	0.0472	2.51	0.0434
45	99.52	9.28	0.1717	0.90	0.0167	2.00	0.0370	72.72	1.3022	1.3196	6.96	0.1204	2.79	0.0483	2.24	0.0387
101	99.54	30.83	0.5706	8.50	0.1574	3.79	0.0701	68.39	1.2248	1.2201	16.96	0.2933	4.48	0.0776	2.97	0.0514
160	99.56	41.59	0.7701	21.43	0.3968	7.13	0.1321	63.66	1.1404	1.1234	23.92	0.4138	8.17	0.1414	3.91	0.0676
220	99.59	51.71	0.9576	33.24	0.6157	17.47	0.3235	58.10	1.0412	1.0328	27.47	0.4755	11.34	0.1963	5.17	0.0895
280	99.58	55.57	1.0290	44.15	0.8176	29.57	0.5475	53.36	0.9561	0.9496	31.48	0.5447	13.92	0.2409	6.74	0.1166
340	99.55	48.12	0.8907	49.43	0.9150	39.58	0.7327	47.6	0.8526	0.8731	32.03	0.5542	15.59	0.2698	8.29	0.1434



Concentration vs. Time
Top No-flow Test (December 15, 1993)

Canola Repetition

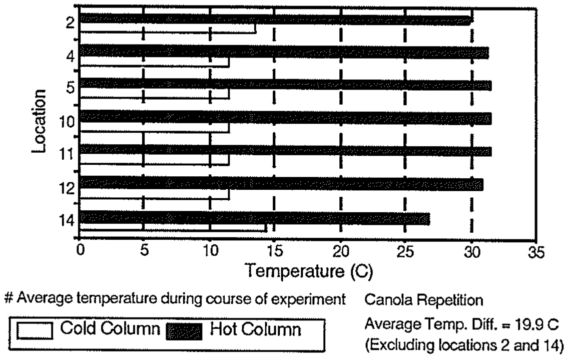
Average Temp. Diff. = 19.9 C



Concentration vs. Time
T2 Model (December 15, 1993)

Canola Repetition

Average Temp. Diff. = 19.9 C



Average Temperature #
At Each Location
Top No-flow Test (December 15, 1993)

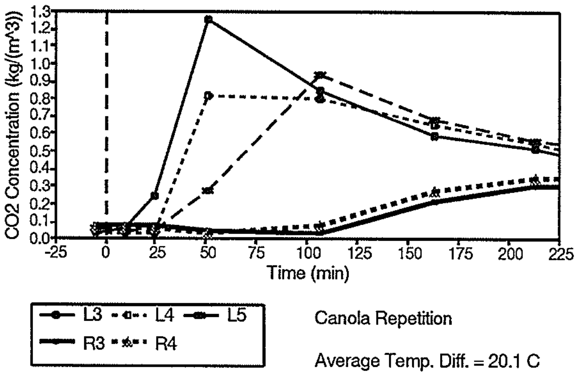
Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 19.9 C
(Excluding locations 2 and 14)

December 16, 1993
Top Bulk Flow Test
Temperature Difference = 20.1 C
Canola Repetition

		Concentration of CO2															
Location		L3		L4		L5			T2			B2		R3		R4	
Temperature (C)		11.30		11.30		11.30			21.00			20.00		31.43		31.43	
Time	Pressure								Actual	Model		Actual	Model				
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-5	99.49	1.85	0.0343	1.49	0.0275	3.14	0.0581	82.22	1.4719	1.4536	0.12	0.0021	0.0049	4.19	0.0725	3.43	0.0593
10	99.49	3.26	0.0603	1.48	0.0274	2.90	0.0537	77.10	1.3802	1.3425	0.36	0.0065	0.0068	4.34	0.0750	3.66	0.0633
25	99.50	13.26	0.2454	2.19	0.0405	2.84	0.0526	70.66	1.2650	1.2399	0.39	0.0070	0.0094	4.25	0.0734	3.41	0.0589
51	99.48	68.09	1.2603	44.40	0.8217	14.72	0.2725	64.87	1.1612	1.0803	0.63	0.0112	0.0164	3.11	0.0537	2.03	0.0351
106	99.47	45.96	0.8506	43.50	0.8050	50.41	0.9329	40.48	0.7244	0.8071	18.65	0.3349	0.0532	1.83	0.0317	4.75	0.0821
163	99.48	32.17	0.5955	35.33	0.6539	36.93	0.6836	29.18	0.5223	0.5967	25.77	0.4629	0.1800	12.47	0.2156	16.13	0.2788
213	99.49	27.64	0.5116	29.20	0.5405	30.72	0.5687	24.72	0.4424	0.4578	27.47	0.4933	0.5248	17.46	0.3019	20.21	0.3494
268	99.51	23.02	0.4263	24.53	0.4542	25.58	0.4736	21.39	0.3830	0.3420	28.64	0.5145	1.7027	19.60	0.3389	21.49	0.3715

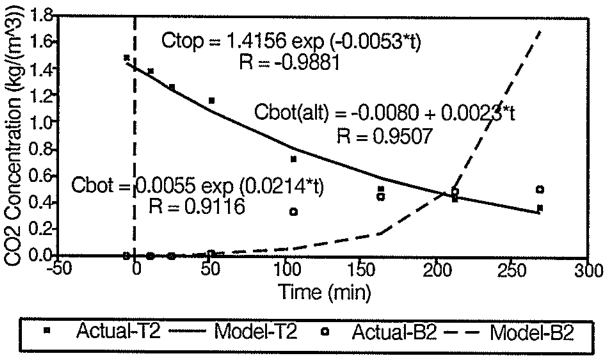
Concentration vs. Time
Top Bulk Flow Test (December 16, 1993)



Canola Repetition

Average Temp. Diff. = 20.1 C

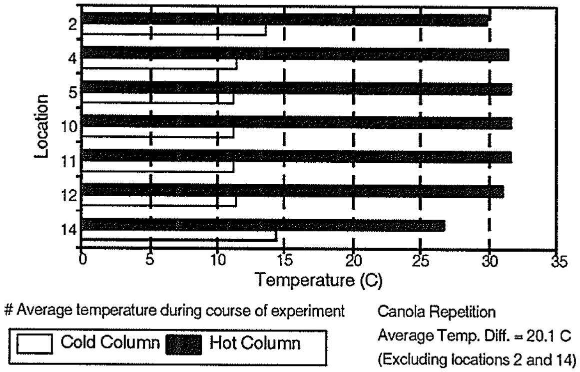
Concentration vs. Time
T2 and B2 Models (December 16, 1993)



Canola Repetition   Average Temp. Diff. = 20.1 C

Average Temperature #
At Each Location

Top Bulk Flow Test (December 16, 1993)



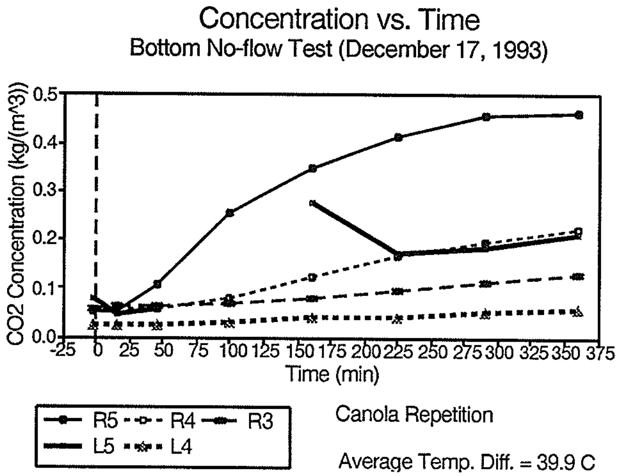
Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 20.1 C
(Excluding locations 2 and 14)

December 17, 1993
Bottom No-flow Test
Temperature Difference = 39.9 C
Canola Repetition

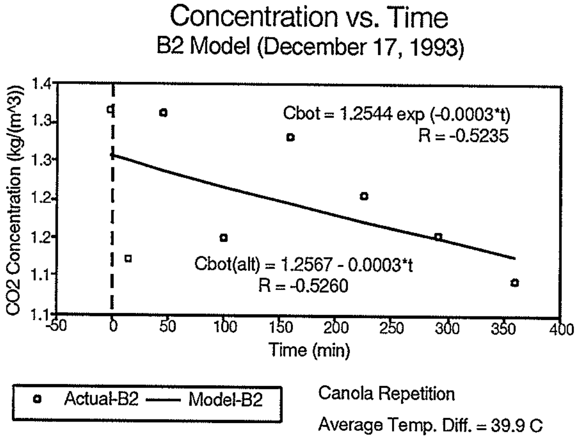
** Note: Blank entries in the table represent missing data.

		Concentration of CO2														
Location		R5		R4		R3		B2			L5		L4		L3	
Temperature (C)		44.55		44.55		44.55		21.00			4.67		4.67		4.67	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	99.23	3.19	0.0527	3.31	0.0547	3.56	0.0589	73.69	1.3158	1.2555	4.21	0.0795	1.46	0.0276	0.96	0.0181
15	99.24	3.29	0.0545	3.48	0.0575	3.85	0.0636	62.77	1.1209	1.2488	2.61	0.0493	1.27	0.0240	1.12	0.0211
45	99.24	6.56	0.1084	3.64	0.0602	3.89	0.0643	73.59	1.3140	1.2376	3.20	0.0605	1.34	0.0254	0.97	0.0184
100	99.24	15.37	0.2541	4.82	0.0797	4.03	0.0667	64.37	1.1494	1.2173			1.72	0.0325	1.11	0.0209
160	99.24	21.12	0.3491	7.66	0.1266	4.78	0.0790	71.76	1.2813	1.1956	14.77	0.2793	2.19	0.0413	1.02	0.0192
225	99.15	24.91	0.4115	10.07	0.1663	5.73	0.0946	67.63	1.2064	1.1725	9.02	0.1704	2.23	0.0422	1.04	0.0195
291	99.07	27.54	0.4546	11.83	0.1952	6.84	0.1128	64.81	1.1552	1.1495	9.83	0.1856	2.67	0.0504	1.02	0.0193
360	99.05	28.04	0.4626	13.47	0.2222	7.90	0.1303	61.46	1.0953	1.1260	11.32	0.2137	2.97	0.0560	1.13	0.0212



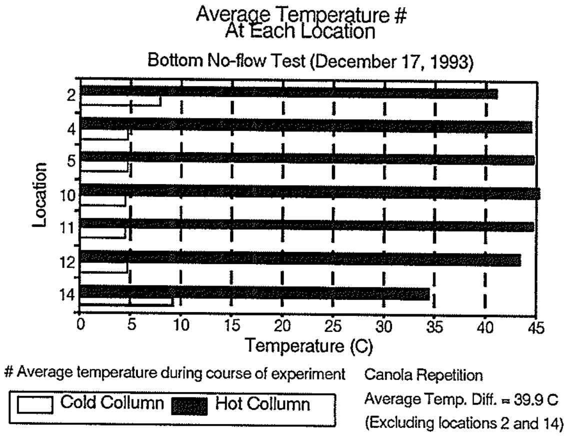
Canola Repetition

Average Temp. Diff. = 39.9 C



Canola Repetition

Average Temp. Diff. = 39.9 C

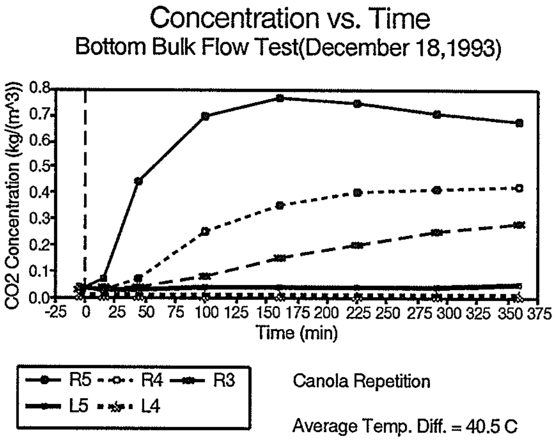


Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 39.9 C
(Excluding locations 2 and 14)

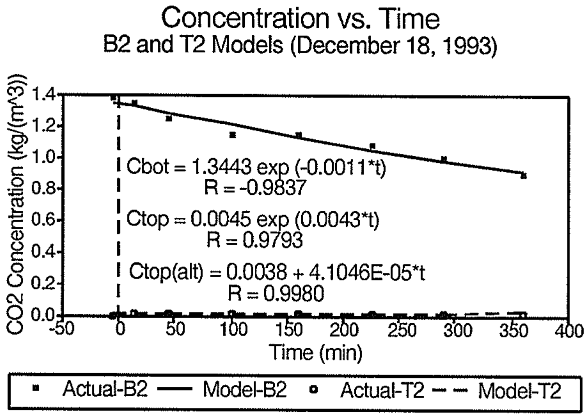
December 18, 1993
Bottom Bulk Flow Test
Temperature Difference = 40.5 C
Canola Repetition

		Concentration of CO2															
Location		R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		44.00		44.00		44.00		21.00			3.53		3.53		21.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	98.80	2.27	0.0375	2.50	0.0412	2.25	0.0371	77.31	1.3744	1.3517	2.24	0.0422	0.75	0.0141	0.20	0.0036	0.0044
15	98.78	4.37	0.0720	2.33	0.0383	2.64	0.0435	75.83	1.3478	1.3223	1.80	0.0341	0.68	0.0128	0.26	0.0046	0.0048
45	98.74	26.95	0.4440	4.25	0.0699	2.57	0.0424	69.93	1.2424	1.2794	1.77	0.0335	0.60	0.0113	0.34	0.0060	0.0055
100	98.74	42.37	0.6981	15.10	0.2487	5.25	0.0864	64.79	1.1511	1.2043	2.04	0.0385	0.64	0.0121	0.46	0.0081	0.0069
160	98.71	46.56	0.7670	21.47	0.3537	9.49	0.1564	64.86	1.1519	1.1274	2.52	0.0476	0.59	0.0111	0.55	0.0098	0.0090
225	98.67	45.30	0.7458	24.46	0.4027	12.67	0.2086	60.48	1.0738	1.0496	2.35	0.0444	0.63	0.0119	0.72	0.0128	0.0118
290	98.57	43.23	0.7111	25.46	0.4188	15.27	0.2512	55.84	0.9904	0.9771	2.11	0.0398	0.70	0.0132	0.88	0.0156	0.0157
360	98.47	41.05	0.6745	26.01	0.4274	17.15	0.2818	50.09	0.8875	0.9047	2.56	0.0482	0.79	0.0150	1.08	0.0191	0.0212

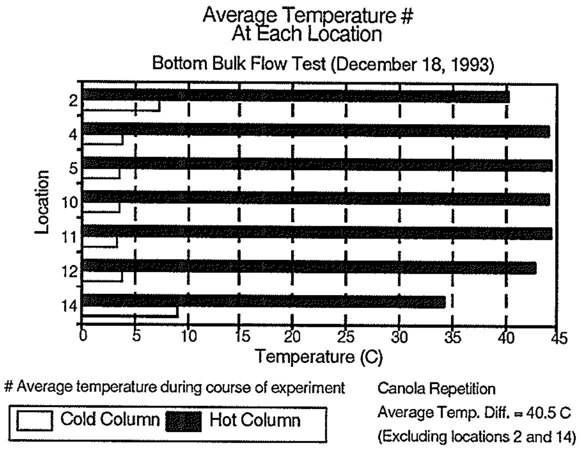


Canola Repetition

Average Temp. Diff. = 40.5 C



Canola Repetition Average Temp. Diff. = 40.5 C



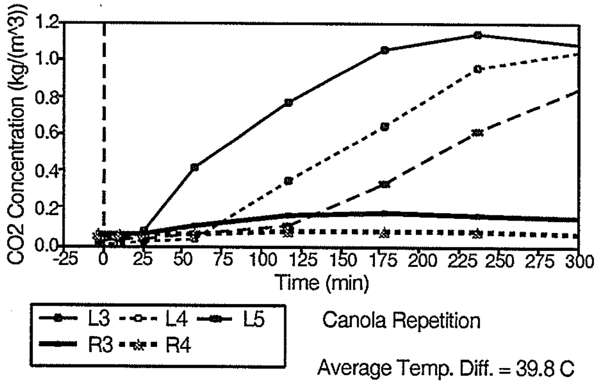
Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 40.5 C
(Excluding locations 2 and 14)

December 19, 1993
Top No-flow Test
Temperature Difference = 39.8 C
Canola Repetition

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		3.82		3.82		3.82		21.00			43.64		43.64		43.64	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	97.84	1.32	0.0246	0.76	0.0143	2.84	0.0531	83.65	1.4727	1.3633	3.65	0.0596	3.85	0.0630	3.47	0.0567
10	97.83	1.98	0.0370	0.76	0.0142	2.04	0.0381	68.87	1.2123	1.3422	3.45	0.0564	3.65	0.0597	3.68	0.0602
25	97.83	4.09	0.0765	0.92	0.0172	2.28	0.0426	75.98	1.3374	1.3183	3.96	0.0648	3.71	0.0606	3.79	0.0619
57	97.83	22.55	0.4216	2.30	0.0429	3.51	0.0655	71.72	1.2625	1.2686	6.35	0.1037	3.96	0.0647	3.79	0.0620
117	97.84	41.53	0.7764	18.70	0.3496	5.80	0.1083	67.75	1.1927	1.1805	9.52	0.1556	4.40	0.0719	3.97	0.0649
177	97.87	56.37	1.0542	34.36	0.6425	17.35	0.3245	61.73	1.0871	1.0985	10.81	0.1768	4.85	0.0794	3.71	0.0607
237	97.88	60.73	1.1358	51.11	0.9559	32.92	0.6157	57.62	1.0148	1.0221	10.14	0.1658	4.70	0.0768	3.41	0.0557
303	97.87	58.09	1.0863	56.09	1.0489	45.45	0.8500	52.87	0.9311	0.9443	8.798	0.1439	4.16	0.0680	2.82	0.0461

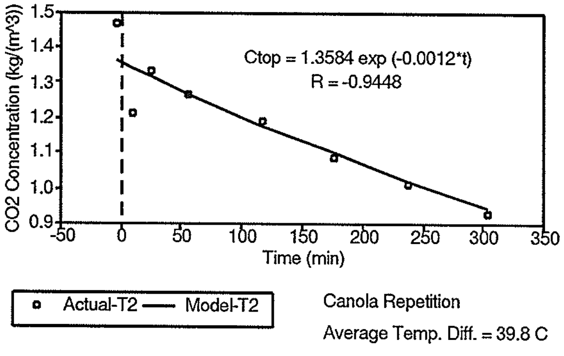
Concentration vs. Time
Top No-flow Test (December 19, 1993)



Canola Repetition

Average Temp. Diff. = 39.8 C

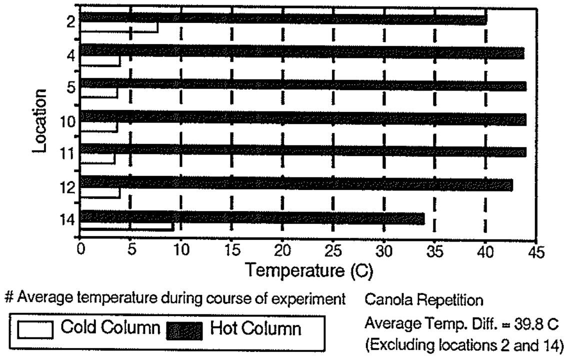
Concentration vs. Time
T2 Model (December 19, 1993)



Canola Repetition

Average Temp. Diff. = 39.8 C

Average Temperature # At Each Location
Top No-flow Test (December 19, 1993)



Average temperature during course of experiment

Canola Repetition

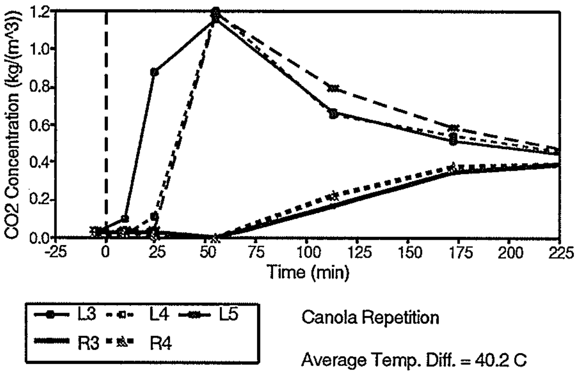
Average Temp. Diff. = 39.8 C
(Excluding locations 2 and 14)

December 20, 1993
Top Bulk Flow Test
Temperature Difference = 40.2 C
Canola Repetition

Concentration of CO2

Location		L3		L4		L5		T2			R3		R4		B2		
Temperature (C)		3.44		3.44		3.44		23.00			43.68		43.68		20.00		
Time	Pressure								Actual	Model						Actual	Model
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-5	98.66	1.88	0.0356	0.99	0.0187	2.23	0.0420	82.54	1.4553	1.3759	1.88	0.0310	1.62	0.0267	0.09	0.0015	0.0045
10	98.66	5.15	0.0971	1.20	0.0227	2.22	0.0419	76.97	1.3571	1.2594	1.60	0.0263	1.46	0.0240	0.27	0.0048	0.0065
25	98.66	46.72	0.8819	6.48	0.1224	2.51	0.0473	67.76	1.1946	1.1527	1.70	0.0280	1.34	0.0221	0.38	0.0068	0.0094
55	98.66	61.12	1.1539	63.55	1.1997	63.06	1.1905	53.28	0.9394	0.9657	0.54	0.0089	0.48	0.0079	3.10	0.0551	0.0195
113	98.66	35.59	0.6720	35.17	0.6639	42.53	0.8030	31.18	0.5498	0.6859	9.89	0.1629	13.52	0.2229	22.70	0.4043	0.0804
173	98.62	27.36	0.5164	29.03	0.5479	30.95	0.5841	25.55	0.4503	0.4814	21.32	0.3513	22.67	0.3734	27.75	0.4940	0.3474
237	98.53	22.9	0.4318	23.29	0.4391	24.49	0.4618	22.2	0.3908	0.3300	24.42	0.4019	23.52	0.3872	27.11	0.4823	1.6558

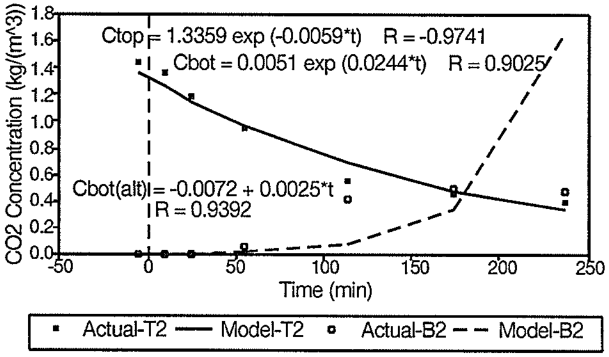
Concentration vs. Time
Top Bulk Flow Test (December 20, 1993)



Canola Repetition

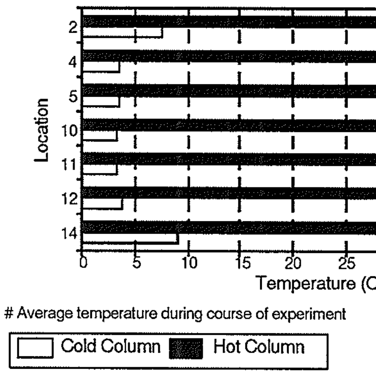
Average Temp. Diff. = 40.2 C

Concentration vs. Time
T2 and B2 Models (December 20, 1993)



Canola Repetition Average Temp. Diff. = 40.2 C

Average Temperature #
At Each Location
Top Bulk Flow Test (December 20, 1993)

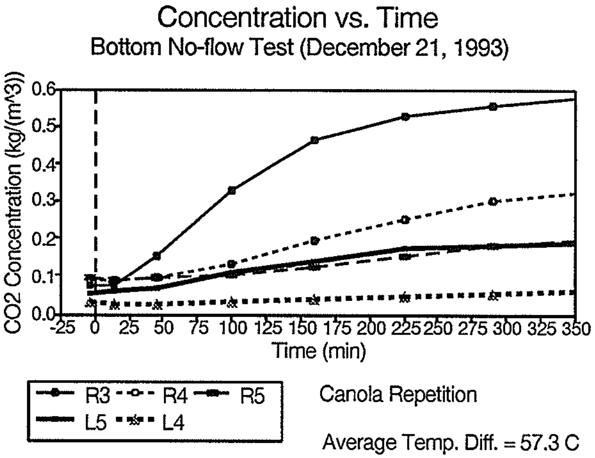


Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 40.2 C
(Excluding locations 2 and 14)

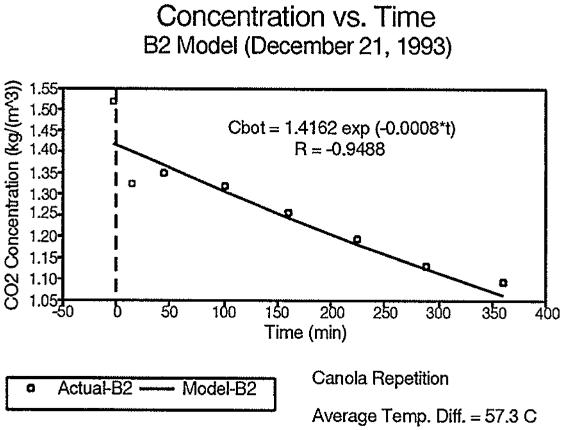
December 21, 1993
Bottom No-flow Test
Temperature Difference = 57.3 C
Canola Repetition

		Concentration of CO2														
Location		R5		R4		R3			B2		L5		L4		L3	
Temperature (C)		60.55		60.55		60.55			22.00		3.27		3.27		3.27	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	98.85	4.58	0.0718	5.42	0.0850	6.06	0.0950	85.61	1.5174	1.4196	2.81	0.0532	1.43	0.0270	1.15	0.0218
15	98.88	4.79	0.0751	5.66	0.0888	5.70	0.0895	74.78	1.3259	1.3993	3.21	0.0607	1.41	0.0268	1.05	0.0199
45	98.93	9.50	0.1490	5.92	0.0928	5.98	0.0938	75.92	1.3468	1.3661	3.64	0.0689	1.37	0.0260	1.18	0.0223
100	99.00	20.96	0.3290	8.48	0.1332	6.75	0.1059	74.19	1.3171	1.3073	5.93	0.1123	1.76	0.0333	1.26	0.0238
160	99.05	29.38	0.4616	12.23	0.1921	7.80	0.1225	70.57	1.2533	1.2460	7.45	0.1412	1.95	0.0370	1.12	0.0213
225	99.09	33.49	0.5264	16.27	0.2557	9.64	0.1515	67.02	1.1908	1.1829	9.01	0.1710	2.32	0.0439	1.21	0.0229
290	99.11	35.29	0.5547	19.09	0.3000	11.47	0.1803	63.61	1.1304	1.1230	9.51	0.1804	2.70	0.0512	1.29	0.0246
360	99.14	36.81	0.5789	20.97	0.3297	12.58	0.1979	61.39	1.0914	1.0618	9.96	0.1890	2.97	0.0563	1.16	0.0221



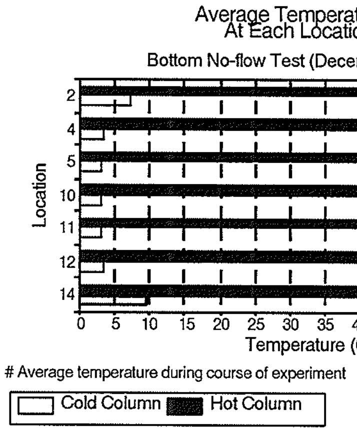
Canola Repetition

Average Temp. Diff. = 57.3 C



Canola Repetition

Average Temp. Diff. = 57.3 C



Average temperature during course of experiment

Canola Repetition

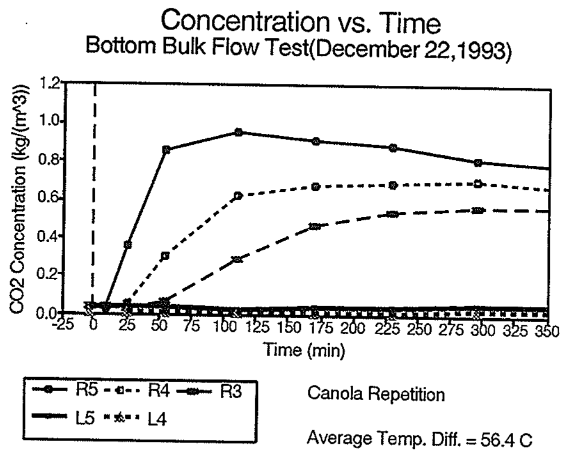
Average Temp. Diff. = 57.3 C

(Excluding locations 2 and 14)

December 22, 1993
Bottom Bulk Flow Test
Temperature Difference = 56.4 C
Canola Repetition

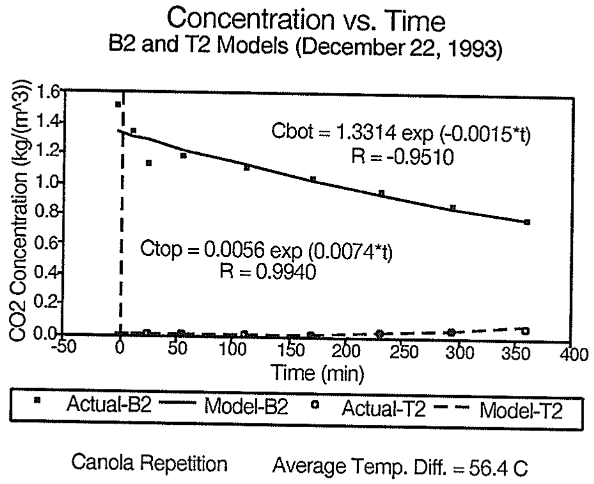
** Note: Blank entries in the table represent missing data.

Location		Concentration of CO2 R5		R4		R3		B2			L5		L4		T2		
Temperature (C)		60.24		60.24		60.24		22.00			3.79		3.79		23.00		
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	Actual (kg/(m^3))	Model (kg/(m^3))
-4	99.15	1.97	0.0309	2.23	0.0350	2.38	0.0374	85.00	1.5112	1.3394	2.23	0.0422	0.43	0.0081			0.0054
10	99.13	2.57	0.0404	1.90	0.0298	2.24	0.0353	75.46	1.3413	1.3116	2.30	0.0436					0.0060
25	99.11	23.07	0.3630	3.02	0.0475	1.83	0.0288	64.04	1.1380	1.2824	1.80	0.0341					
55	99.06	54.78	0.8615	19.41	0.3053	4.64	0.0730	66.93	1.1889	1.2260	1.92	0.0363	0.40	0.0076	0.32	0.0057	0.0067
110	99.01	60.48	0.9506	39.14	0.6153	18.27	0.2871	62.45	1.1087	1.1289	1.46	0.0276	0.56	0.0105	0.53	0.0093	0.0084
170	98.98	58.00	0.9113	43.52	0.6839	29.42	0.4623	59.17	1.0502	1.0317	1.95	0.0368	0.45	0.0084	0.71	0.0126	0.0126
230	98.97	56.38	0.8858	44.23	0.6950	34.22	0.5376	54.37	0.9650	0.9429	1.96	0.0371	0.72	0.0136	1.13	0.0200	0.0197
295	98.98	52.00	0.8171	44.74	0.7030	36.36	0.5713	49.24	0.8739	0.8553	2.54	0.0480	0.81	0.0154	1.91	0.0337	0.0307
360	98.98	49.83	0.7829	43.02	0.6760	35.93	0.5645	44.36	0.7874	0.7759	2.86	0.0541	1.74	0.0330	4.05	0.0716	0.0804

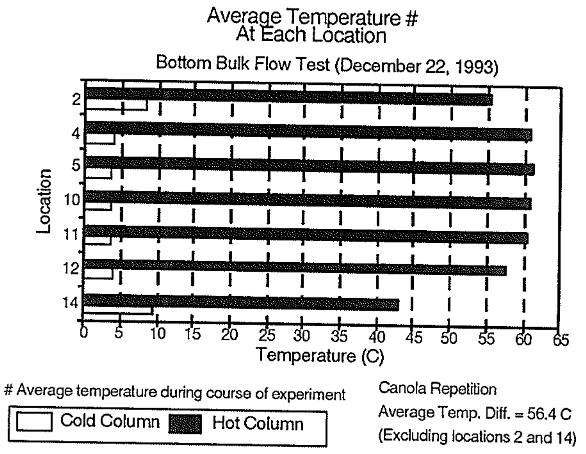

Concentration vs. Time
Bottom Bulk Flow Test(December 22,1993)

Canola Repetition

Average Temp. Diff. = 56.4 C


Concentration vs. Time
B2 and T2 Models (December 22, 1993)

Canola Repetition Average Temp. Diff. = 56.4 C

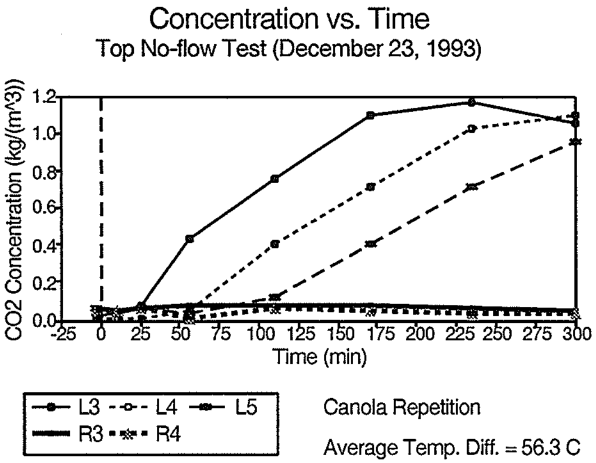

Average Temperature #
At Each Location
Bottom Bulk Flow Test (December 22, 1993)

Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 56.4 C
(Excluding locations 2 and 14)

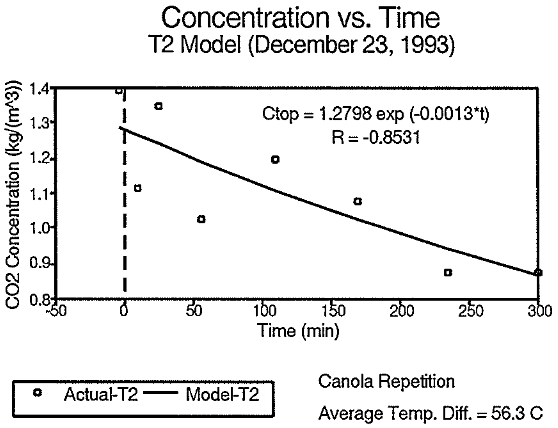
December 23, 1993
Top No-flow Test
Temperature Difference = 56.3 C
Canola Repetition

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		R5	
Temperature (C)		4.10		4.10		4.10		23.00			60.37		60.37		60.37	
Time	Pressure								Actual	Model						
(min.)	(kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))
-3	99.65	0.80	0.0153	0.51	0.0097	2.96	0.0564	77.91	1.3876	1.2848	3.60	0.0569	3.37	0.0532	3.02	0.0477
10	99.67	1.64	0.0311	0.55	0.0105	1.70	0.0324	62.59	1.1149	1.2633	3.35	0.0530	3.36	0.0532	3.25	0.0514
25	99.68	3.60	0.0685	0.67	0.0127	3.39	0.0645	75.73	1.3490	1.2389	4.10	0.0648	3.68	0.0582	3.16	0.0500
56	99.72	22.50	0.4282	2.42	0.0461	1.91	0.0364	57.57	1.0260	1.1899	4.44	0.0703	0.24	0.0038	2.81	0.0444
110	99.76	39.82	0.7584	21.15	0.4029	6.07	0.1157	66.94	1.1935	1.1093	5.08	0.0803	3.43	0.0542	2.68	0.0425
170	99.76	57.47	1.0944	37.51	0.7143	21.32	0.4061	60.39	1.0766	1.0260	5.06	0.0800	3.00	0.0474	2.38	0.0376
235	99.73	61.32	1.1673	53.77	1.0236	37.47	0.7134	49.06	0.8744	0.9429	4.27	0.0676	2.43	0.0384	1.76	0.0279
300	99.69	55.84	1.0626	57.69	1.0978	50.73	0.9653	49.00	0.8729	0.8665	3.24	0.0512	1.91	0.0302	1.49	0.0236


Concentration vs. Time
Top No-flow Test (December 23, 1993)

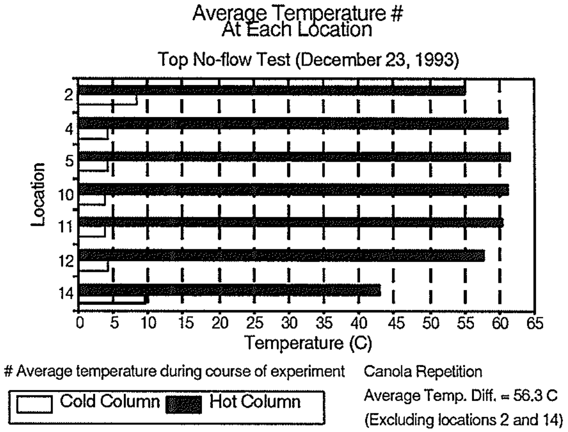
Canola Repetition

Average Temp. Diff. = 56.3 C


Concentration vs. Time
T2 Model (December 23, 1993)

Canola Repetition

Average Temp. Diff. = 56.3 C


Average Temperature #
At Each Location
Top No-flow Test (December 23, 1993)

Average temperature during course of experiment

Canola Repetition
Average Temp. Diff. = 56.3 C
(Excluding locations 2 and 14)

December 24, 1993
Top Bulk Flow Test
Temperature Difference = 56.2 C
Canola Repetition

** Note: Blank entries in the table represent missing data.

		Concentration of CO2														
Location		L3		L4		L5		T2			R3		R4		B2	
Temperature (C)		3.96		3.96		3.96		23.00			60.15		60.15		20.00	
									Actual	Model					Actual	Model
Time (min.)	Pressure (kPa)	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(%)	(kg/(m^3))	(kg/(m^3))
-4	97.98	1.39	0.0260	0.99	0.0185	4.23	0.0791	75.12	1.3154	1.2385	2.09	0.0325	1.90	0.0296			0.0071
10	97.97	4.59	0.0858	1.14	0.0214	2.67	0.0500	65.20	1.1415	1.1371	1.66	0.0259	1.41	0.0219	0.30	0.0053	0.0099
20	97.96	31.38	0.5872	3.61	0.0676	3.16	0.0591	66.60	1.1659	1.0698	1.44	0.0224	1.43	0.0222	0.38	0.0067	0.0126
52	97.93	58.46	1.0933	63.45	1.1868	60.33	1.1283	45.65	0.7989	0.8801	0.48	0.0074	0.47	0.0072	2.96	0.0524	0.0270
110	97.80	33.96	0.6343	36.78	0.6870	39.83	0.7440	30.57	0.5343	0.6178	12.26	0.1904	15.72	0.2442	24.62	0.4347	0.1081
170	97.77	26.03	0.4860	27.69	0.5171	27.76	0.5184	24.39	0.4261	0.4285	21.72	0.3371	22.75	0.3531	26.37	0.4654	0.4536
206	97.75	23.04	0.4302	24.26	0.4530	25.28	0.4719	21.86	0.3818	0.3440	23.67	0.3674	24.59	0.3817	25.92	0.4574	1.0723