AN ABSTRACT OF THE THESIS OF

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Title: Residence Time Distribution of Solids in Staged Spouted Beds.

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Abstract approved: ______________ Goran Jovanovic

A new type of multistage spouted bed is developed for a counterflow of gas and solids. A one-stage and a three-stage units are studied, the RTD's of solids therein are measured, and a solids flow compartment model is developed to represent obtained family of RTD curves.

Colored particles, identical to those used as a bed material (D_{ave} = 1.78 mm, ρ_s = 2.64 grams/cm^3), are adopted as tracer particles in impulse-response experiments. The RTD of solids is measured in both one-stage and three-stage columns of spouted beds with draft tubes. The hold-up of particles in each stage is self controlled by a specially designed feature of the bed. The recirculation of solids within each stage is controlled by the flow of gas (air) through the draft tube. The solids are continuously withdrawn from the system through a modified "L-valve" which operates with oscillating air pressure for a more uniform throughflow of solid material.

A simple compartment model consisting of a plug-flow vessel, with dead space, in series with a continuous-stirred-tank vessel is developed to represent the flow of solids through a single spouted bed vessel:

$$E(t) = \begin{cases} 0 & \text{for } t < \tau_p \\ \dfrac{1}{\tau_M} \exp\left[\dfrac{-(t-\tau_p)}{\tau_M}\right] & \text{for } t \geq \tau_p \end{cases}$$

A self-convolution of the above model/equation yields the residence time distribution expression for the three-stage column,

$$E(t)=\begin{cases}0 & \text{for } t<3\tau_{pi}\\ \dfrac{(t-3\tau_{pi})^2}{2\tau_{Mi}^3}\exp\left[\dfrac{-(t-3\tau_{pi})}{\tau_{Mi}}\right] & \text{for } t\geq 3\tau_{pi}\end{cases}$$

System parameters τ_p and τ_M (or τ_{pi} and τ_{Mi}) are correlated to operating variables (solid flow rate, S_o, gas flow rate, GFR, and recirculation time, t_R) by,

$$\frac{\tau_p}{\tau}=\alpha\exp\left[-\beta(t_{Ro}-t_R)\right]$$

where α and β are functions of the solid flow rate, S_o. This correlation is tested with an independent set of data. The correlation represents data well in the solid flow range of 6.0 to 17.0 g/sec, and in the gas flow range of 3.5 to 3.7 lit/sec.

This particular multistage spouted bed design has clear operating and scale-up advantages over previous reported designs. It can tolerate a wide range of solid flow, it starts operating without difficulties, and when shut down it empties readily. The countercurrent system, also can be easily transformed in a cross-current multistage system.

Residence Time Distribution of Solids in Staged Spouted Beds

by

Enrique Arriola

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Enrique Arriola, Author

ACKNOWLEDGMENTS

I am deeply indebted to many people that made this work possible. My caring and loving mother, Aurelia Guevara, I want to dedicate this work to her. My beloved sisters, Catalina, an example of honesty and integrity, and Susana, who was always ready to sacrifice anything for me. My brothers Paco, Miguel and Guevara, my family in law, "los Guatemala", and my family in Guanajuato, México, "los Cervantes", who are close to my heart at all times. My love and gratitude also to my children, Gabriela, Enrique, Luis, and María Elena for their support and encouragement. Special thanks to "my family in Corvallis, Oregon," Jaime and Carmelita Davila, we will miss you!

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Enrique Arriola Guevara

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NOMENCLATURE

b	Area under the curve (Figure 3.5)
$C(t)$	Tracer concentration
$C_{in}(t)$	Tracer concentration at vessel inlet
$C_{out}(t)$	Tracer concentration at vessel outlet
$C_{in}(s)$	Tracer concentration at vessel inlet (Laplace domain)
$C_{out}(s)$	Tracer concentration at vessel outlet (Laplace domain)
D_{ave}	Average particle diameter
d_p	Particle diameter
$E(t)$	Residence time distribution function
$E_1(t)$	Residence time distribution function for plug flow
$E_2(t)$	Residence time distribution function for mixed flow
$E_3(t)$	Residence time distribution function for mixed flow
$E_4(t)$	Residence time distribution function for mixed flow
$E_1(s)$	Residence time distribution function for plug flow (Laplace domain)
$E_2(s)$	Residence time distribution function for mixed flow (Laplace domain)
$E_3(s)$	Residence time distribution function for mixed flow (Laplace domain)
$E_4(s)$	Residence time distribution function for mixed flow (Laplace domain)
$E(\theta)$	Dimensionless residence time distribution
GFR	Gas flow rate
$(GFR)_o$	Minimum gas flow rate to spout the solid particles over the edge of the draft tube

h	Height of solids in bed
Hs	Separation between draft tube and bottoms of bed
L	Draft tube length
N	Number of stages
RTD	Residence Time Distribution
R_v	Volume recirculated
SFR	Solids flow rate
So	Mass flow rate of solids
S_R	Mass flow rate of solids in the spout
t	Time
t_R	Recirculation time
t_{Ro}	Recirculation time at $(GFR)_o$
$\bar{t}_{obs}$	Mean residence time (observed) in Levenspiel (1993)
v	Flow rate
V_d	Dead volume
V_M	Mixed flow volume
V_p	Plug flow volume
W	Bed Weight
W_0	Total amount of tracer material
W_d	Dead weight
W_p	Plug flow weight
W_M	Mixed flow weight
ΔP	Pressure drop across the spouted bed

Δt	Time interval
ΔW	Amount of tracer material leaving the vessel between time t and $t + \Delta t$

Greek letters

ρ_g	Gas density
ρ_S	Density of solids
θ	Dimensionless time
θ_i	Dimensionless time for stage "i"
τ	Mean residence time = W/S_o
τ_d	Mean residence time of the dead space = $W_d/S_o = \tau - \tau_{obs}$
τ_i	Mean residence time for stage "i"
τ_M	Mixed flow time
τ_{Mi}	Mixed flow time for the "i" vessel
τ_{obs}	Mean residence time (observed) = $\dfrac{\sum_{i=1}^{n} t_i C_i \Delta t_i}{\sum_{i=1}^{n} C_i \Delta t_i}$
τ_p	Plug flow time
τ_{pi}	Plug flow time for the "i" vessel
τ_R	Solids recirculation time
τ_θ	Mean residence time of the curve $E(\theta)$ curve (equal to 1)
σ^2	Variance

σ_t^2	Variance of the E(t) curve
σ_θ^2	Dimensionless variance of the E(θ) curve
$\sigma_{\theta i}^{\ 2}$	Variance of the $E(\theta)_i$ curve

To the memory of

Francisco Arriola Adame, my father

and

Luis F. Cervantes Jauregui, my lifetime friend

whose standards and lifelong achievements

serve to inspire me

RESIDENCE TIME DISTRIBUTION OF SOLIDS IN STAGED SPOUTED BEDS

CHAPTER 1

INTRODUCTION

Spouting is a gas-solid contact operation in which a high velocity jet of fluid moves through a bed of solids forcing them up to the center of the vessel until they reach the top of the bed, where particles then drop back around the spout. The flow of solids is circulatory, and if a cylindrical column is used, the flow is symmetrical, on average, about the axis. One of the major advantages claimed by the originators (Mathur and Gishler, 1955) of these gas-solid contactors, is that they can handle particles that are in a size range (> 10^{-3} m) which are too coarse to fluidize. The technical terms relating to the fields of fluidization and fluid flow will be used in this thesis as defined by Levenspiel (1972, 1991).

According to Mathur and Epstein (1974), "the operations for which the use of a spouted bed attract attention are remarkably varied". Applications, ranging from drying (Peterson, 1962), heating and cooling of granular solids (Fisons Ltd., 1969), blending (Bowers *et al*, 1960), to coating and granulating all type of coarse particles (Siginser *et al*, 1966; Berquin, 1964; Nichols, 1966), are now commercially used. Even though it is still possible to affirm that spouting serves the same purpose for coarse particles as fluidization does for fine solid materials (with the additional advantage, for some cases, of the regular cyclic motion of solids and low pressure drop), spouted beds have lately been used for processing micron-size particles, which otherwise would be difficult to fluidize (Hattori and Takeda, 1978; Littman *et al*, 1990; Jovanovic, 1994).

The addition of a tubular insert as a draft tube in a spouted bed, changes some of the operational and design characteristics of an ordinary spouted bed, as previously shown by Buchanan and Wilson (1965), Ishida and Shirai (1975), Yang and Keairns (1978, 1988), and Tsutsumi and Yoshida (1996) among others. The big advantages in using draft tubes is that there is practically no limitation on the maximum spoutable bed height, the solid circulation rate in the bed can be easily controlled, and pressure drop and minimum gas flow rates, are both lower compared to a bed without a draft tube.

Most of the previous studies (Quinlan and Ratclife, 1970; Chatterjee, 1970; Mann and Crosby, 1972; Pallai and Nemeth, 1972) are done with a batch of solids rather than in a truly throughflow operation. One of the challenges presently faced by the spouted bed technique is that of designing a suitable, simple, continuous solid-flow operation. The solids in a continuous solid-flow single spouted beds behave very similarly to a *continuous stirred tank reactor* (CSTR) (Mathur and Epstein, 1974). Some solid particles entering the bed leave almost immediately since material is being continuously withdrawn from the vessel, while other particles remain in the vessel for a very long time because all solid particles are never entirely removed from the vessel at one time. Some particles, however, leave the vessel after spending a period of time approximating the mean residence time. Consequently, in a single spouted bed there is a wide solid *residence time distribution* (RTD), which can be a serious disadvantage if, as in many commercial applications, uniform treatment of solids is desired.

The idealized plug-flow vessel is the only class of continuous flow vessels in which all particles in the vessel have the same residence time. However, the plug flow of solids through the vessel, in which all particles have the same residence time, is difficult to accomplish in practice. It has been shown that for CSTR's in series, when the number of tanks becomes large ($N > 20$), the behavior of the system approaches that of an idealized plug-flow vessel. (Levenspiel and Bischoff, 1963). Accordingly, if enough stages are provided, one would expect that a multistage spouted bed should approach the behavior of an idealized plug-flow vessel.

Some experimental work has been done involving multistage spouted beds: Madonna et al (1961) used a batch system to demonstrate savings in spouting air; Malek and Walsh (1966) tried a multistage continuous system of spouted beds, but their system had operational disadvantages as will be shown later in this thesis; and Van Weert and

Van Hasselt (1997) recently tested a countercurrent flow of dissimilar solids in a vertical, multistage, spouting-bed configuration, in a semi-continuous operation.

This investigation directly addresses the problem of determining the RTD of solids in a new, much simpler design of a continuous multistage spouted system with draft tubes. We believe that our design, does not have problems of hydrodynamic instabilities, and improves operational characteristics and controllability of the bed. To prove these claims we used solid tracer technique and RTD analysis. Even though the RTD does not carry complete information about the flow and structure of a particular bed, it is possible to affirm that the RTD is a characteristic of the mixing that occurs in that bed (Fogler, 1992; Levenspiel, 1991; Bischoff, 1966).

Our goal is to extend our basic understanding of the motion of solid phase (particles) in a multistage spouted bed through the study of the *residence time distribution* (RTD) of solids in this operation. With some exceptions, all previous investigations on spouted beds have been conducted in either cylindrical or semicylindrical batch columns. Furthermore, none of the previous work in this field was done using "two-dimensional", half-rectangular, continuous, multistage spouted beds with draft tube, which we believe is a better design in terms of operation, control, and scale-up criteria. The approach used in this study is based on meeting four specific objectives:

i) **Design, construction and operation of a single stage-spouted bed**.- This required the appropriate use of related previous experience in general design criteria, followed by preliminary laboratory tests with some suitable solid material. A single-stage bed with the geometric characteristics mentioned above is designed and tested. Since there is no available information for this specific geometry, the "best" design is chosen in terms of experimental observation. Parameters depending on solid and fluid properties, bed size, and geometry are obtained.

Two specific design details are of particular interest and importance: feeding and discharging of solids, and application of a draft tube. The objective is to design a possible feeding/discharge device with no moving parts which "automatically" maintains particles in the bed, and provides stable mass flow of solids. As far as the draft tube is concerned, the objective is to establish its operational characteristics visually, i.e.: location, geometry, size, and pressure drop in the bed.

ii) **Design, construction and operation of a multistage column**.- Based upon the experience acquired with a single-stage spouted bed, a multistage column system is designed and tested. Hydrodynamic stability of bed operation, which is a typical problem for multistage operations, is resolved without compromising the overall symplicity of the operation.

Two specific problems that are not properly solved in any of the known multistage spouted bed designs are addressed: (a) start-up procedure/conditions, and (b) shut-down procedure/conditions. Both operations should be easy to perform and should not demand special procedures and devices with moving parts.

iii) **RTD studies for both single and multistage operation.-** In the absence of known theoretical models applicable to the operation of multistage spouted bed, information concerning gross mixing behavior of solids come from stimulus-response experiments where the residence time distribution of particles fed into and discharged from the bed at a steady rate are measured. Again, simplicity in choosing both the tracer and the appropriate method of detection is a major goal. Data from these experiments are properly manipulated and analyzed.

iv) **Modeling.-** From the analysis of the experimental data, an appropriate solids circulation model is proposed and tested.

CHAPTER 2

BACKGROUND AND LITERATURE SURVEY

2.1 The Spouted Bed

Spouting is a technique for contacting fluids with solid particles. Initially developed as a method for drying grains and peas (Peterson,1962; Sevilla and Pinder, 1970; Clary *et al*, 1970), spouted beds are used now in many other processes, such as solid separation (Van Weert and Van Hasselt, 1997), granulation (Tsvik, 1966 and 1967), catalytic reactions (Uemaki, 1968), and heat and mass transfer operations in general (Uemaki and Kugo, 1967 and 1968).

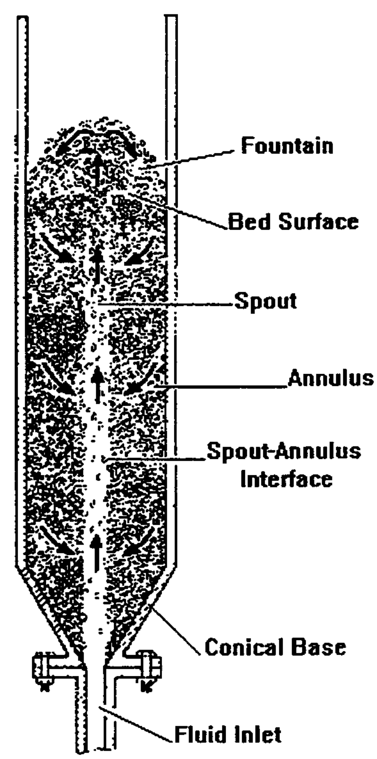


Figure 2.1 Schematic diagram of a spouted bed

We may consider a spouted bed as a combination of a dilute, fluidized phase and a coexistent moving bed of solids. Figure 2.1 shows a schematic diagram of a typical spouted bed: a vessel, open at the top, is filled with solid particles. A fluid enters coaxially through a small opening in the apex of the conical base. Since the injection rate of the fluid is very high, it produces a high velocity jet causing a stream of solid particles to rise rapidly and form a central channel within the bed of solids. At the upper end of this channel, the solids spill over and rain back as a fountain onto an annulus that defines the column of descending solids in the moving bed. Coexistence of the two phases (fluid and solids) produces a characteristic solids circulation pattern: the solid material is carried upward by a cocurrent flow of fluid in the central core and it descends by gravity, through the surrounding dense phase annular region, with countercurrent percolation of fluid.

Spouting is a visually observable phenomenon which occurs over a certain range of fluid velocity for a given combination of fluid, solids, and geometry of the vessel. Figure 2.2, represents an example of a phase diagram which shows, in general, the range of conditions for transitions from a static, to a fluidizing, to a slugging, and to a spouting bed. From this type of diagram one may conclude that spouting is a phenomenon that usually occurs at high fluid velocities and small bed depths.

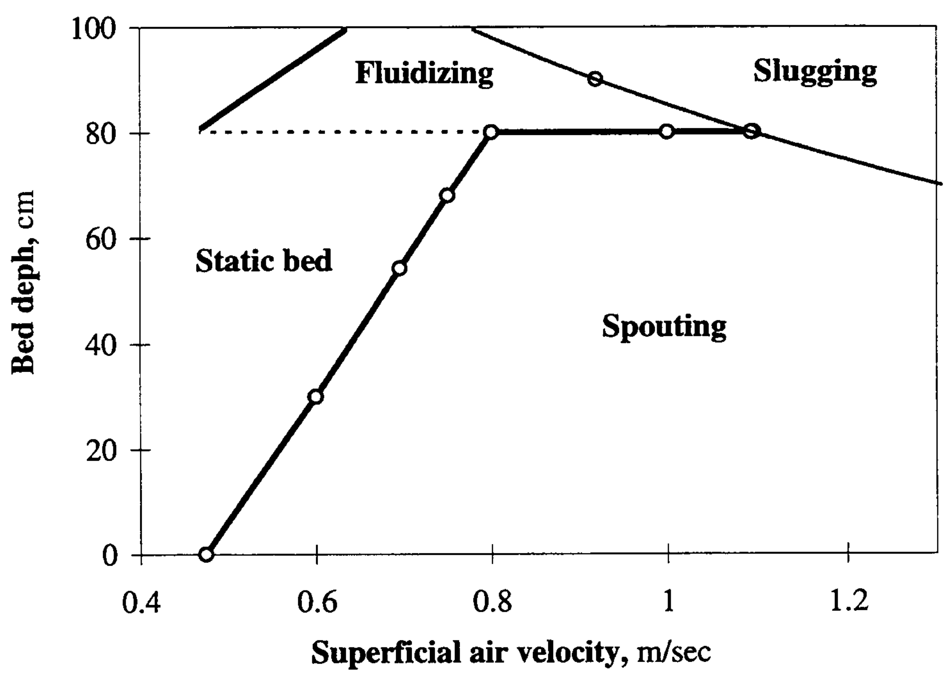


Figure 2.2 Phase diagram for semicoke (particle diameter range from 1mm to 5mm). Adapted from Dumitrescu and Ionescu (1967).

2.2 Spouting And Fluidization

It seems obvious to compare a spouting bed with an "ordinary" fluidized bed during channel formation. In this respect, according to several authors -Zenz and Othmer (1960), Leva (1959), Zabrodsky (1966), Davidson and Harrison (1963)- a spouted bed is qualitatively similar to a channeling, fluidized bed; however, in a spouting bed, the agitation of the entire bed is achieved by means of the fluid jet causing the intimate and desired contact in both dilute and dense phases. Channeling is an undesirable phenomenon in a fluidized bed. Madonna *et al* (1961) propose that "channeling is an accidental by-passing of gas in the fluidized bed while spouting is an intentional by-passing in a packed bed system". They present a comparison between channeling and spouting pressure drop curves to support their statement.

Another parallel between spouting beds and fluidized beds is the *jetting* region located on the bottom of the fluidized bed. This region is nothing more than a miniature spouted bed with considerably finer particles using a very small gas inlet. Indeed, according to Lefroy and Davidson (1969), and Fakhimi and Harrison (1970), the use of sieve plates distributors for fluidized beds gives rise to spout formation above each hole, and the spouts breaking into bubbles further up the bed. If, however, a single small hole is used to spout fine particles, Vainberg *et al* (1967) show that the allowable holdup and capacity of the bed would also be small, and any attempt at scale-up by enlarging the inlet hole would give rise to nonhomogeneous fluidization rather than spouting.

While the original statement by Mathur (1955) that "spouting appears to achieve the same purpose for particles as fluidization does for fine materials" remains true, it is clear now that for certain applications (granulation and particle coating processes) the cyclic movement of solids in a spouted bed is an important and unique feature. As Mathur later explained, "spouted beds allowed a very systematic cyclic movement of particles which are too coarse (millimeter size) for good fluidization. An overall circulatory movement of particles could, no doubt, be achieved in a fluidized bed with draft tube, but it would not be as systematic as in a spouted bed" (Mathur and Ratcliffe, 1974). Beside achieving gas-solid contact spouted beds provide a very good way of agitation of coarse particles. They can be applied for mechanical operations like grinding, blending, and dehusking.

We may attempt to establish a comparison between spouting and fluidization by observing differences and similarities of their characteristics. Table 2.1 summarizes all these characteristics. Those observations include:

a) **Particle Size.-** Spouting seems to be a practical operation for coarse particles with a minimum diameter of about 1 mm. This particle size is about the maximum above which the "ordinary" fluidized bed gas-solid contacting effectiveness is clearly affected by formation of big bubbles (Davidson and Harrison, 1963). Moreover, according to Geldart's classification (Geldart, 1973), particles suitable for the spouting operation are "Geldart D solids" while those for fluidization fall into the region of "Geldart A and B solids". For particles in air at ambient conditions, Levenspiel (1991) adapted the Geldart classification that is shown in Figure 2.3.

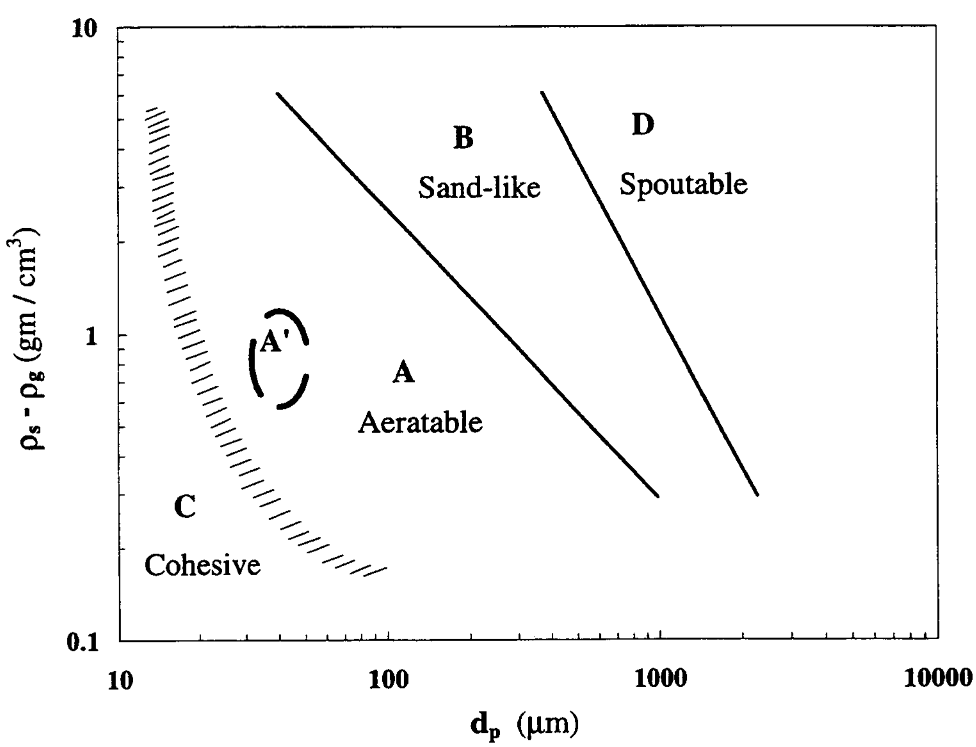


Figure 2.3 The Geldart Classification of particles for air at ambient conditions. Adapted from Levenspiel (1991).

	SPOUTING	FLUIDIZATION
Particle Size	coarse particles (> 1mm) Geldart D	fine particles (40 - 500 µm) Geldart A, B
Pressure Drop	low	high
Motion Of Solids	systematic cyclic movement	almost random motion
Heat and Mass Transfer Coefficients	large	large
Fluid Velocity	very high	low-high
Fluid-Solid Contact Time	short to large (greater flexibility in controlling it)	larger than in conventional spouted bed

Table 2.1 Comparison Between Spouting and Fluidization Characteristics

b) **Pressure Drop.-** Epstein and Mathur (1974) established that "the total pressure drop across a fully spouting bed is always lower by at least 20% than that required to support the weight of the bed".

c) **Motion of Solids.-** The previously mentioned systematic cyclic movement of solid particles is a unique characteristic of spouted beds and can be a very important feature valuable for certain applications such as: particle coating (Heiser *et al*, 1960; Singinser and Lowenthal, 1961; and Siginser, Heiser, and Prillig, 1966), and many different chemical processes (Ratcliffe and Rigby, 1969, Berti, 1968; Vavilov *et al*, 1967 and Uemaki *et al*, 1970)

d) **Heat and Mass Transfer Coefficients.-** For gas-solid systems, the wall-to-bed heat transfer coefficient h_W, exhibits a sharp increase once a spouting state is reached (Uemaki and Kugo, 1967). This is also true for fluidization; but for spouting, the coefficient increases with increasing particle diameter, a characteristic which is the opposite of that observed in fluidization of the same particles.

e) **Contact Time.-** Spouted beds have more flexibility in gas-solid contacting (Uemaki *et al*, 1970). Nominal values for contact times may be obtained by dividing the packed height of the solids in the bed by the *superficial velocity* of the spouting gas. One can easily control the length of contact time by changing the bed depth, by varying the diameter of the gas inlet, or by changing the draft tube operating characteristics. Uemaki further note that for a given solid material, there is only one way to control the contact time in a fluidized bed and that is to reduce the depth of the bed. This cannot be done beyond a certain limit since a sizable depth is required to keep isothermal conditions. On the other hand, the contact time in a spouted bed remains short even in relatively deep beds. Some specially designed spouted beds may have very long contacting times between reacting gas and solids. (see Figure 2.4.).

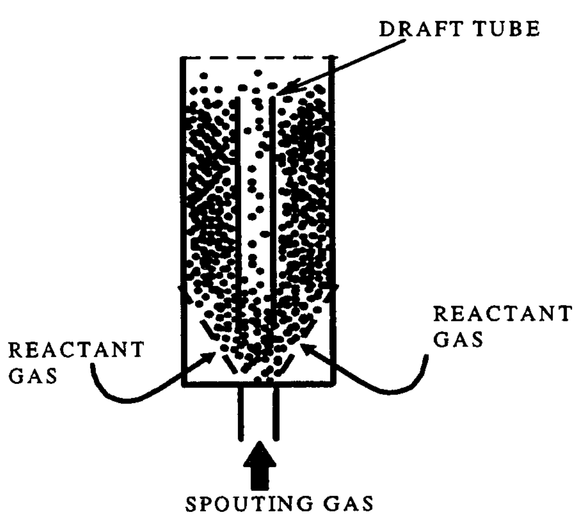


Figure 2.4. Long contacting time spouted bed.

The idea behind these designs (Johnston *et al*, 1961; Vukovic *et al*, 1973; Jovanovic, 1995) is to superimpose two entirely different mechanisms for gas-solid contacting: a very effective, long, contact between solids and reactant gas in the annular region, and a characteristic spouting circulation pattern without the necessity of expensive mechanical agitation.

2.3 Multistage Spouting

Multistage operation of spouted beds involving countercurrent flow of solids and spouting fluid has been reported by several researchers: Elperin (1955, 1960 and 1965), Khokhlov (1959 and 1965), Madonna (1961), Malek and Walsh (1966), Rovero and Watkinson (1990). Different types of units of varying design were used. Two different multistage operations involving flow of solids in series through more than one spouted bed were developed:

1- Flow of spouting gas in parallel (Figure 2.5)

2- Flow of spouting gas in series (Figure 2.6)

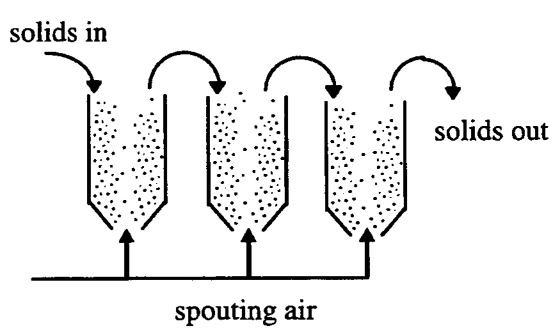


Figure 2.5 Flow of spouting gas in parallel.

A good example of flow of spouting gas in parallel is the work done by Paterson *et al* (1983). Works by Elperin and Khokhlov (1965), Madonna *et al* (1961), Malek and Walsh (1966) and, more recently, Rovero and Watkison (1990) may well represent the flow of spouting gas in series. Depending on the purpose of the process, a multistage continuous operation has several advantages over the batch operation; among the most important ones are:

a) Continuous operation.

b) Less gas flow rate requirement for a given depth of solids.

c) Prolonged gas contact time with solids in the bed.

d) Shorter solid residence time distribution and increase of the uniformity in solids treatment.

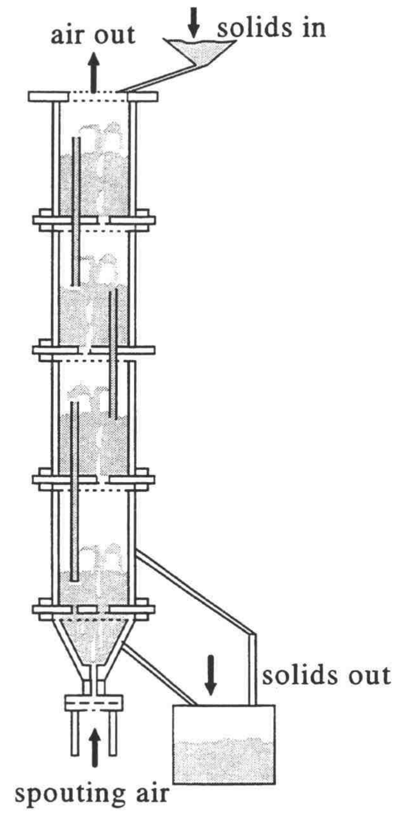


Figure 2.6 Flow of spouting gas in series

2.4 Modifications to the Spouting Technique

There are many alternate configurations for the spouted bed operation, such as multiple spouting, pulsed flow spouting, spouting with tubular inserts, slot spouted bed, two-fluid phase spouting, as well as others. (Mathur and Epstein, 1974, Chapter 12). For the present work it is important to examine two of these configurations in more detail:

a) Spouted Beds with draft tubes

Mathur and Epstein (1974), believe that "as far as solids circulation is concerned, flow of fluids through the annulus region of a normal spouted bed serves little purpose". Bowers *et al* (1960) and Buchanan and Wilson (1965) were among the first to try the use of draft tubes in spouted beds.

In the draft tube, the spouting gas is forced to go up through the central core without contacting the solids in the bed except for a very short distance between the fluid inlet and the lower end of the draft tube (see Figure 2.7a).

Certain advantages and limitations are observed in the use of draft tubes. The most important to mention are: (1) they allow the spouting of small size particles as shown by Hattori and Takeda (1978); (2) the spouting process can be done with smaller pressure drop and/or higher bed depths, (3) the so-called minimum spouting velocity will also be smaller because the fluid in the draft tube is confined and does not leak out along the spout height as in an ordinary spouted bed, (4) the advent of draft tube spouted beds also eliminated the bubbling problems in gas-particle systems (Hattori and Takeda, 1978), (5) the overall mixing efficiency is reduced. The hydrodynamic behavior of spouted beds with draft tubes is extensively discussed by Yang and Keairns (1983) and Hadzismajlovic *et al* (1992).

b) Slot Spouted Bed

A modification involving the introduction of the fluid into the base of the bed through a narrow slot running across the longer dimension of a rectangular bed has been widely studied by Mitev (1967), Romankov and Rashkovskaya (1968), and by Volkov (1970). One of the favorable features of the slot spouted beds is the relative ease with which the design can be scaled up: it can be achieved by simple parallel arrangement of a series of slot units into a multiple system, resulting in a considerable throughput increase. The slot may be either continuous or with spaced openings; in both cases, a stable spouting of solids can be obtained (see Figure 2.7b).

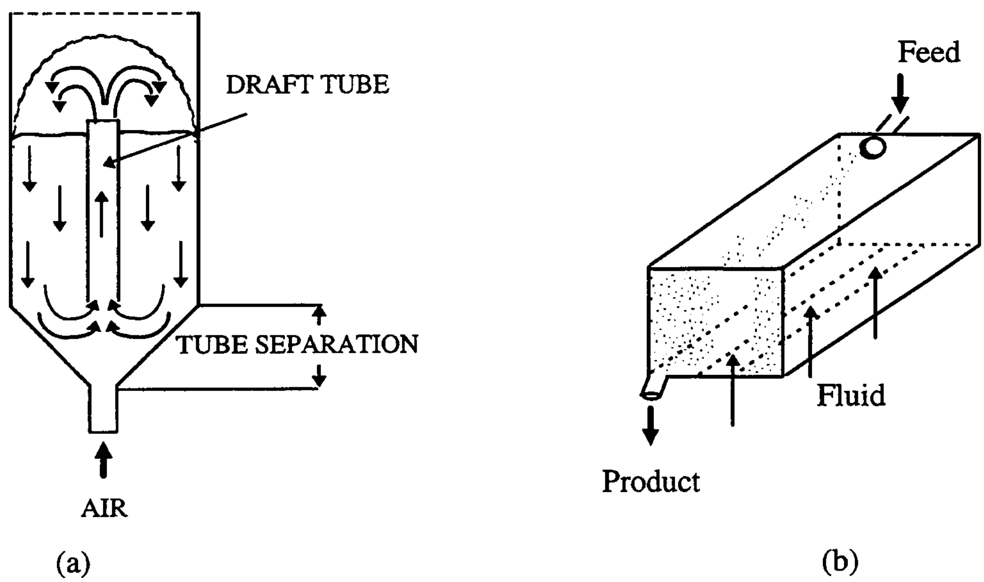


Figure 2.7 Modifications and variations to the Spouting Technique. (a) Spouted Bed with draft tube, (b) Slot Spouted Bed.

2.5 The RTD Approach To Modeling Flow In Mobile Beds

In an idealized plug-flow vessel, all the solid particles leaving the vessel have been inside it for exactly the same amount of time. Similarly, in an batch vessel, all the particles within the vessel have been inside it for an identical length of time. This time is called the residence time of the particles in the vessel. These two vessels are the only two classes of vessels in which all the particles have the same residence time. In all other types of vessels, the solid particles spend different times within the vessel; in other words, there is a *residence time distribution* of these particles inside such vessels.

It can be visually observed that in a continuous single spouted bed there is a wide solids residence time distribution. This fact is inevitably associated with the solids mixing characteristics of the single-stage spouted bed. This can be a serious disadvantage if uniform treatment of particles is desired.

2.5.1 Tank-In-Series-Model

According to Becher and Sallans (1961), Kugo *et al* (1965), Barton *et al* (1968), Quinlan and Ratcliffe (1970), and Pallai and Nemeth (1972), the solid mixing in a single stage spouted bed is close to perfect mixing:

Becher and Sallans (1961) used a pulse of dyed wheat injected at bed top, and the concentration of colored particles in the bed was measured periodically. Kugo *et al* (1965) also experimented with wheat, but they observed the output response to a step change in solids input: the feed was changed to colored particles, and their concentration measured in wheat discharging from the opening in the conical base of the vessel. Barton *et al* (1968) fitted their own experimental concentration-time data by linear regression, and obtained an empirical equation.

Quinlan and Ratcliffe (1970) reached the conclusion that only 8-10 % of the total spouted volume is in plug flow, while the remainder is perfectly mixed. According to them, dead space and bypassing are negligible. Finally, Pallai and Nemeth (1972) arrived at the conclusion that solids mixing in spouted beds is nearly but not quite perfect.

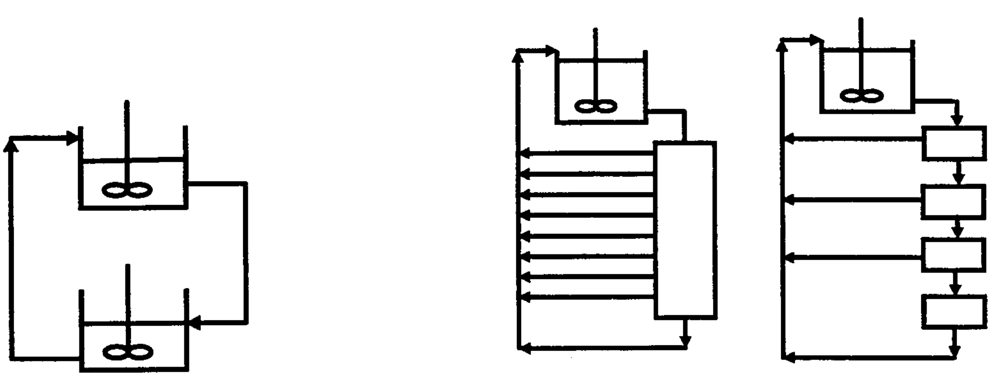
Although all those researchers claim that the assumption of perfect mixing would be a good approximation for most practical purposes, none of them ever adopted the "tank-in-series-model" and/or tested a multistage system. Furthermore, we know of no published work attempting the utilization of tank-in-series-model to describe the multistage spouted bed behavior of solid particles.

2.5.2 Compartment Models

According to Levenspiel (1972), "when one-parameter models are unable to account satisfactorily for deviations from the ideals of plug and mixed flow, the more complicated models must be attempted". One approach is to look at all possible combinations that one can use to model a nonideal vessel using only plug flow, dispersed plug flow, mixed flow, dead volume and bypassing. The rate of transfer between such vessels is one of the model parameters. This approach, however, is not based upon the careful visual observation of the flow patterns.

A second approach is to obtain a compartment model with parameters that are based upon *phenomenological* observation. In this case, an actual flow situation may better be described.

A suitable model carefully checked by appropriate measurements of tracer particle concentration can be quite helpful in estimating the actual solids circulation in a spouted bed. Chatterjee (1970) proposed a model based on measurements of the degree of mixing of tracer particles at the top of the bed as a function of time. The model proposed by Chatterjee describes the spouted bed as two stirred tanks connected in series, as shown in Figure 2.8a, with the output of the second tank recycled to the first tank.



(a) (b)

Figure 2.8 (a) Twin continuous stirred tank model by Chatterje (1970), (b) Circulation models by Mann and Crosby (1972).

According to Mann and Crosby (1972), the model by Chatterjee fails to represent actual movement of solids because: (1) concentrations of tracer particles are assumed uniform in both upper and lower sections of the annulus, (2) there is an actual short-circuiting along the spout which is not included in the model and, (3) the fraction of the particles in the spouting region is not necessarily insignificant. Therefore, Mann and Crosby proposed a more realistic model, shown in Figure 2.8b, which takes into account the cross-flow of solids from the annulus to the spout as well as the holdup in the spout. However, it should be noted that the, Chatterjee and Mann and Crosby analyses, concern the mixing behavior of a *batch* of solids rather than a continuous flow system, and unfortunately they do not present an analytical solution.

2.6 Research With Multistage Units In Series

A large volume of information on spouted beds has appeared in technical journals and books showing that their use is becoming extraordinarily popular. There are now hundreds of papers on the subject that initially was referred to as "Canadian Fluidization". Most of the past work has been done using cylindrical beds with no draft tubes, and the operations were performed in a single, batch fashion. Multistage systems, i.e. vertically superimposed spouting beds, have not been well described in the literature, and there are no good commercial designs available. Moreover, there are no known published papers dealing with the experimental determination of the RTD of solids in a multistage spouted bed with draft tubes, and the use of such data for modeling purposes.

Elperin and Khokhov (1965), were among the first to experiment with multistage operation involving countercurrent flow of solids and spouting fluid in a manner characteristic of spouted beds. They constructed units consisting of several retorts vertically superimposed one upon the other. Each retort was connected to the next one via a throat. The fluid velocity in the throat was then higher than in the widest parts of the beds. Pulsating downward flow of solids was caused by pulsations of the upward-flowing gas. Units of that type are hydrodynamically unstable and they have been used for many different purposes, such as cement clinker production, drying, heating, and gypsum production. More recently, Paterson *et al* (1983) experimented with parallel spouted beds in a batch process (Figure 2.9). Their experiments were conducted with two different types of solids to determine the solids flow rate and the pressure drop through different sections of the loop.

The works by Madonna *et al* (1961) and by Malek and Walsh (1966) are important to us because they are all investigations of multistage units.

Madonna and coworkers used a group of four 6-in diameter Pyrex tubes of equal length stacked one above the other, and separated from each other by septa each with a central orifice. These stages contain spouted batch systems designed simply to show that the air requirement to spout the entire assembly was reduced compared to the air requirement for the accumulated depth of all four beds taken as a unit.

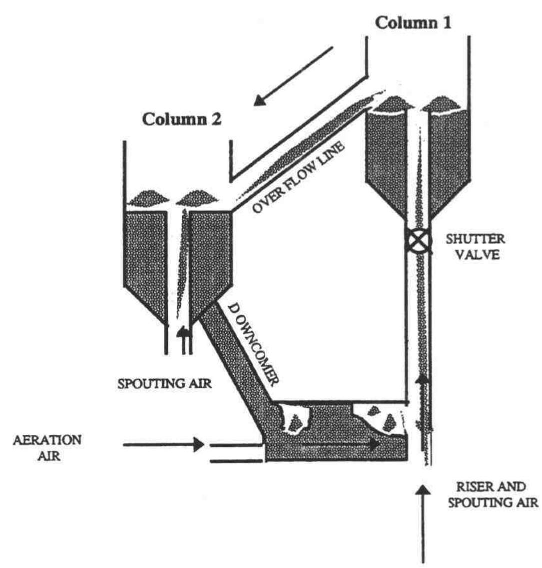


Figure 2.9 Parallel spouted beds in a batch process. Adapted from Paterson, Grace and Watkinson (1983)

The multistage column used by Malek and Walsh is of the type shown in Figure 2.10 and it deserves special attention since these workers experimented with continuous multistage units with countercurrent flow of gas-solids in series. Transfer of particles from stage to stage is accomplished by the use of 1-inch internal downcomers. No mechanical device is used, and the solids are taken from the upper stage, either in the moving bed zone or from the dilute phase zone. For the later case, the top end of the internal downcomer is extended above the bed level so that the only material transferred in the tube is solids falling directly from the spout itself. The discharge end is located in the lower moving bed zone. Malek and Walsh agree that the position of this lower end is critical, since a slight displacement upwards changes the flow rate of solids until the end becomes totally exposed and the spouting of the upper bed stops.

Clearly, since the location of the downcomer is very sensitive, Malek and Walsh suggest the possibility of using a "mechanical feeding device that could be superior in practice". These researchers also attempted the use of external downcomers. According to their own words, "primarily because of the number of bends necessary, it proved impossible to maintain a reliable flow of solids, although a slight improvement was obtained when a smooth liner was installed". Later investigations used only vertical, internally mounted transfer lines.

At this point, it is very important to realize that, in our opinion, the column used by these workers has other disadvantages besides those mentioned for its possible industrial application. Our first objection has to do with the feeding and discharging procedures for solids. To start the operation of the column, it is necessary first fill up to all stages using "extra" external downcomers (with all the problems mentioned above). On the other hand, at shut-down time, a large fraction of solids remains within the column, and there is no way to clean out the column completely unless it is disassembled. Obviously this amount of solids never was in contact with the gas during the operation, and represent an undesirable dead space.

Our second, and no less important objection has to do with the high peak pressure drop within the column. This is a serious limitation for a continuous, multistage, stable, inexpensive operation. We have found that the use of draft tubes in each stage will certainly solve the problem of high pressure drop, and we will illustrate this later.

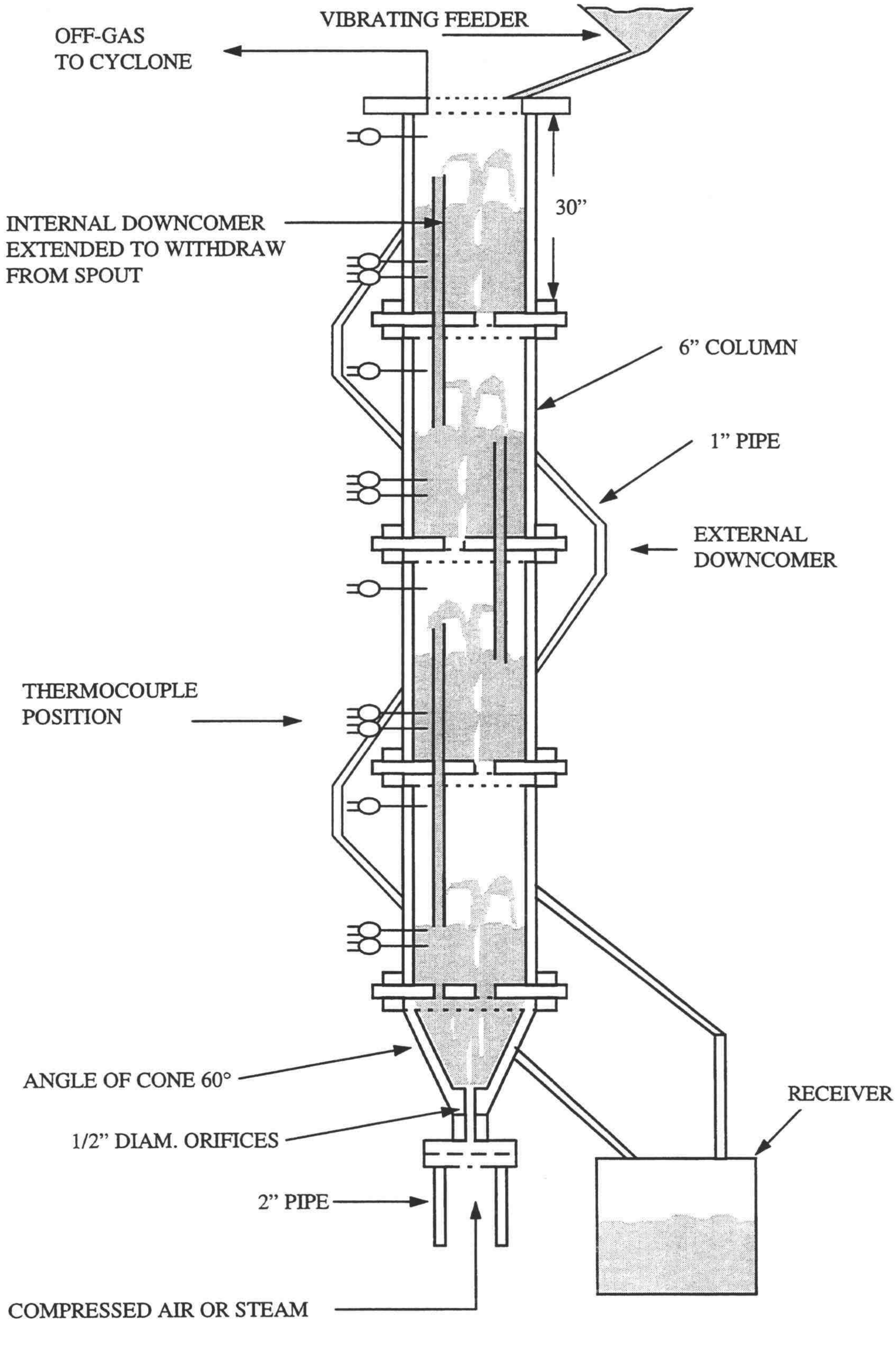


Figure 2.10 The multistage column used by Malek and Walsh (1966)

Finally, we are persuaded that the column of Malek and Walsh, although it represents an important contribution toward the use of multistage systems of spouted beds for industrial applications, has operating characteristics that place numerous constrains for its possible operation on an industrial scale.

The Himsley column, adopted for uranium extraction, and the NIMCIX column developed in South Africa for the same application, are briefly mentioned in Anon (1990) and in Van Weert and Van Hasselt (1997). According to these authors, very little is published on this equipment, but it is known that these columns have a semi continuous operation with serious hydrodynamic instabilities due to the plugging of their screens that cause gold extraction inefficiencies.

The spouting bed configuration by Van Weert and Van Hasselt, shown in Figure 2.11, was also used to separate dissimilar solid particles.

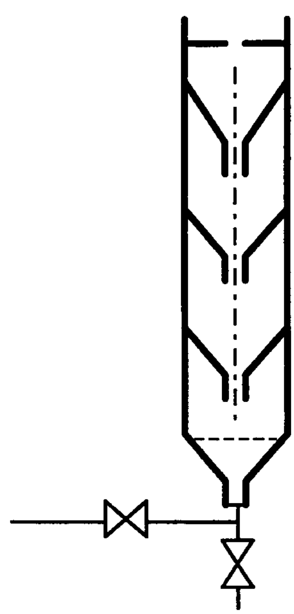


Figure 2.11 Multistage spouting bed test facility as used by Van Weert and Van Hasselt (1997).

The vertical multistage spouting bed was investigated as an alternative to mechanical devices, such as screens or cyclone separators to achieve separation of solids. The operation of their column could be characterized as a semicontinuous operation. Periodically the upward velocity of the gas is lowered, allowing the solid particles to settle and be collected in the cone of each stage. At the moment of zero velocity the solid particles slide through the opening in the cone into the lower compartment, after which the regular upward velocity of the gas is resumed. This transport of particles into the next lower compartment happens simultaneously for all stages. Van Weert and Van Hasselt found that their spouting configuration requires "internal modification" to achieve hydrodynamic stability.

CHAPTER 3

MODEL DEVELOPMENT

3.1 Introduction

The application of population-balance principles to modeling of non-ideal flow and mixing characteristics in vessels was formally organized by Danckwerts (1953). He was the first to define the distribution functions for the residence time of fluid elements in a vessel. RTD functions give information about the fraction of the fluid that spends a certain time within the vessel. It allows a possible velocity distribution map for the fluid, which frequently is sufficient information to give adequate estimation of the behavior of the vessel.

3.2 Tanks In-Series Model

It has been shown (Levenspiel and Bischoff, 1963) that the residence time distribution of solids in a perfect mixed flow vessel is well described by:

$$E(t)=\frac{1}{\tau}\exp\left(-\frac{t}{\tau}\right) \tag{3.1}$$

where E(t), the residence-time distribution function, describes in a quantitative manner how much time different particles have spent in the vessel. Therefore, for the case of a continuous single-spouted bed, E(t)dt is the fraction of solids staying in the bed between time t and t + dt, and τ is the mean residence time. Equation (3.1) can be likewise obtained from conceptual considerations in a fairly straightforward manner by a material balance on an inert tracer that has been injected as a pulse into a CSTR. Also,

$$\int_0^\infty E(t)\,dt = 1 \tag{3.2}$$

For an ideal multistage spouted system of N equal-sized perfectly mixed beds (see Figure 3.1),

$$\tau E(t) = \left(\frac{t}{\tau}\right)^{N-1} \frac{N^N}{(N-1)!} \exp\left(-\frac{tN}{\tau}\right) \tag{3.3}$$

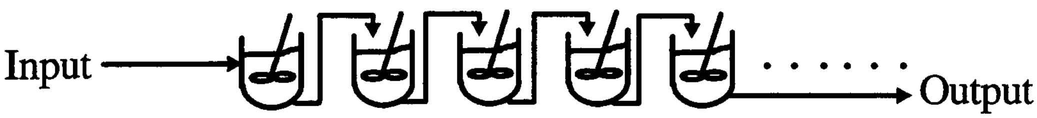


Figure 3.1 Graphical representation of the tank-in-series model.

Similarly,

$$\tau_i\ E(t) = \left(\frac{t}{\tau_i}\right)^{N-1} \frac{1}{(N-1)!} \exp\left(-\frac{t}{\tau_i}\right) \tag{3.4}$$

Where τ_i is the mean residence time in each stage given by

$$\tau_i = \frac{\tau}{N} \tag{3.5}$$

It can be noted that for N= 1, equation (3.4) reduces to equation (3.1).

Variance for this model is given by

$$\sigma_i^2 = N\tau_i^2 = \frac{\tau^2}{N} \tag{3.6}$$

Frequently, a normalized RTD, E(θ), is used instead of the function E(t). The flow performance inside beds of different sizes can be compared directly. Consequently, if the normalized RTD is used,

$$\theta = \frac{t}{\tau} \tag{3.7}$$

then equation (3.1) becomes

$$E(\theta) = e^{-\theta} \tag{3.8}$$

where $E(\theta) = \tau\, E(t)$. Similarly, equation (3.3) can be written as

$$E(\theta) = [N t_i] \cdot E(t) = \frac{N \cdot (N\theta)^{N-1}}{(N-1)!} e^{-N\theta} \tag{3.9}$$

with the mean $\tau_\theta = 1$ and the variance $\sigma_\theta^2 = \frac{1}{N}$; also, equation (3.4) becomes

$$E(\theta_i) = \tau_i E(t) = \frac{\theta_i^{N-1}}{(N-1)!} e^{-\theta_i} \tag{3.10}$$

with the mean and the variance both equal to N. The graphical representation of equation (3.9) is shown in Figure 3.2.

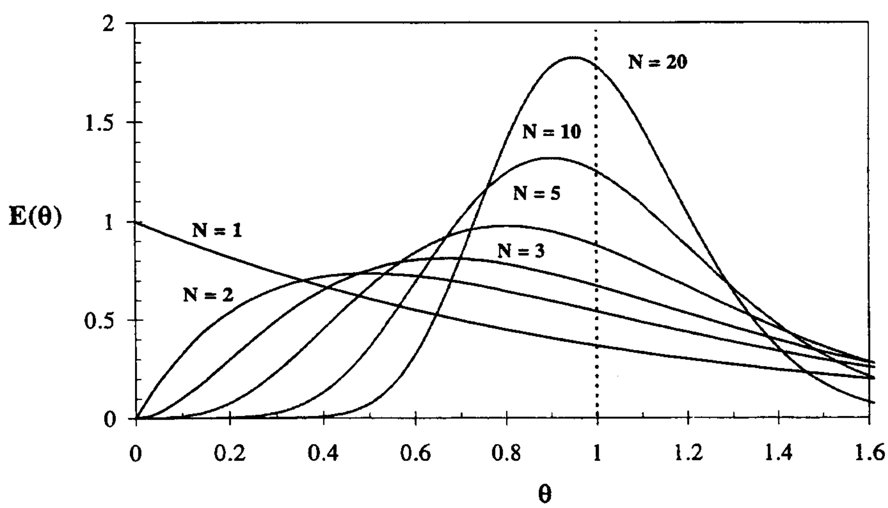


Figure 3.2 Tank-in-series responses to a pulse tracer input for different numbers of tanks. Adapted from Levenspiel (1993).

Figure 3.2 illustrates the RTD for various numbers of stages. It should be noted that on increasing the number of stages, the uniformity of solids residence time also increases, approaching plug-flow behavior as this number becomes very large.

3.3 Compartmet Model

Figure 3.3 shows the actual E(θ) curve obtained in one of our stimulus-response experiments with a single-stage spouted bed with draft tube.

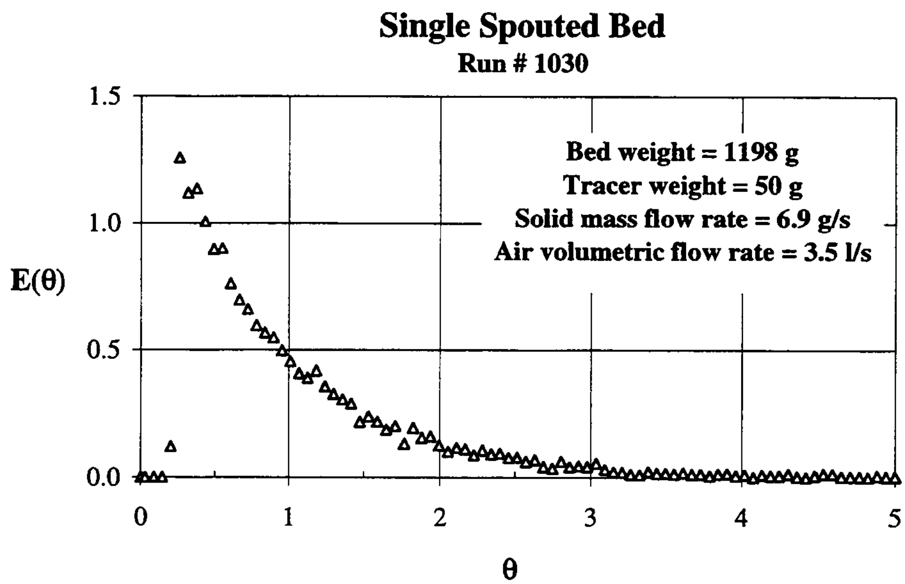


Figure 3.3 E(θ) curve obtained from measured concentrations

Clearly, the shape of this curve suggest that the assumption of a "perfect solid mixing behavior" is not entirely correct for this case. Fortunately, there are several other alternatives to describe what is really happening in this situation. A real vessel might be modeled by different combinations of "ideal" vessels. As was mentioned earlier, two types of ideal flow are commonly used as limiting cases of flow patterns: the "plug" or "piston" flow or the "perfectly mixed" flow. Often, flow patterns found in actual vessels, lie between these ideal flow behaviors. According to Levenspiel (1993), the "compartment models" consider an almost unlimited number of combinations that could be made, and as an example, he presents a wide variety of models with their characteristic E(θ) curves. Several elements of flow patterns could be included: *channeling* (termed *bypassing*), when part of the solids slip or pass through the vessel considerably faster than others do; *stagnant pockets* of solids (termed *dead space*), representing regions with extremely poor contact between solids and gas (considerable bypassing is an indication of poor design and is not desirable since the stagnant regions reduce the effective or useful volume); and *recycling*, when a certain amount of solids is recirculated (in general a desirable characteristic in dealing with drying operations and/or autocatalytic or autothermal reactions). Figures 3.4, 3.5, and 3.6 show some possible flow models that could give a better explanation or be a base for the good development of a new model that can successfully describe the actual situation depicted in Figure 3.3. Levenspiel (1993) and Fogler (1992) show that for the case of plug flow and ideal mixed tank in series, no matter where the CSTR occurs within the PF/CSTR vessel sequence, the same RTD results as long as the sum of the residence times in the two sections are the same.

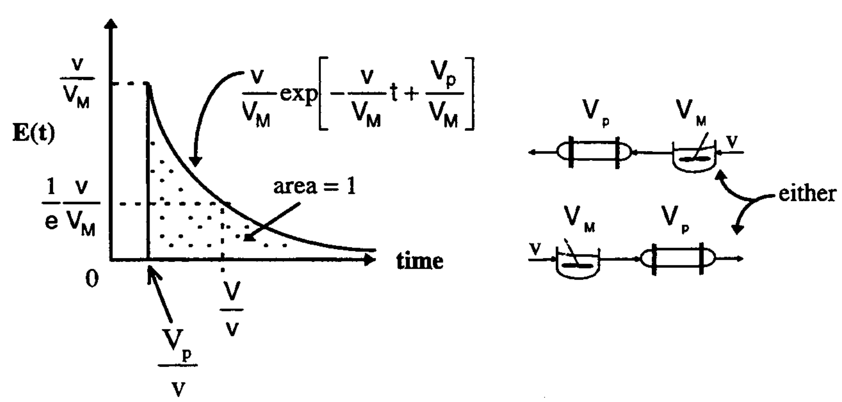


Figure 3.4 E(t) curve for plug flow and ideal mixed tank in series. Adapted from Levenspiel (1993).

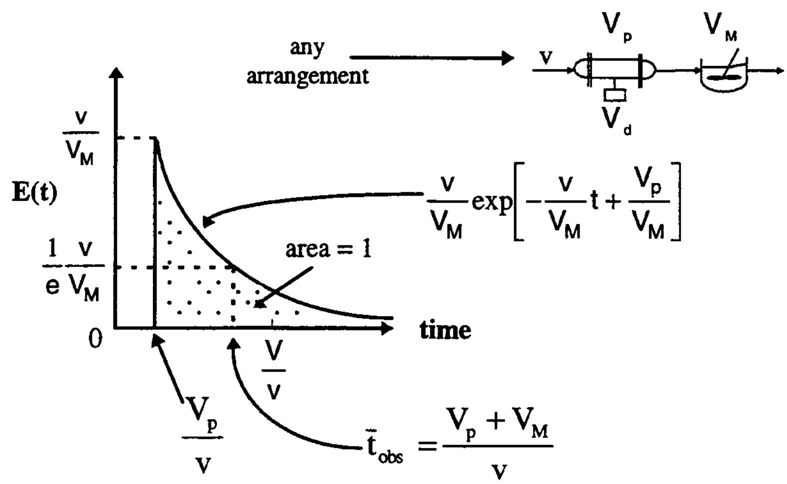


Figure 3.5 E(t) curve for plug flow, with dead space, and ideal mixed tank in series. Adapted from Levenspiel (1993).

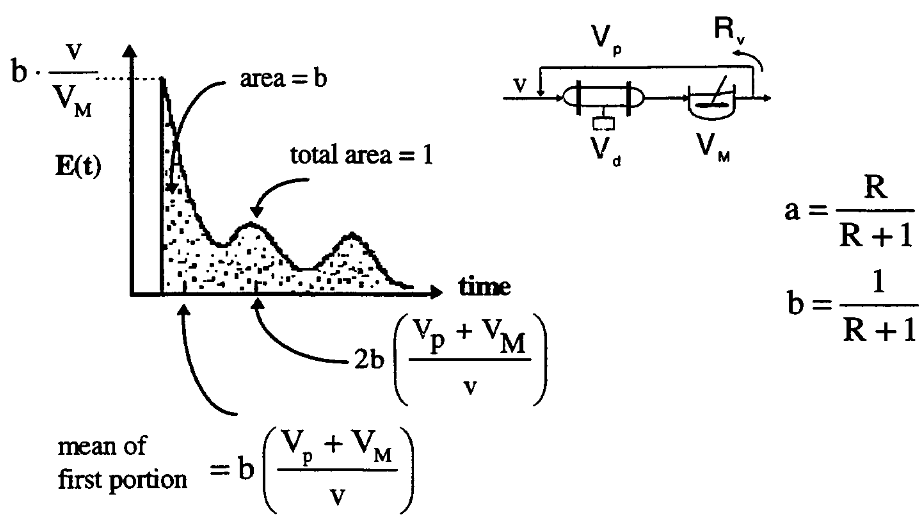


Figure 3.6 E(t) curve for plug flow, with dead space, followed by ideal mixed tank in series, with recirculation. Adapted from Levenspiel (1993).

By comparing the E(t) experimental curves for the actual bed with the theoretical curves for different combinations of ideal vessels or compartments and flows, the "best" model (the one that best fits the data) can be found. According to Fogler (1992) "There appears to be only one almost inviolable rule for a reasonable model of a nonideal vessel: The maximum number of adjustable parameters in the model is two". If a model with more than two adjustable variables is used then the modeling process probably becomes an exercise in curve fitting.

Our experimental system, as will be shown in Chapter 4, is compounded of vessel(s) and downcomer(s). Figure 3.3 reveals that the first data points are a collection of zero concentration values. This may be modeled as a plug-flow vessel (PFV), a type of flow expected in a downcomer. After these initial points, we recognize that there is a highly agitated zone, occurring within each vessel/stage, which can be modeled as a perfectly (ideal) mixed continuous stirred tank vessel (CSTV). Also, as will be shown later in this thesis, only runs at very low gas flow rates combined with high flow rate of solids, show a difference between the mean residence time, "τ", and "τ_{obs}" computed from the experimental data. This implies, as was mentioned before, the presence of stagnant pockets of solids for those flow conditions. According to Levenspiel (1963), this dead space can be assigned to either the plug-flow vessel or to the CSTV. Figure 3.7 shows a diagram of the designed single-stage spouted bed and the observed flow regions.

Mixing occurring in the plug-flow region is lumped with mixed region in order to reduce the number of parameters in the model. Similarly, all plug-flow regions (within the vessel and in the downcomer) can be lumped in a single larger plug-flow vessel as shown by Levenspiel (1993). Thus, this type of single-spouted bed may be modeled as a plug-flow vessel, with dead space, in series with a CSTV (see Figure 3.8).

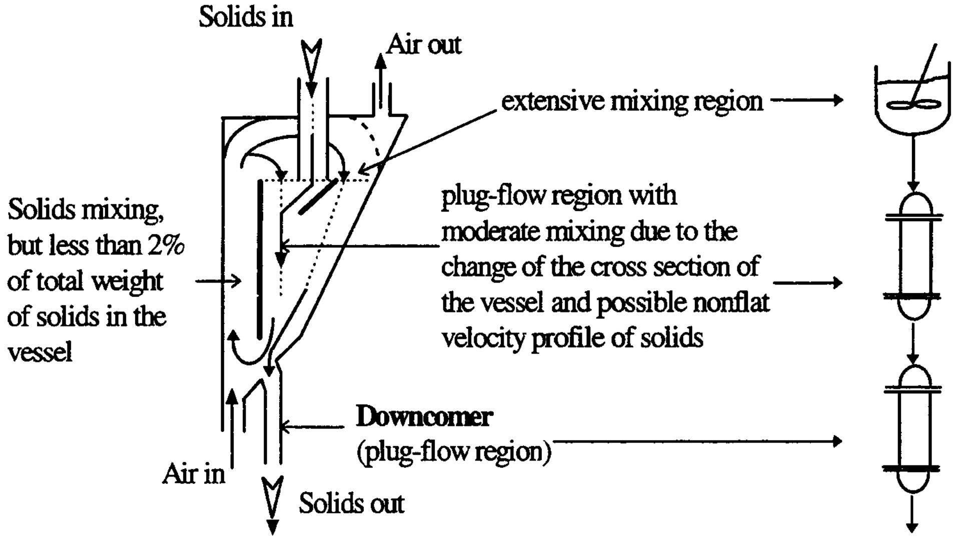


Figure 3.7 Observed flow regions

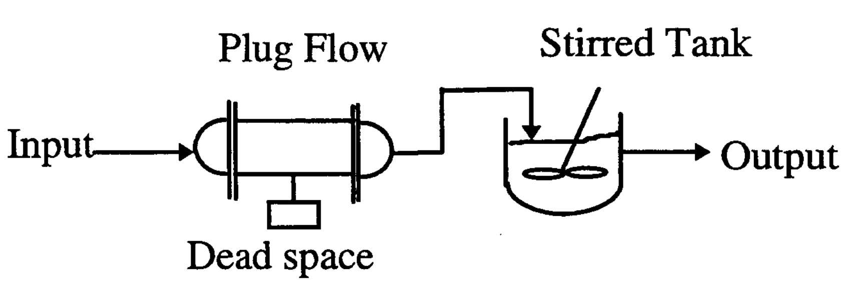


Figure 3.8 A possible model for the data shown on Figure 3.3.

For this situation, it can be shown that

$$E(t)=0 \qquad \text{for } t<\tau_p$$

$$E(t)=\frac{1}{\tau_M}\exp\left[\frac{-(t-\tau_p)}{\tau_M}\right] \qquad \text{for } t\geq\tau_p \qquad (3.11)$$

where "τ_p" and "τ_M" represent the mean residence time of the plug-flow vessel and the ideal CSTV respectively.

If the assumption of *identical* stages is made, then self-convolution of eq. (3.11) yields the E(t) expression for the three-stage column,

$$E(t) = 0 \qquad t < 3\tau_{pi}$$

$$E(t) = (1/2)(1/\tau_{Mi}^3)(t - 3\tau_{pi})^2 \exp\{-(t - 3\tau_{pi})/\tau_{Mi}\} \qquad t \geq 3\tau_{pi} \qquad (3.12)$$

where "τ_{Mi}" and "τ_{pi}" represent the mean residence time of each plug-flow vessel and each ideal CSTV respectively (see Figure 3.9).

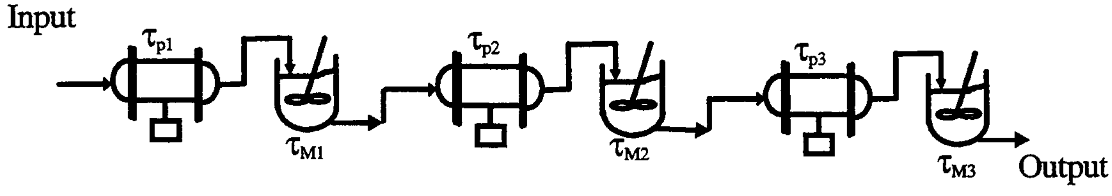


Figure 3.9 A possible model for a three-stage column of spouted beds.

CHAPTER 4

EXPERIMENTAL EQUIPMENT DESIGN

In Chapter 2, few multistage systems of spouted bed designs were presented and discussed. It was shown that all of them have problems of a similar nature, i.e. lack of stability, intermittent operation, improper feeding and discharging of solids, and high pressure drop. Our main objective and a goal is therefore to develop a design for a system of multistage spouted beds, capable of simple, continuous, stable operation, with very low pressure drop. In addition to that, the entire focus of many other experiments with both the single spouted bed and the multistage system is to define a model capable of predicting the behavior of solids in a vessel in a comparable situation.

4.1 Geometry Of The Vessels

Based on general considerations typically explored in literature, a single spouted bed with draft tube was designed. In the absence of any applicable theoretical and/or deterministic guidance, the objective of an "adequate design" of the spouted bed is to obtain a very intensive particle circulation with no dead zones within the bed. Variables such as "particle attrition", "minimum spouting velocity", "maximum spoutable bed depth", and the like, are not considered here. Consequently, greater emphasis is placed on the geometry of the bed and on the simplicity of its operation. In order to decide which bed design is "better", a series of experiments were conducted changing key parameters such as: height, thickness and "cone angle", size and location of the draft tube, location, shape and dimensions of inlets and outlets, ways of controlling hold up of solid particles, and determination of some operating variables such as: pressure drop, gas velocity, and solid-flow rate.

For construction, operation, control, and simplicity in scale-up, a "two-dimensional", half-rectangular vessel was preferred. For better scrutiny of the movement of solids in all experiments, the vessels and every connection between them were made of plexiglass. The particular geometry and measurements -shown in Figures 4.1 and 4.2- were determined after analyzing several experiments in which we were looking for an intensive movement of particles, with limited dead zones within the vessel, and stable spouting operation.

A narrow screened slot running across the bottom of the vessel lets the spouting gas (air) enter into the bed. To avoid particles coming into the air pipes, small screens were appropriately installed.

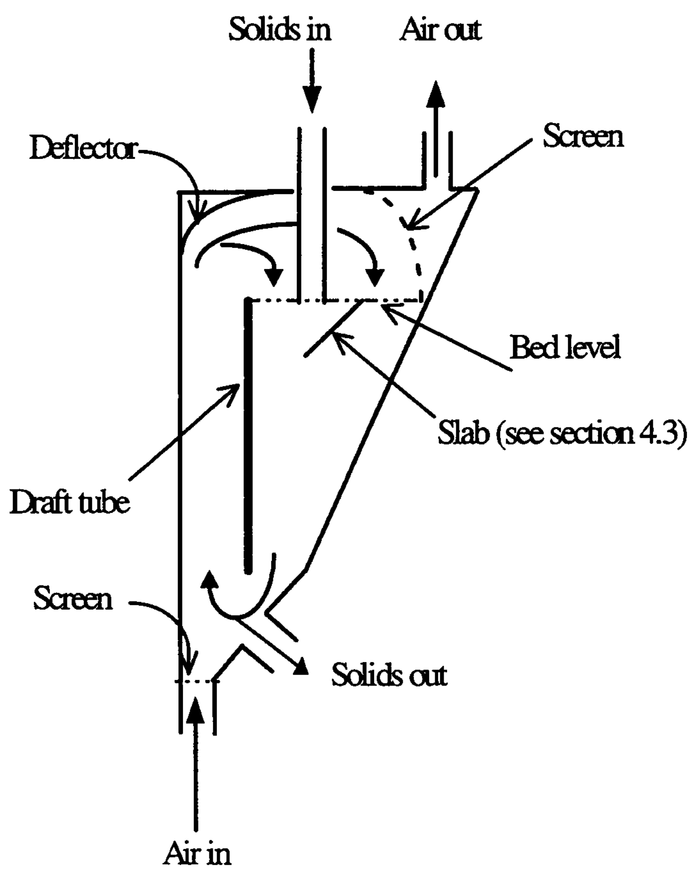


Figure 4.1 Diagram of the designed vessel showing input/output streams of air and solids.

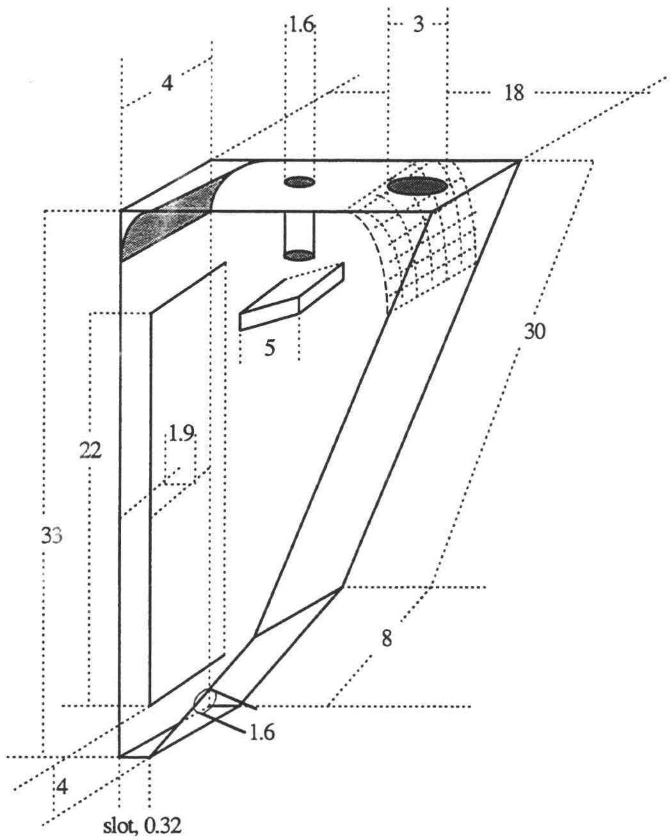


Figure 4.2 Diagram of the designed vessel showing important measurements in cm.

4.2 Interconnection of the Stages

The multistage system was constructed using three *identical* spouted beds (see Appendix E for corresponding test) placed one upon the other, and connected with plexiglass tubes for flow of ascending air and descending solids. The diameter of the air pipes was chosen concurrent to the thickness of the vessel, and with the objective of achieving a low pressure drop. On the other hand, the diameter of the tubes for solids circulation was limited by the necessary free space between the pipe and the walls of the vessel. The length of the tubes for solids circulation, was determined such that a continuous operation could be achieved at the maximum pressure drop within the system.

Figure 4.3 shows the three-stage spouted bed system used in our experiments. The addition of a draft tube to each stage allows the operation at very low pressure drop per stage ($\Delta P_{max} \approx 15$ cm of water/stage). Consequently, there should be practically no limitation in the number of stages that could be used, nor in the maximum spoutable bed height. Also, the recirculation of solids within each stage was improved, as expected.

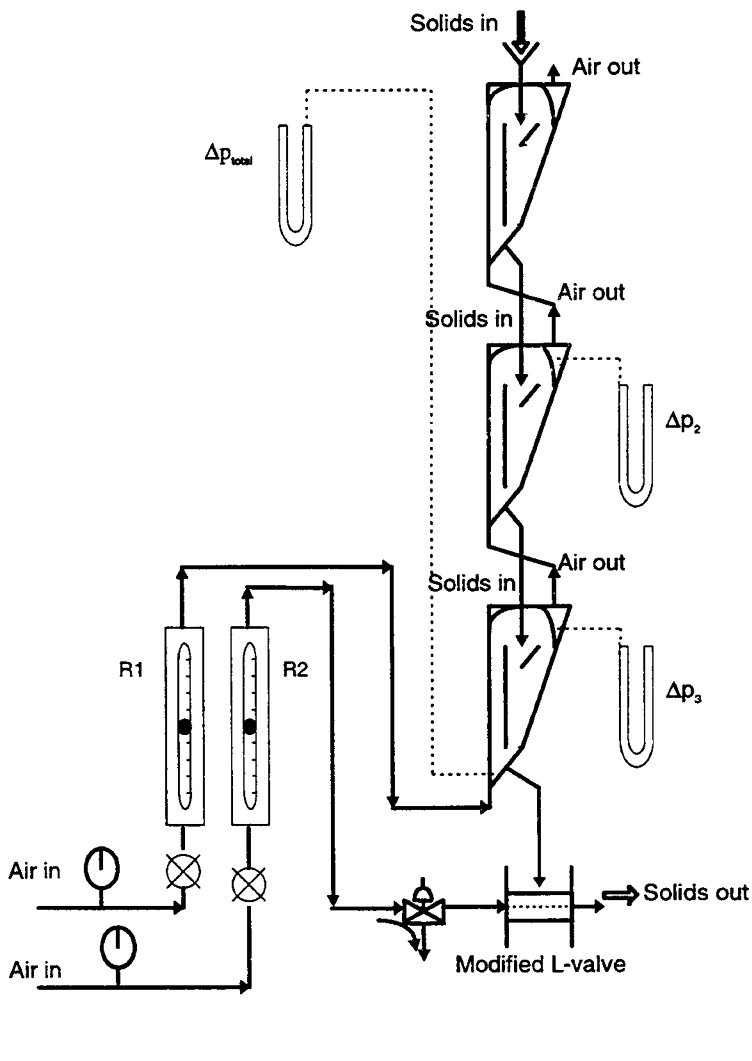


Figure 4.3 Three-stage spouted bed configuration

4.3 Feeding/Discharging. L-valve.

Special attention in the design was given to self controlled-hold-up of particles within the vessel. Consequently, location of the solids inlet is crucial. If solids are to enter into a "moving bed zone", they will continuously keep flowing into the bed, no matter how deeply the feeding pipe penetrates; however, if solid particles coming into the vessel find a "packed bed zone", they will cease to flow through the feeding pipe. In this design, shown in Figures 4.1 and 4.2, the internal configuration allows continuous operation with a uniform level of solids -at fixed operating conditions- within the vessel.

A small (5 x 4 cm) angled slab of plexiglass, located close to the inlet pipe for solids, provides the necessary packed bed zone of solids. This allows a constant level of solids within the bed. The slab angle is such that it forces the incoming solids to follow a path close to the wall of the draft tube. An increase of the probability of recirculation of solids within the vessel is then achieved.

Figure 4.4 shows the typical solid trajectory observed in most experiments. The vessel geometry, the position of the draft tube, and the angled slab, are designed to provide good circulatory movement of solids within the vessel. The size of the dead space is found to be negligible for almost all working conditions, and it can be observed that solids complete at least one full cycle within the vessel before exiting.

Discharging solid particles out of the one stage or three-stage unit is also a very simple and efficient operation. It requires no moving parts and/or complex mechanical devices. In this design, the solids are continuously withdrawn from the vessel (the bottom vessel in the case of the three-stage unit) through a modified "L-valve". This valve works with compressed air as a "pushing fluid", and plays an important role since it is a simple way of driving the solids out of the system as shown by Geldart and Jones (1991).

Although it has not yet been thoroughly documented, we recommend a pulsating valve for feeding air to the L-valve. Visual observations show that, compared to constant pressure, a more uniform flow of solids is obtained when oscillating air pressure is used. This modification of the L-valve transforms it into a "spitting valve", which should be tested in further studies.

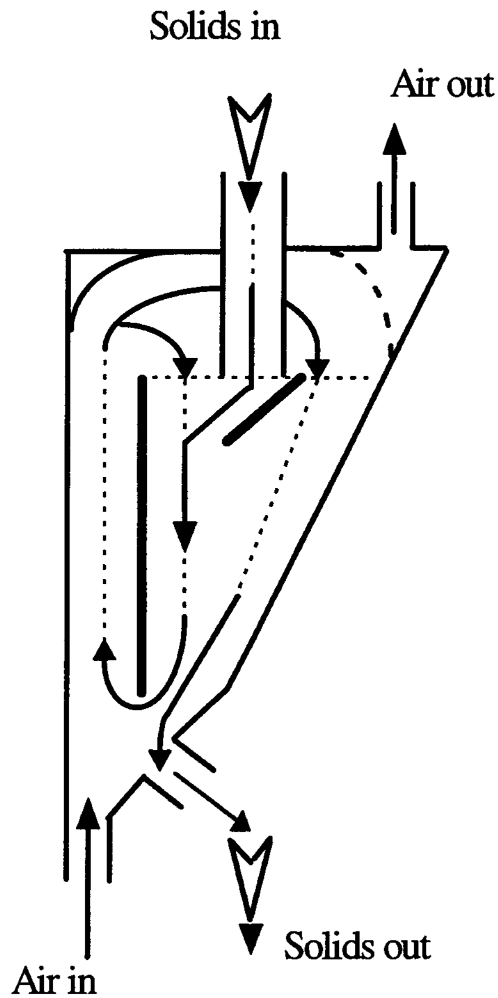


Figure 4.4 Observed solid circulation in a single-stage unit.

One last adjustment to a typical L-valve configuration was confirmed to be essential. When pressure within the system increases, solid particles are being pushed out by the air *inside* of the vessel. This causes a continuous flow of solids out of the system due to this *extra* force. Moreover, this force could be really important, especially in the case of the three-stage operation. Unless an airtight sealing is provided, the outflow of particles becomes unpredictable, and control is no longer achieved. We found that just a slight arching of the outlet pipe of the L-valve provided the sealing wanted.

Figure 4.5 shows a schematic diagram of the modified L-valve with all relevant dimensions in centimeters.

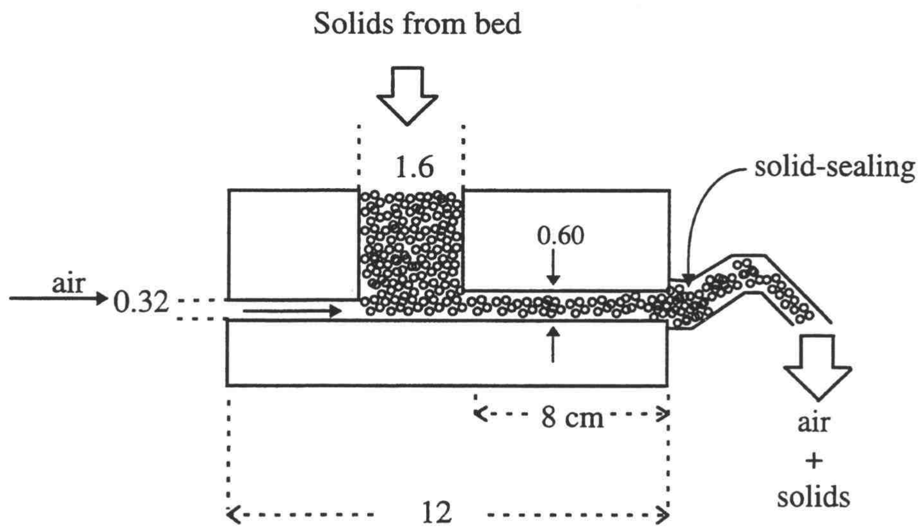


Figure 4.5 Diagram of the modified L-valve.

The mean solids residence time in the valve is negligible small, since the total weight of particles in this device is less than 4 grams. Since no written information was found describing similar devices, more research should be done on this type of modified L-valve (here called "*spitting valve*"), its characteristics, and mathematical modeling.

CHAPTER 5

EXPERIMENTAL MEASUREMENTS AND PROCEDURES

In order to meet budget limitations, we adapt for use experimental methods and procedures not requiring expensive and/or sophisticated laboratory equipment and materials. Accordingly, the criteria behind most experimental procedures and selected materials were to acquire reliable results at the lowest possible cost.

5.1 Spouted Bed Material

Glass beads were used as the bed solids throughout all the experiments. To estimate their average size, we first classified them using sieve trays. After this first gross classification, we measured particle diameters using digital calipers. Samples of hundreds of particles, chosen at random, were used for this evaluation. Following this procedure, the average diameter turns out to be, D_{ave} = 1.78 mm (σ^2 = 0.0140).

The average density of particles was determined with the aid of an appropriate picnometer. The density of the solids obtained in this manner was, ρ_s = 2.64 grams/cm^3 (σ^2 = 0.0176).

5.2 Tracer

The residence time distribution (RTD) for the solids can be determined easily and directly by the so-called "*stimulus-response*" technique. With this method, the RTD is experimentally obtained by injecting an inert particle, called a *tracer*, into the inlet stream of solids at time t = 0, and then measuring the tracer concentration in the effluent stream of the vessel as a function of time. According to Levenspiel (1972), "any material that can be detected and which does not disturb the flow pattern in the vessel can be used as tracer". Moreover, the tracer has to meet the following general characteristics:

1. It should be "miscible" in all proportions, and have physical properties similar to all solid particles within the vessel under investigation. If the experiment involves more than one phase, then the tracer should stay in the phase of interest.
2. It has to be nonreactive and perfectly detectable even in very small concentrations.
3. The detection device and the tracer itself have to be unquestionably inexpensive.

Consequently, the tracer was prepared by using the same glass beads adopted as a bed material. The solid particles were coated with permanent marker red ink.

5.3 Experimental Procedures

The experimental setup is shown in Figure 5.1. The spouting fluid (air) is supplied from the high-pressure air system available in the laboratory. Before entering into the spouting vessel, air flows through a pressure regulator, equipped with a water trap and a filter, and a calibrated rotameter. The air inlet to the vessel is a screened, narrow slot (0.32cm x 4cm). Pressure drop for each stage is measured with a U-tube water manometer conveniently installed.

The solid particles -spouted bed material- are continuously fed into the system (one or three stages) by gravity from a hopper located above the system. They may also be continuously withdrawn from the bottom vessel through the modified L-valve.

The air to the modified L-valve also comes from the building high-pressure pipe line. Likewise, it flows through a pressure regulator, filter, water trap, and rotameter assemblage before entering to a *solenoid* valve. The function of this valve is to provide a controlled, pulsating flow of air to the modified L-valve.

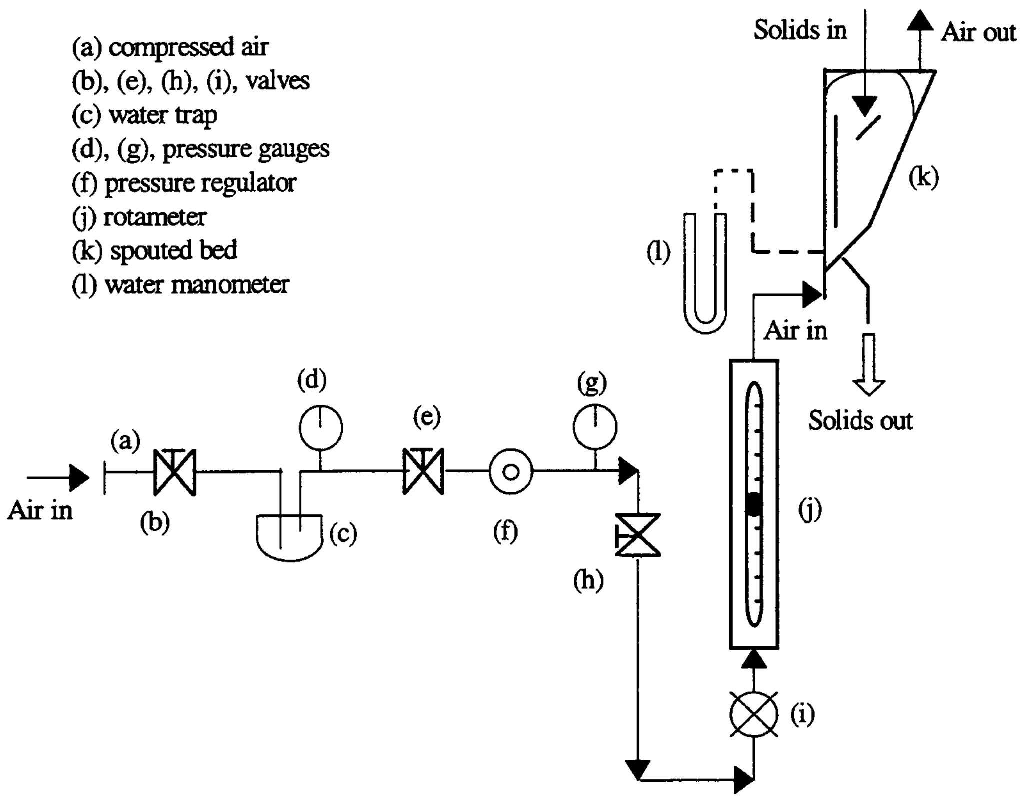


Figure 5.1. Experimental set up for the RTD of solids in a single-stage unit.

5.3.1 Preliminary Steps

For each experiment several preliminary steps were taken:

1. Prepare solid particles (i.e, glass beads) for the experiment. This requires their treatment with fabric softener which instantly eliminates static electricity and prevents the static build-up that otherwise would produce an "extra-resistance" that would keep the solids from flowing through the pipes and/or vessels.
2. Visually inspect the air filter and water trap. Clean them if needed.
3. Pour solid particles into the vessel/column.
4. Weigh precise amount of tracer.

5. Set the solenoid valve for desired flow rate of solids.
6. Let air into the modified L-valve.
7. Let spouting air into the vessel/column. Set required gas flow rate.
8. Adjust, if needed, the ON/OFF percentage in solenoid valve, by taking and weighting several samples of solids coming out of the system to obtain a known flow rate of solids.
9. Allow enough time for the system to reach a steady-state regime.
10. Take necessary readings of all instruments (pressure drops, flow rates, ON/OFF %)
11. Measure level of solids within the vessel(s).
12. Estimate time of solids flowing per 10 cm length in pipes and within the vessel(s).

5.3.2 Running The RTD Experiment

After all preliminary set-up procedures are complete, we proceed as follows:

1. At time equal to zero (t = 0) instantaneously introduce 50 grams of colored particles (tracer) into the system. Tracer particles enter the vessel together with the solids entering the system (see Figure 5.2). At the same time, start collecting samples at the exit of the modified L-valve .
2. Take samples at prescribed intervals of time.
3. When practically all tracer particles are out of the system, simultaneously stop the in/out flow of solids, and turn off the spouting gas.
4. Using a special container, collect the remainder of the solids by reestablishing only the solids flow out of the system.
5. The column is now empty again, ready for the next experiment.

5.3.3 Analytical Steps

After collecting all samples from each experiment, the following steps are taken:

1. Obtain total weight of each sample and weight of the hold-up of the bed.

2. Colored particles (tracer) are separated from the rest of the particles in each sample.
3. Weigh tracer particles.
4. Separate colored particles in the hold-up of the bed and weigh them.

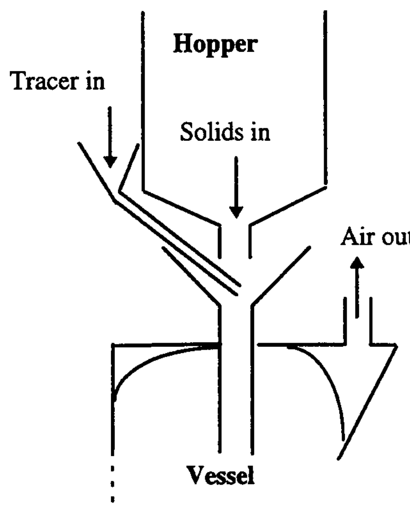


Figure 5.2 Diagram showing how tracer particles are introduced into the system.

5.4 Experimental Plan

Once we were satisfied with the operating characteristics of the designed system (single-stage and three-stage column), in order to achieve all the aforementioned objectives of this research, the following experimental plan was conceived and put into practice:

A. Determination of operating variables, such as: pressure drops, air superficial velocities, and gas flow rates. Results for a single-stage unit and for the three-stage column are shown in Figures 5.3 to 5.7. It is important to notice, in both cases, the resultant very low pressure drop due to the presence of the draft tube, and the ΔP differences due to the location of the pressure ports (see Figure 4.3).

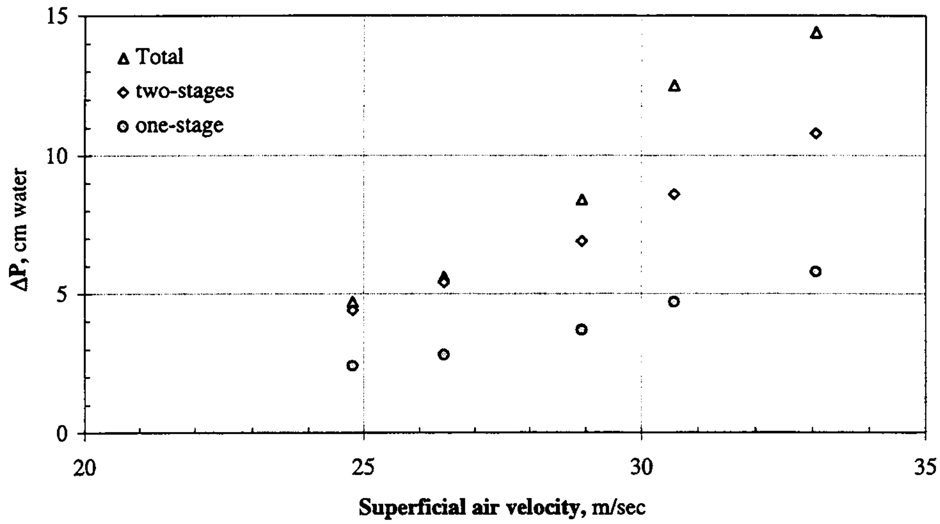


Figure 5.3 Pressure drop for an empty column.

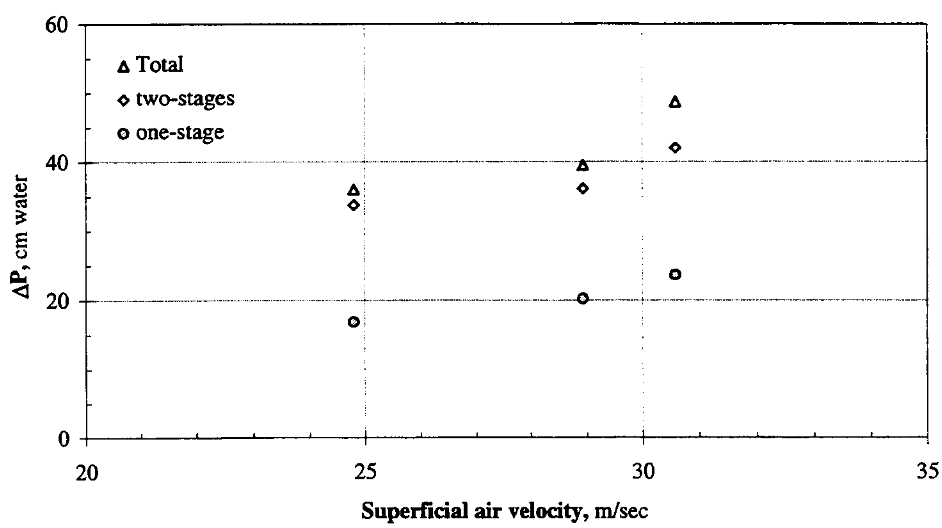


Figure 5.4 Pressure drop for a SFR = 2 g/s.

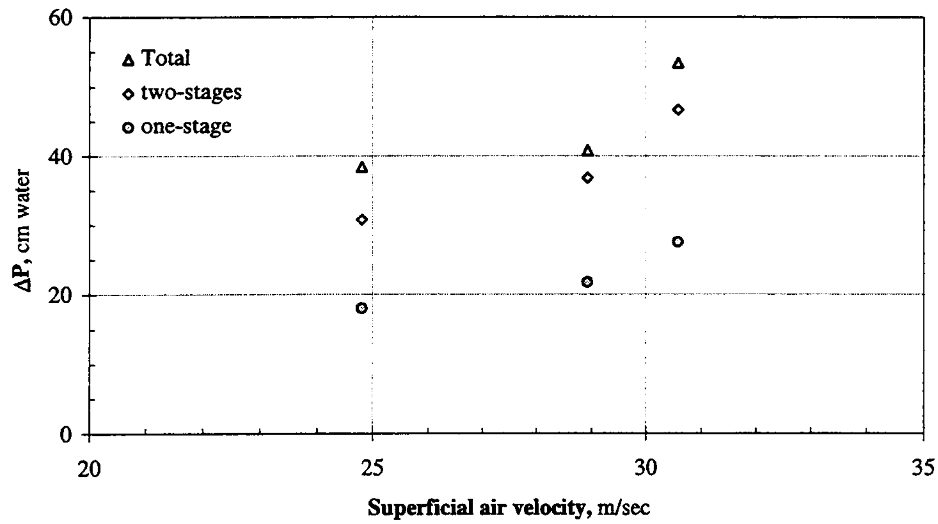


Figure 5.5 Pressure drop for a SFR = 7 g/s.

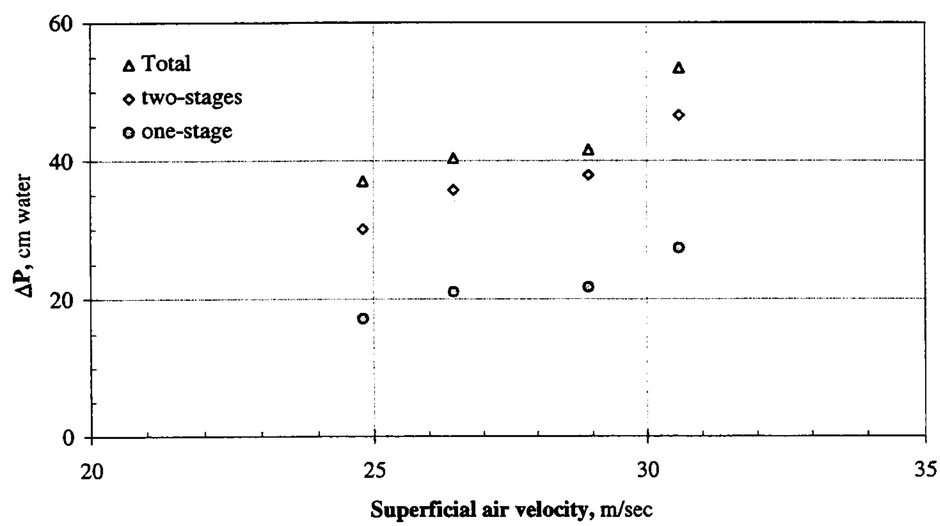


Figure 5.6 Pressure drop for a SFR = 17 g/s.

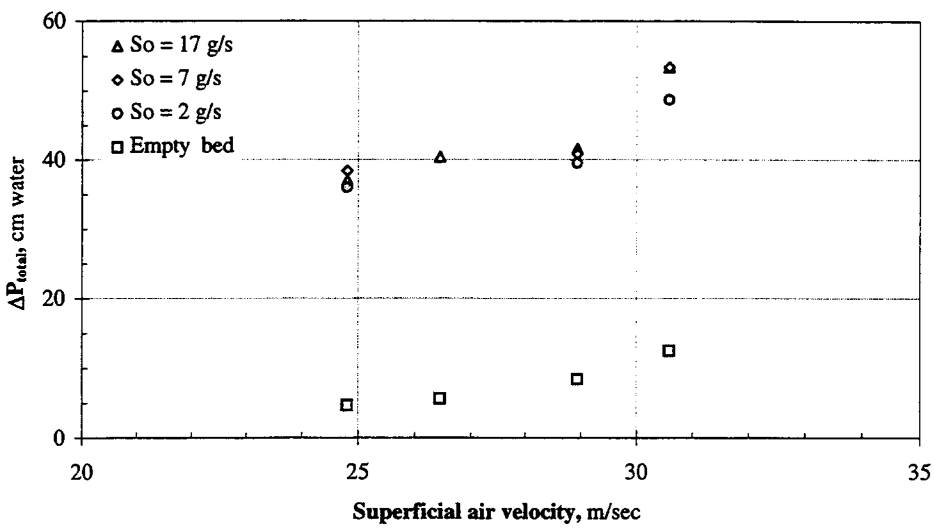


Figure 5.7 Total pressure drop for different solid flow rates.

B. Acquisition of information about the solid flow rate (SFR) for different ON/OFF percentages on the solenoid valve. As was mentioned before, the function of this valve is to provide a controlled, pulsating flow of air to the modified L-valve. Consequently, for a fixed gas flow rate fed *to the solenoid valve*, there is a certain amount of solids per unit time being pushed out of the system. Figure 5.8 shows the solid flow rate obtained for different ON/OFF percentages used at four different gas flow rates (GFR) within the unit. This graph shows that there is a maximum possible flow rate of solids when the air flow rate to the solenoid valve (pushing gas) is fixed. For the particular case of 0.55 liters/second of pushing gas used, the maximum solid flow rate (100 %ON/OFF) turns out to be approximately 15 grams/second for any GFR to the column.

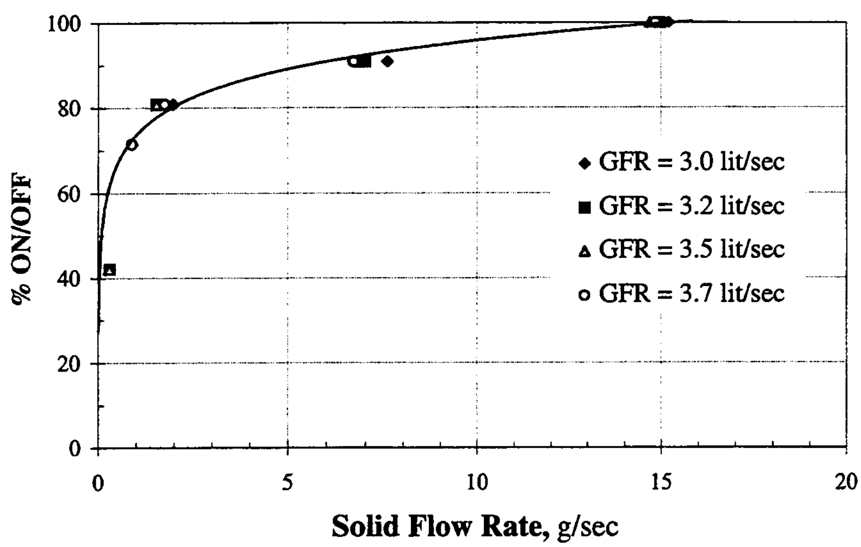


Figure 5.8 Modified L-valve behavior for a flow rate of 0.55 lit/sec of pushing gas.

C. Determination of the recirculation time of solids within each stage. This time was obtained using a video camera to film the movement of the solids inside the vessels for different gas flow rates. From this time, the solids recirculation rate for each stage, in grams/sec, is computed. Here the solids recirculation rate is defined as

$$\text{solids recirculation rate} = \frac{W_{active}}{t_R} \qquad \left(\text{grams}/\text{second}\right) \tag{5.1}$$

Where W_{active} is the weight in grams of solids that are truly recirculated within the vessel, and t_R is the measured recirculation time in seconds. Since

$$W_{active} = \tau_{obs} \times S_o \tag{5.2}$$

then

$$\text{solids recirculation rate} = \frac{\tau_{obs} \times S_o}{t_R} \qquad \left(\text{grams}/\text{second}\right) \tag{5.3}$$

Results are shown in Figure 5.9. According to this figure, increasing the gas flow rate will also cause an increase in the solids recirculation rate within the bed as expected. Also, when the recirculation time is short, we have many recirculations per mean residence time of solids within the vessel and, therefore, a closer approach to CSTR behavior.

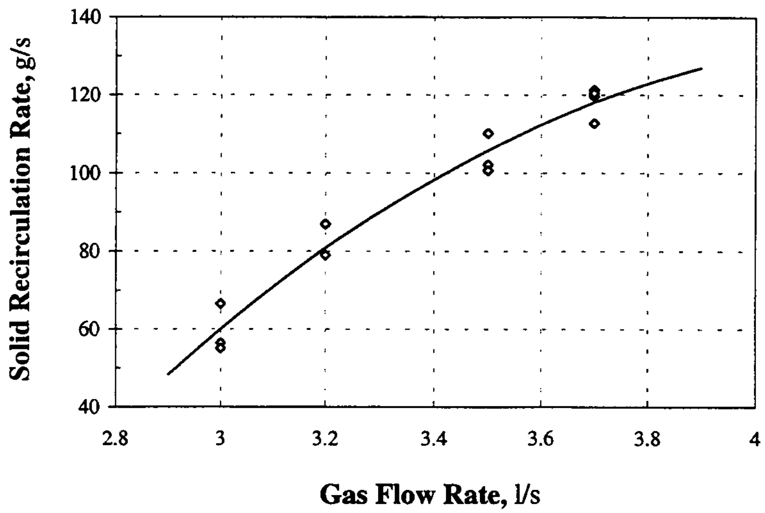


Figure 5.9 Recirculation rate of solids

D. Investigation of the RTD of solids for different solid flow rate and gas flow rate conditions. Table 5.1 and 5.2 show all combinations used of these two variables for the single-stage spouted bed unit and for the three-stage column experiments, Four different gas flow rates and three different solid flow rates were used. The range of these conditions was limited by the size characteristics of the system. Figures 5.10 to 5.23 show the results for the single-stage unit, and Figures 5.24 to 5.33 show the results for the three-stage column.

Table 5.1 Combinations of gas and solids flow rates used in the single-stage spouted bed unit.

FLOW OF SOLIDS ↓ (grams/sec) \ FLOW OF GAS → (lit/sec)	0	3.0	3.2	3.5	3.7
2.7		Run #1035	Run #1037	Run #1040	Run #1041
6.1	Run #1034	Run #1031	Run #1033	Run #1030	Run #1043
17.0		Run #1036	Run #1042	Run #1038	Run #1032

Table 5.2 Combinations of gas and solids flow rates used in the three-stage spouted bed column.

FLOW OF SOLIDS ↓ (grams/sec) \ FLOW OF GAS → (lit/sec)	0	3.0	3.5	3.7
2.0		Run #2001	Run #2002	Run #2000
7.2	Run #2008	Run #2009	Run #2004	Run #2006
17.0		Run #2007	Run #2003	Run #2005

5.5 Results

A total of 24 RTD experiments were carried out. Investigated operating variables or parameters were the spouting gas flow rate and the flow rate of solids. A range of gas (0 to 3.7 lit/sec) and solids (0 to 17.0 g/s) flow rates, were used for stimulus-response experiments. Three specific time indicators of solids within each stage were of particular interest: *residence time distribution*, E(t), *mean residence time*, τ, and *recirculation time*, τ_R. Figures 5.10 to 5.33 show concentration-time data obtained from the RTD experiments. From the data of a tracer concentration-time curves for both single-stage unit and three-stage column, nearly all the desired system parameters can be obtained. Specific conclusions are drawn from these data in Chapters 6 and 7.

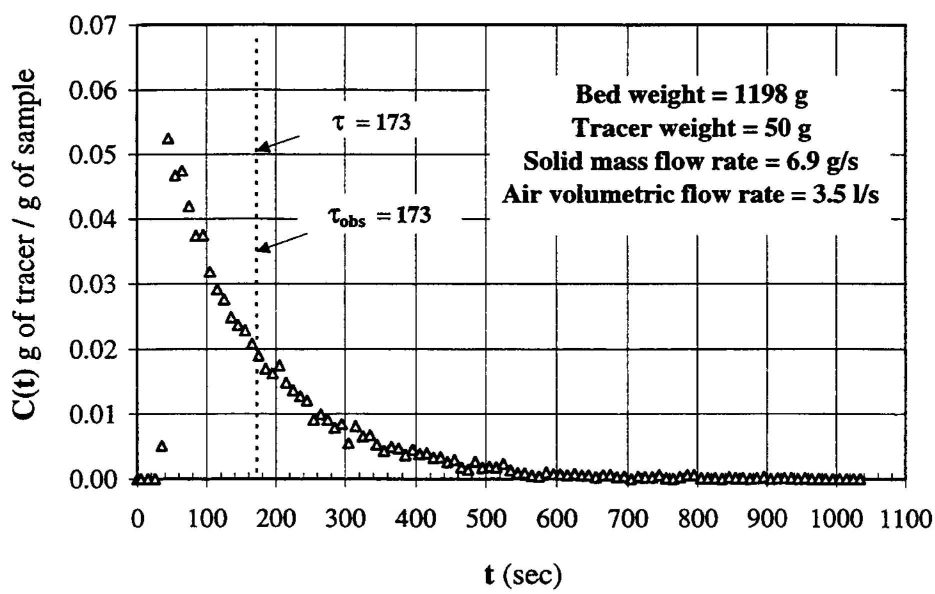


Figure 5.10 C(t) curve of experiment #1030 (single-stage unit)

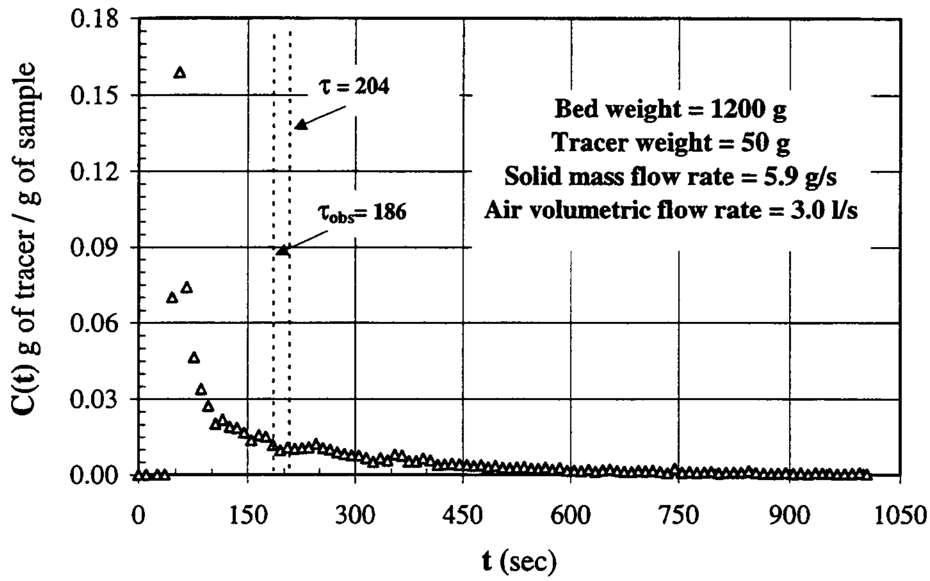


Figure 5.11 C(t) curve of experiment #1031 (single-stage unit)

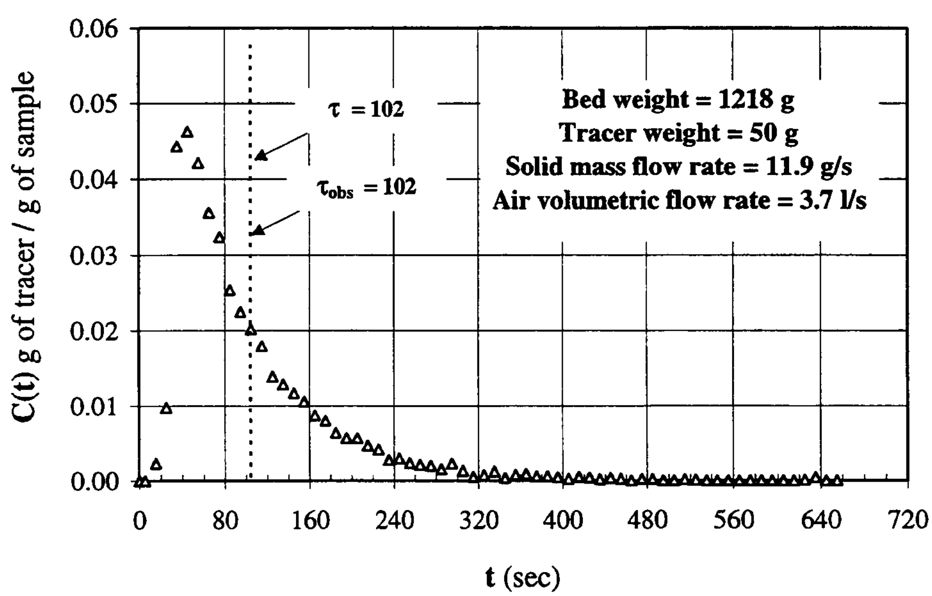


Figure 5.12 C(t) curve of experiment #1032 (single-stage unit)

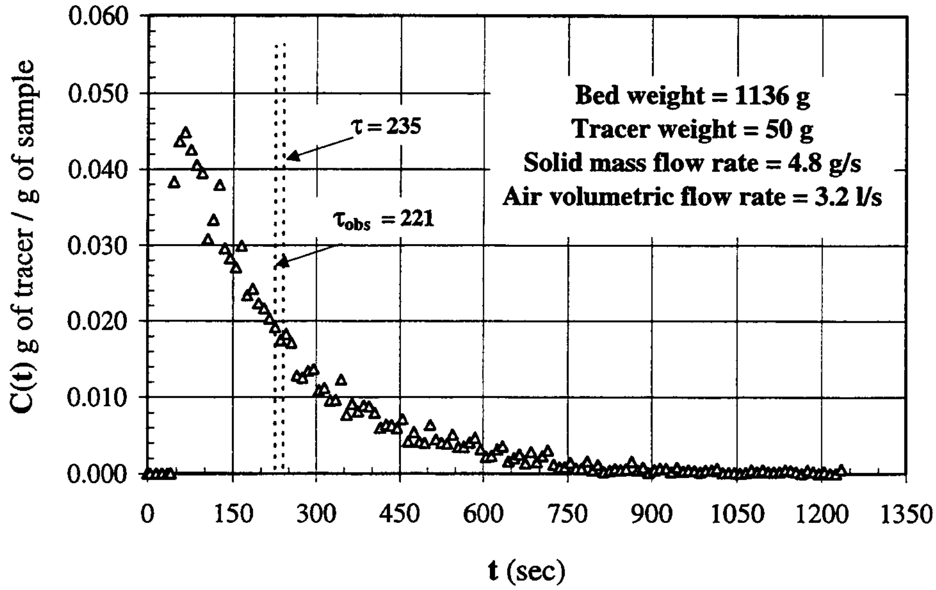


Figure 5.13 C(t) curve of experiment #1033 (single-stage unit)

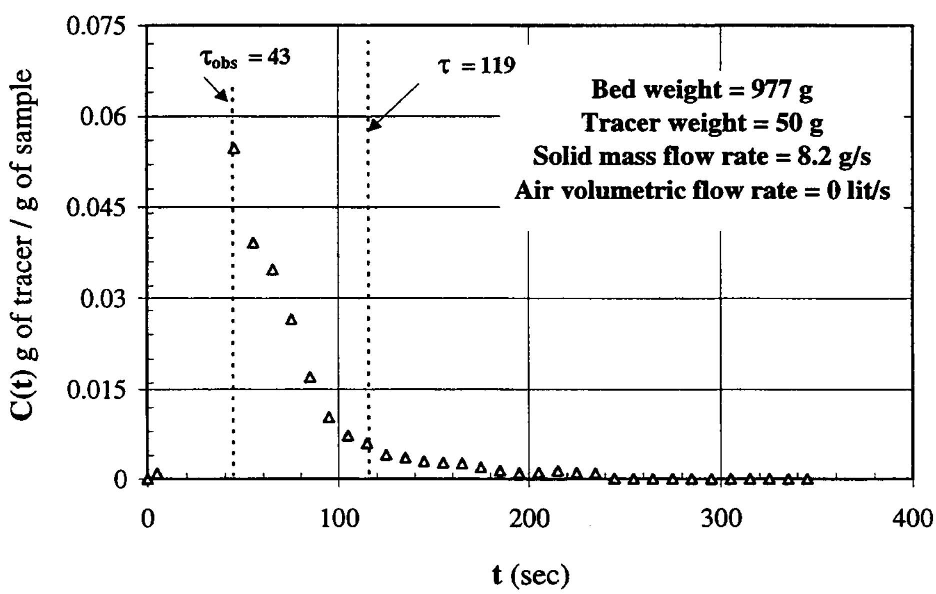


Figure 5.14 C(t) curve of experiment #1034 (single-stage unit)

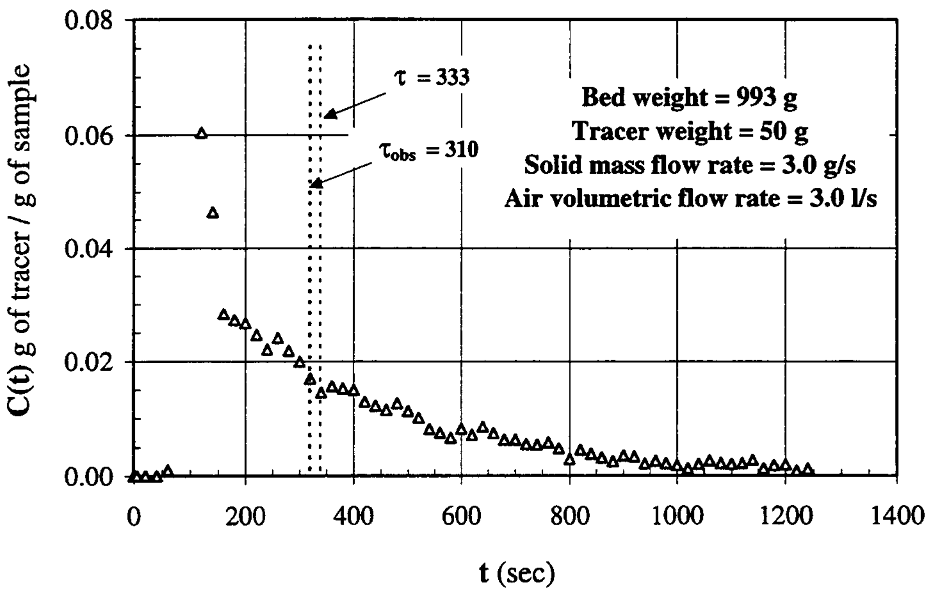


Figure 5.15 C(t) curve of experiment #1035 (single-stage unit)

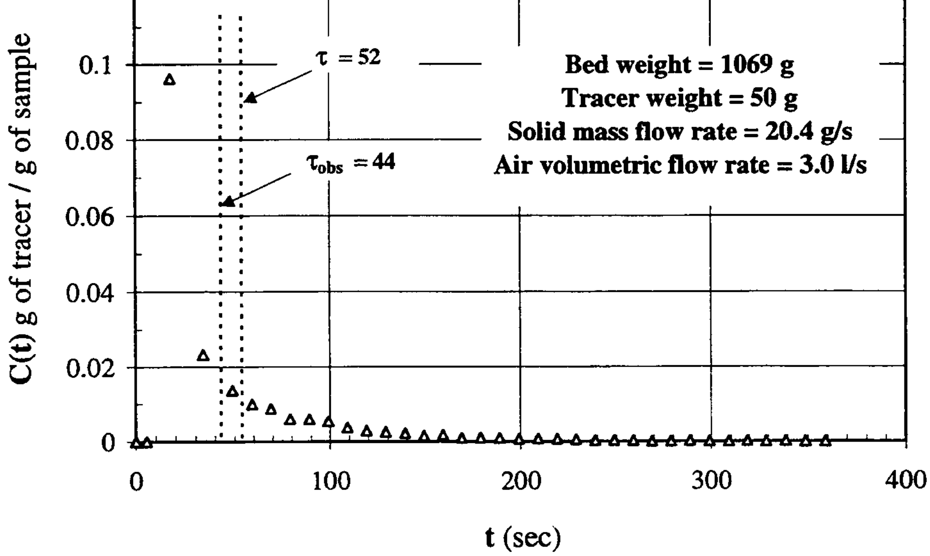


Figure 5.16 C(t) curve of experiment #1036 (single-stage unit)

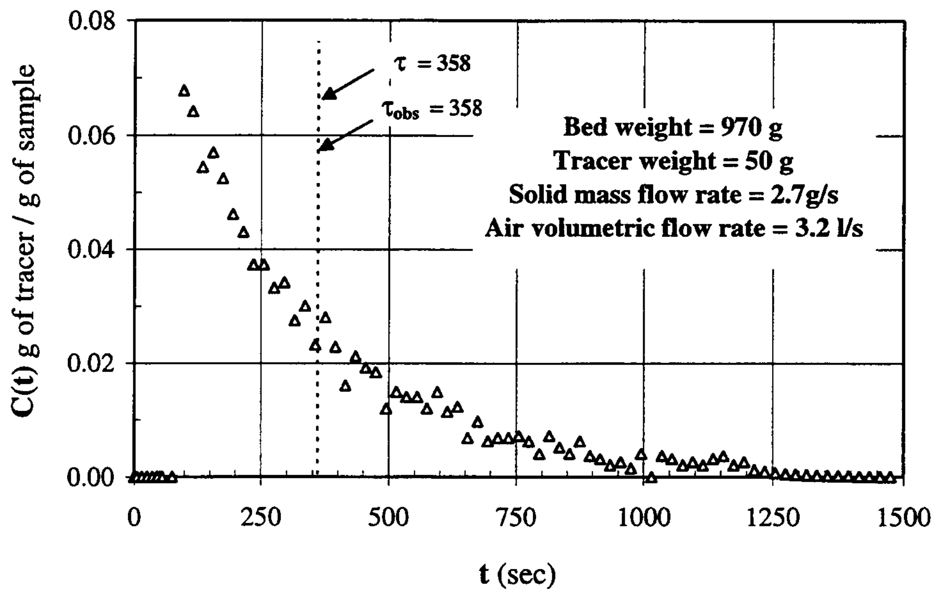


Figure 5.17 C(t) curve of experiment #1037 (single-stage unit)

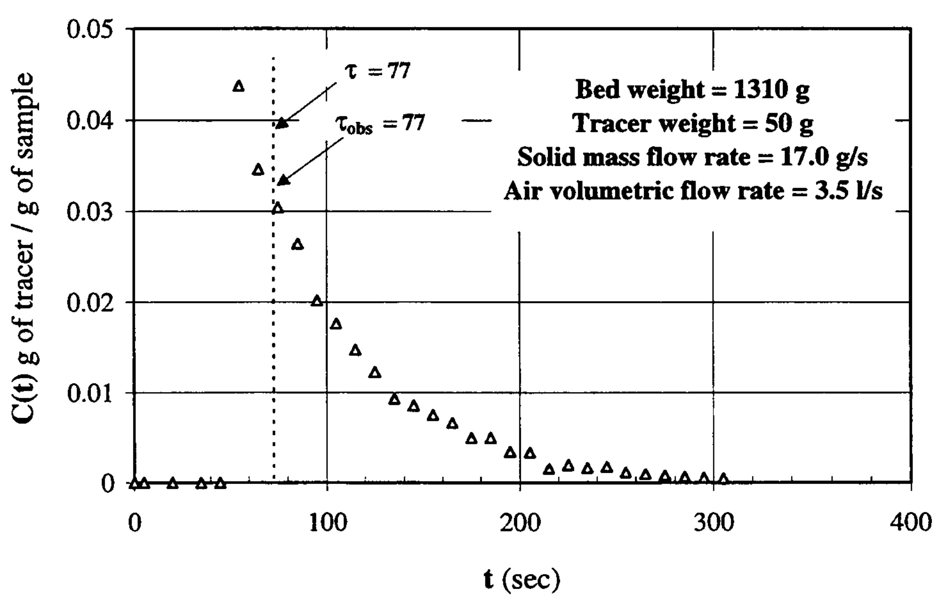


Figure 5.18 C(t) curve of experiment #1038 (single-stage unit)

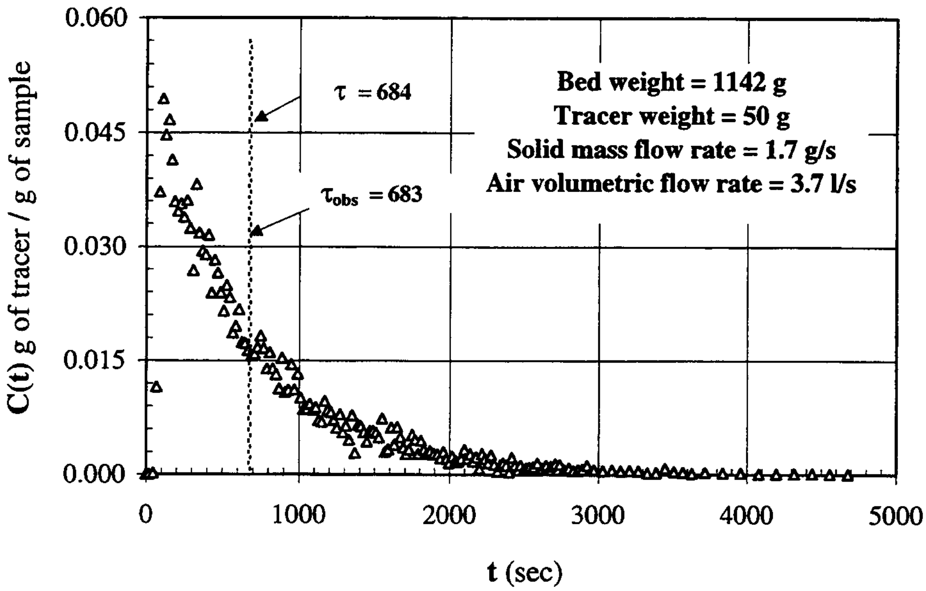


Figure 5.19 C(t) curve of experiment #1039 (single-stage unit)

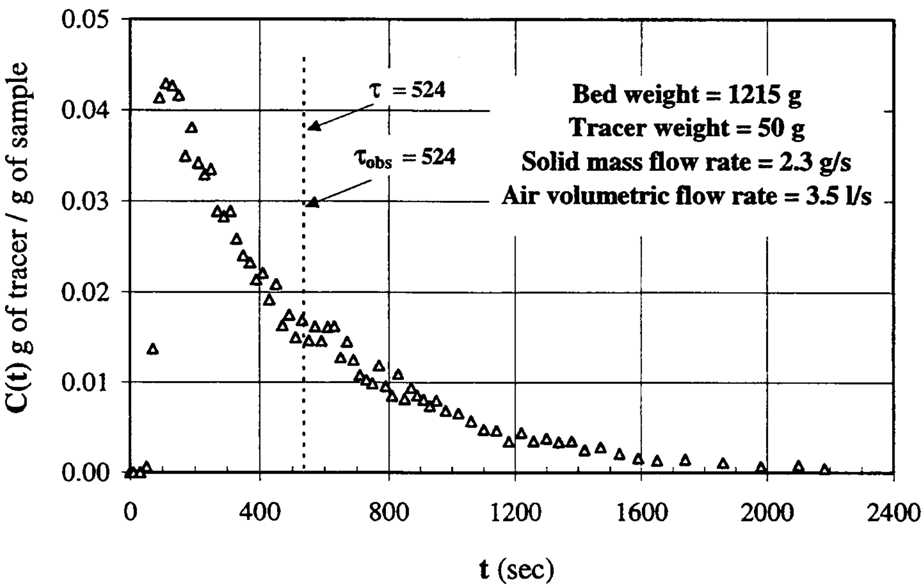


Figure 5.20 C(t) curve of experiment #1040 (single-stage unit)

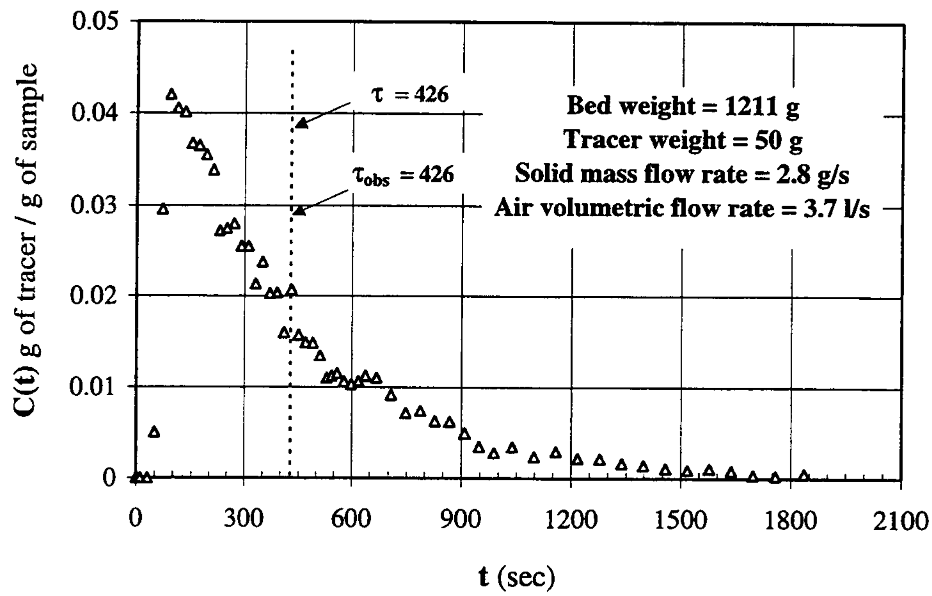


Figure 5.21 C(t) curve of experiment #1041 (single-stage unit)

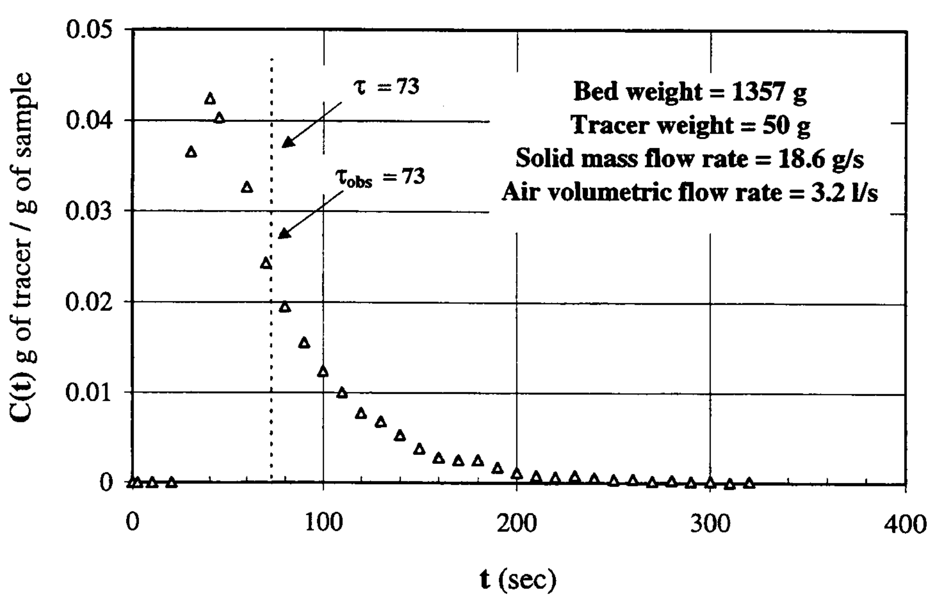


Figure 5.22 C(t) curve of experiment #1042 (single-stage unit)

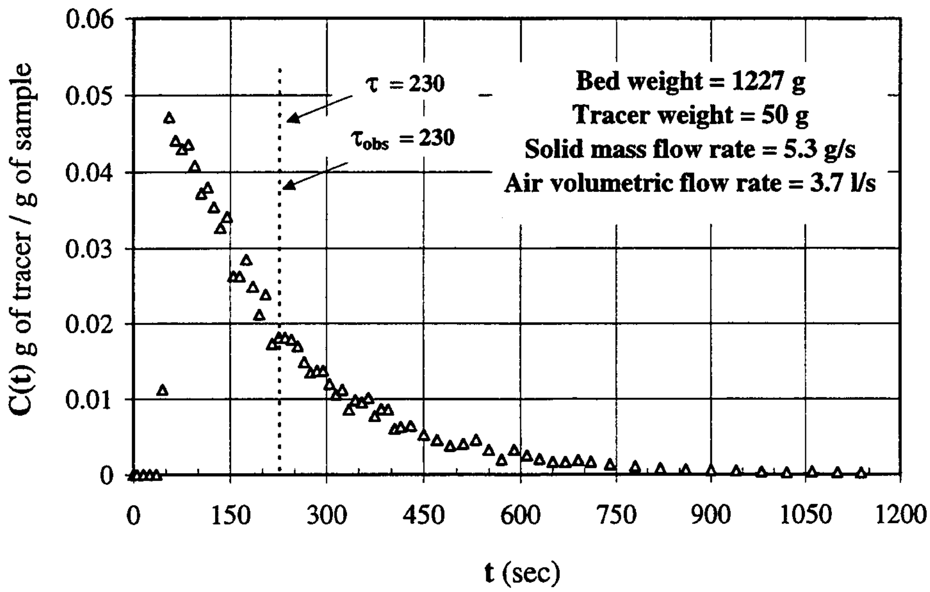


Figure 5.23 C(t) curve of experiment #1043 (single-stage unit)

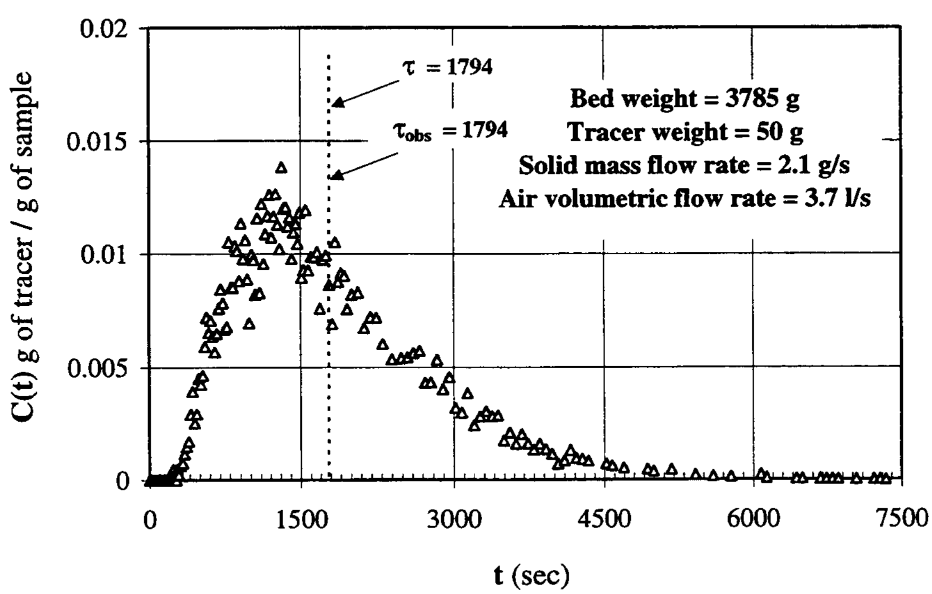


Figure 5.24 C(t) curve of experiment #2000 (three-stage column)

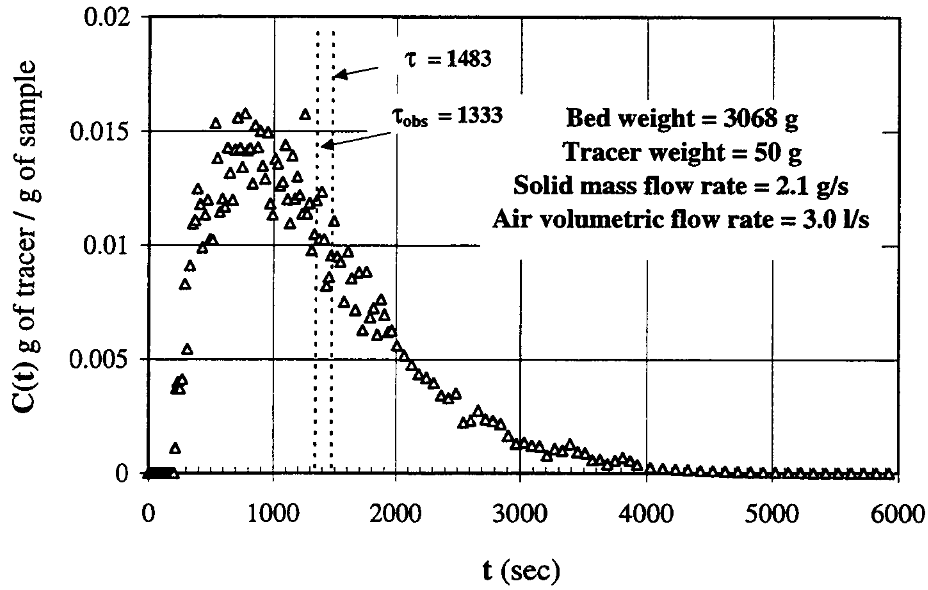


Figure 5.25 C(t) curve of experiment #2001 (three-stage column)

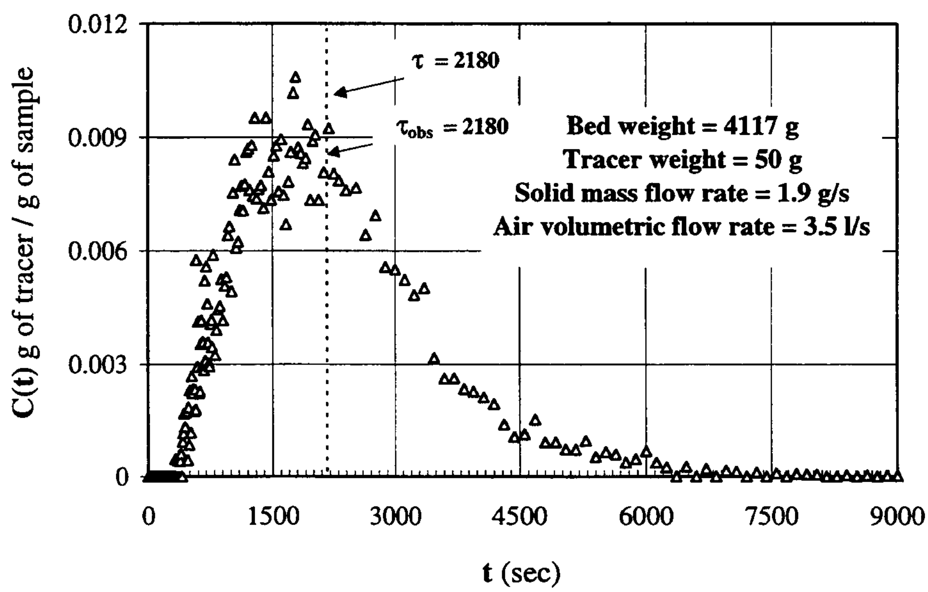


Figure 5.26 C(t) curve of experiment #2002 (three-stage column)

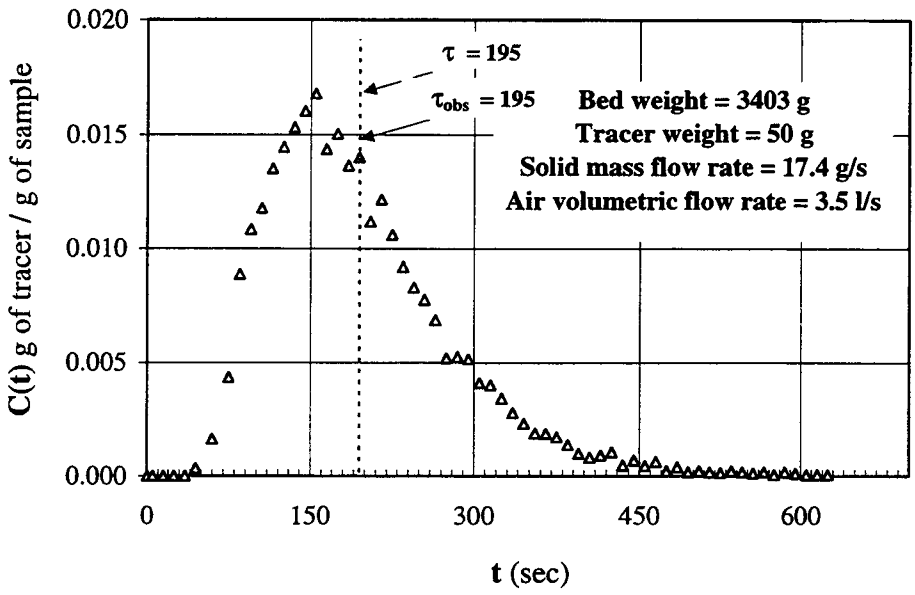


Figure 5.27 C(t) curve of experiment #2003 (three-stage column)

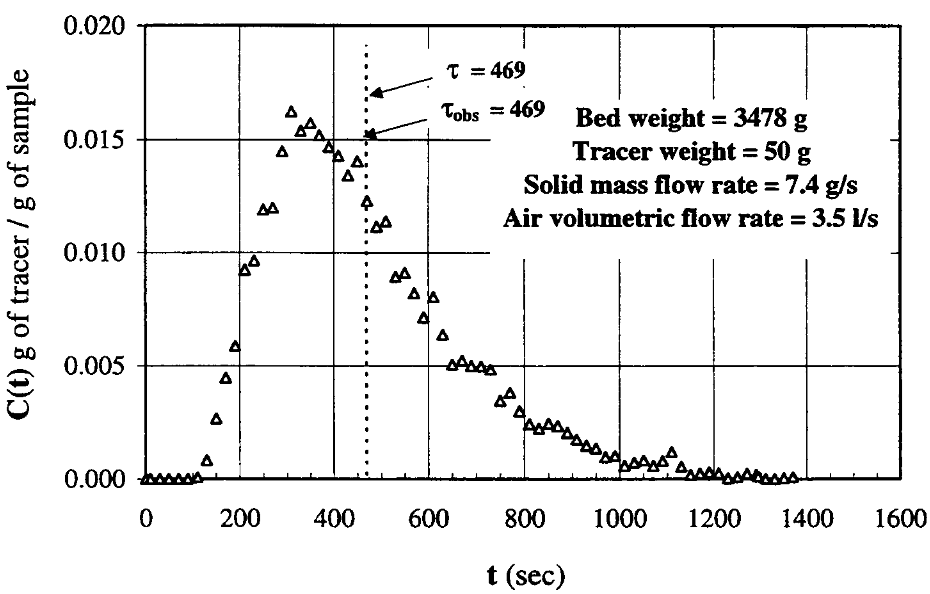


Figure 5.28 C(t) curve of experiment #2004 (three-stage column)

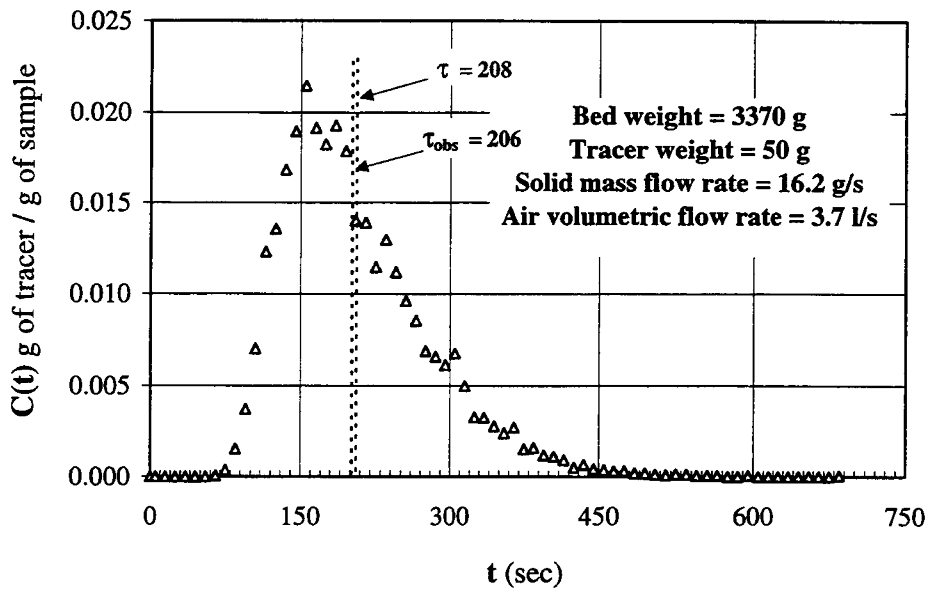


Figure 5.29 C(t) curve of experiment #2005 (three-stage column)

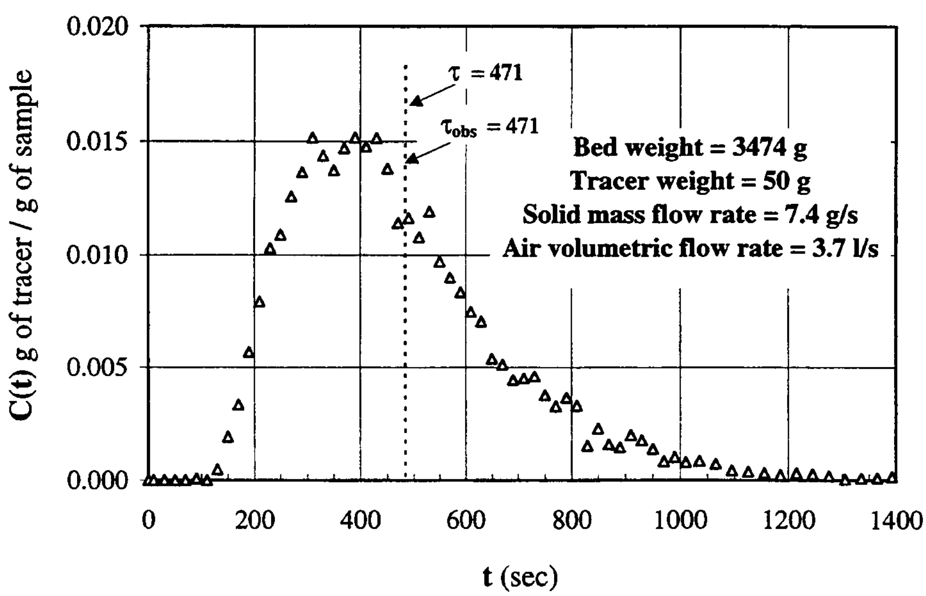


Figure 5.30 C(t) curve of experiment #2006 (three-stage column)

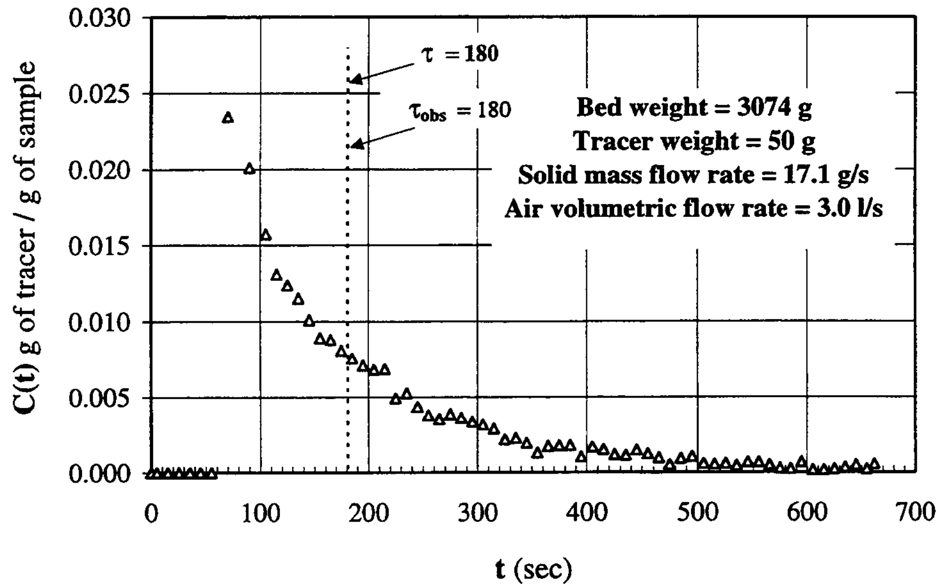


Figure 5.31 C(t) curve of experiment #2007 (three-stage column)

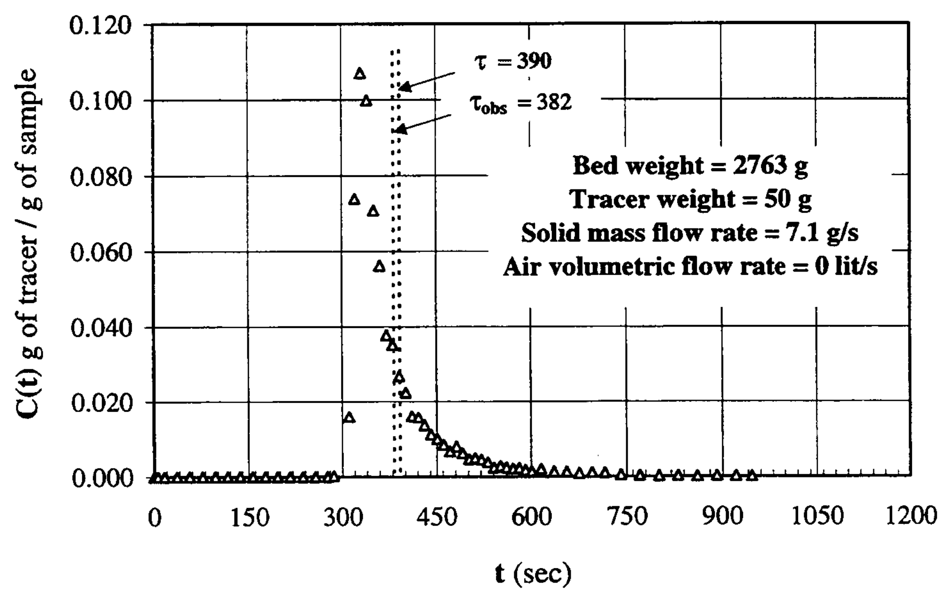


Figure 5.32 C(t) curve of experiment #2008 (three-stage column)

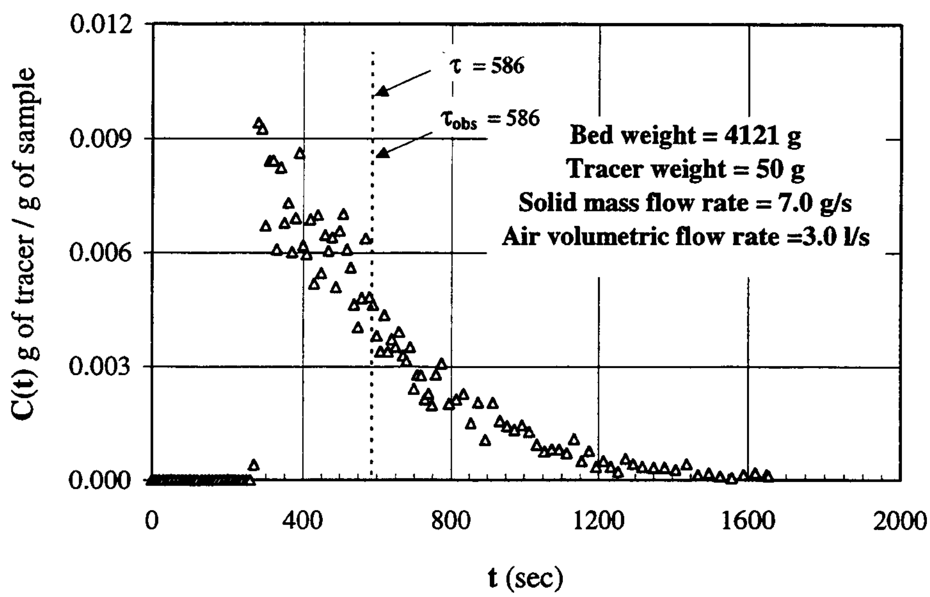


Figure 5.33 C(t) curve of experiment #2009 (three-stage column)

CHAPTER 6

ANALYSIS AND DISCUSSION OF EXPERIMENTAL DATA

6.1 Introduction

The function of residence time distribution of solids gives information about the fraction of solids that spend a given time interval in the vessel. This information is sufficient to provide a description of the flow of solids through the vessel. Engineers have found that various RTD models, called *macromixing* models (in contrast to extremely detailed microscopic modeling) are very useful in providing adequate estimates of important process characteristics, like reaction conversion and efficiency of unit operations.

According to Hoffmann (1979), Levenspiel (1997) and Jovanovic (1997), the characteristics of a simple, reliable RTD model should be:

1. The model should reflect true nature of the flow characteristics observed in the vessel. The building elements of the compartment model: ideal plug flow compartment, ideal mixed flow compartment, and dead zone compartment, should be experimentally observed and identified before they are incorporated into the model. This leads to a class of compartment models that are truly corresponding to existing flow situation: *phenomenological* compartment models.
2. The model should be as simple as possible in its choice of compartment types for the intended application.
3. The model should contain as few parameters as possible
4. Reliable correlations should exist for the parameters of the selected model
5. If possible, the complexity of the mathematical apparatus involved in determination of model parameters should be reasonably simple.

It is crucial to avoid unnecessary model complexity. Complex models inevitably introduce additional parameters for which high resolution data are required. Once a model has been chosen, the values of the characteristic parameters must be determined.

To obtain the model parameters, the measurements of the tracer concentration at the exit of the system are compared with the prediction of the chosen model. The tracer concentration curve, C(t), the response on the impulse tracer stimulus, should be obtained when the system operates at steady-state-flow mode. As for the model, the usual practice is to obtain mathematical representation of the chosen compartment flow model containing pertinent parameters. Furthermore, these parameters are usually expressed as a function of measurable system variables/parameters like: flow rates, volume, hold-up weight, velocity, etc. The model parameters must be picked with the idea of obtaining the closest possible agreement between suggested-model-RTD and real-vessel-RTD. If this agreement is *sufficiently close*, then the model is acceptable. If not, a better model should be found. The quality of the agreement necessary to fulfill the criterion "sufficiently close" depends on engineering judgment.

Most often, the *least square method* is used to find the best set of values for the model parameters. In other words we minimize the function "J",

$$J = \sum_{i=1}^{i=n}\left[E_{model}\left(t_i, \Phi_1, \Phi_2, \ldots \Phi_n\right) - \Psi_i E_{exp.}\left(t_i\right)\right]^2 \tag{6.1}$$

by finding appropriate values for the set of parameters Φ_i. The weighing function Ψ_i is in this study set identically to 1. The details of this simple procedure are found in Appendix D. The amount of tracer material, ΔW, leaving the vessel between time t and $t + \Delta t$ is

$$\Delta W = C(t) S_0 \Delta t \tag{6.2}$$

where S_0 is the solids flow rate. If we now divide by the total amount of tracer material that was injected into the vessel, W_0, we obtain

$$\frac{\Delta W}{W_0} = \frac{S_0 C(t)}{W_0} \Delta t = \text{ fraction of material with residence time between } t + \Delta t \tag{6.3}$$

For pulse injection we define

$$E(t) \equiv \frac{S_0 C(t)}{W_0} \tag{6.4}$$

so that

$$\frac{\Delta W}{W_0} = E(t)\,\Delta t \tag{6.5}$$

where the quantity E(t) is the residence-time distribution function.

6.2 Single-stage Unit

In Section 3.3 we already presented, a model that we believe may well describe the experimental situations depicted in Chapter 5. Visual observation of the spouted bed clearly indicate that the total volume of the bed consist of: a region where particles are vigorously mixed, a region where particles flow in the form of moving bed with insignificant mixing, and a region where there is apparent absence of flow (dead zones).

For the case of a single-stage unit, convolution of the E(t) equations for plug flow and mixed flow compartments yields the E(t) equation [equation (3.11)] that is used to represent the experimental data.

$$\left.\begin{aligned} E(t) &= 0 && \text{for } t < \tau_p \\ E(t) &= \frac{1}{\tau_M} \exp\left[\frac{-(t-\tau_p)}{\tau_M}\right] && \text{for } t \geq \tau_p \end{aligned}\right\} \tag{3.11}$$

Figure 6.1 represents the actual flow situation observed in the single-stage unit. The RTD of this single-stage compartment model can be represented by convolution of the RTD's for plug flow and mixed flow compartment. The dead space is not an active volume of the single-stage and therefore it does not show up in the overall RTD except for the shift in the observed mean residence time.

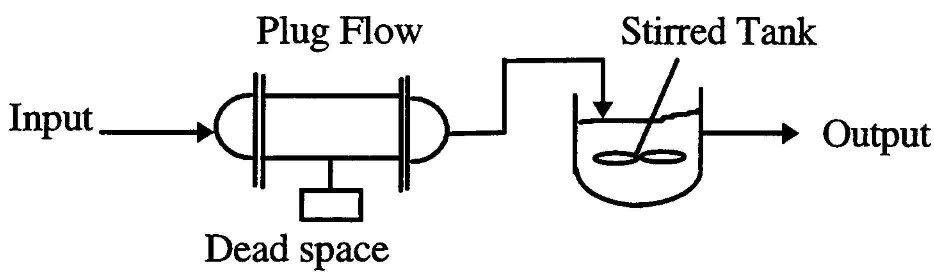


Figure 6.1 Compartment model for the single-stage unit.

The best-fit optimization procedure, using a quasi-Newton search algorithm, yields satisfactory results for most runs. The outcomes are shown in Figures 6.2 to 6.15. Also Figures 6.16 and 6.17 summarize the results for single-stage unit experiments.

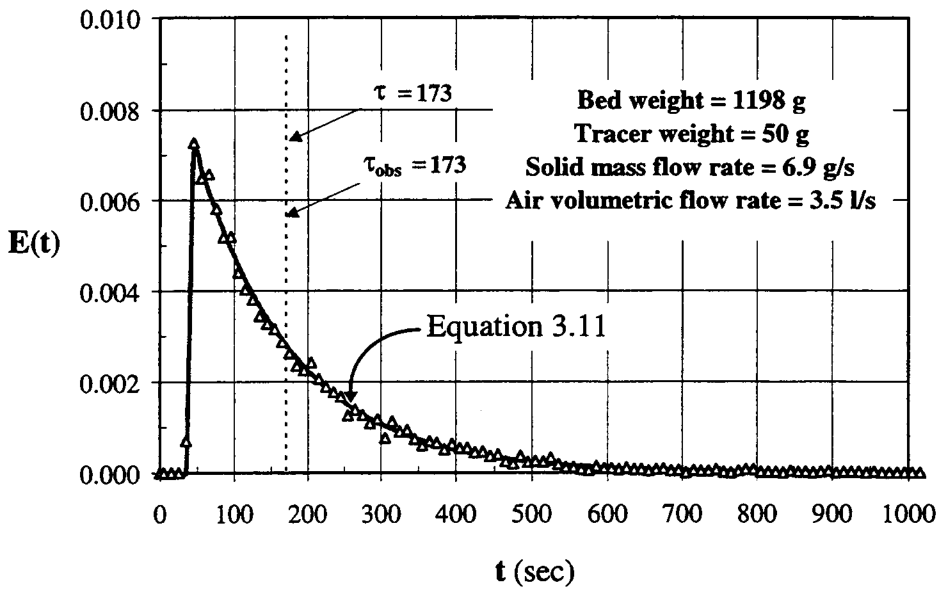


Figure 6.2 E(t) modeling of experiment #1030 (single-stage unit)

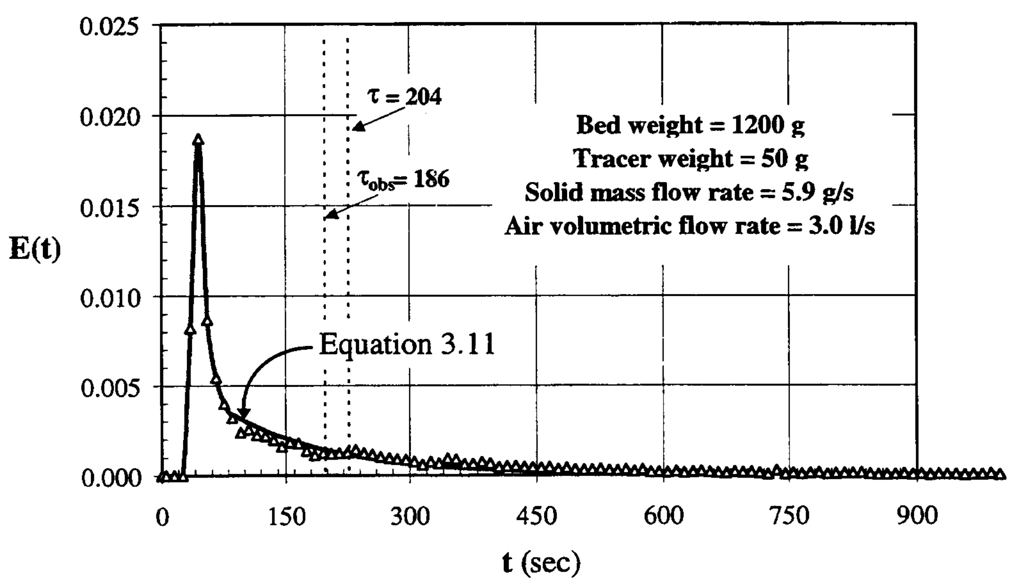


Figure 6.3 E(t) modeling of experiment #1031 (single-stage unit)

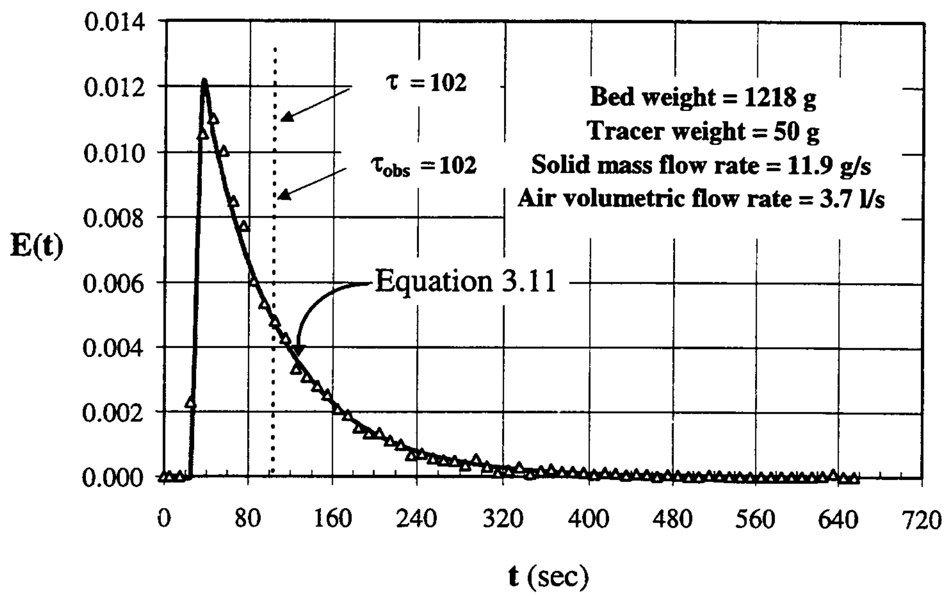


Figure 6.4 E(t) modeling of experiment #1032 (single-stage unit)

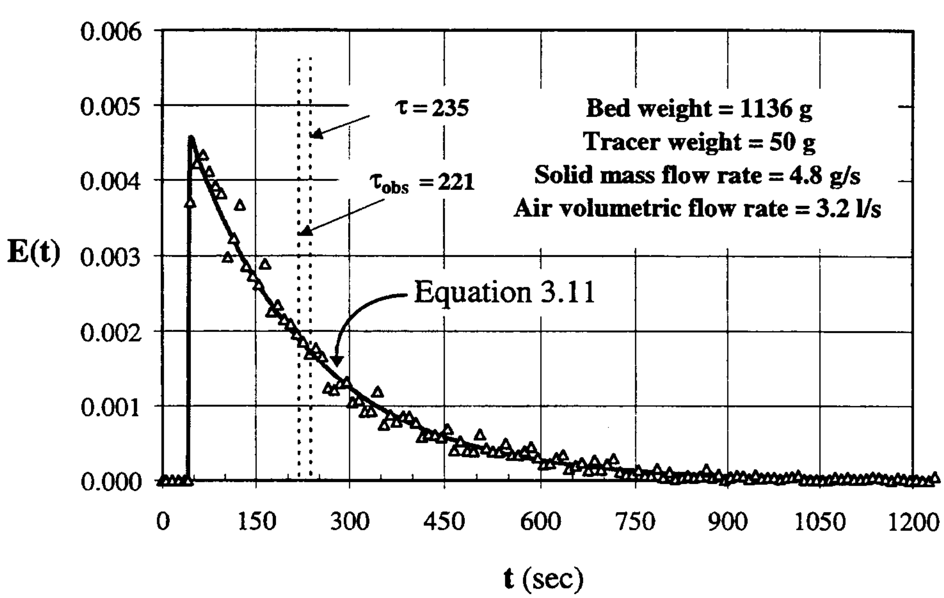


Figure 6.5 E(t) modeling of experiment #1033 (single-stage unit).

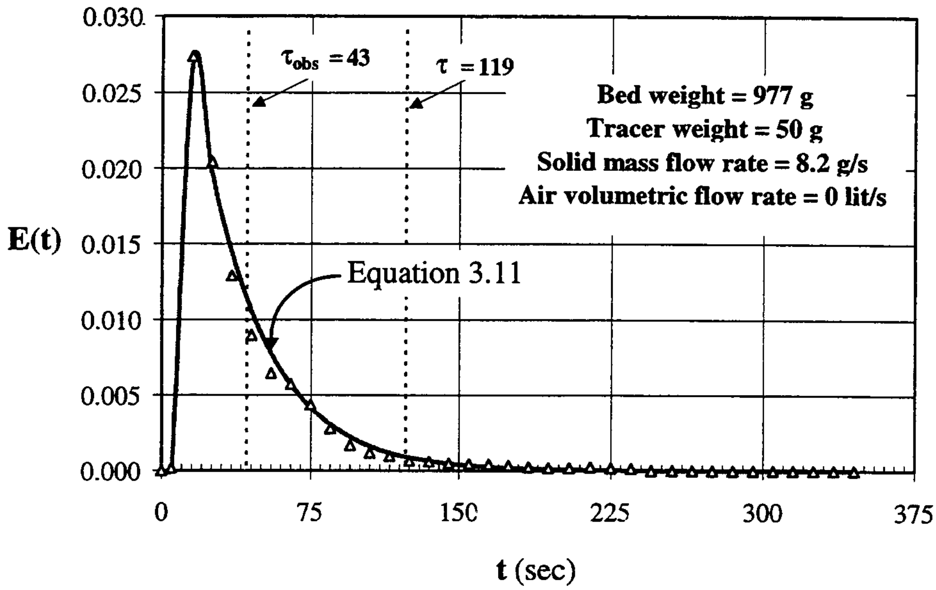


Figure 6.6 E(t) modeling of experiment #1034 (single-stage unit).

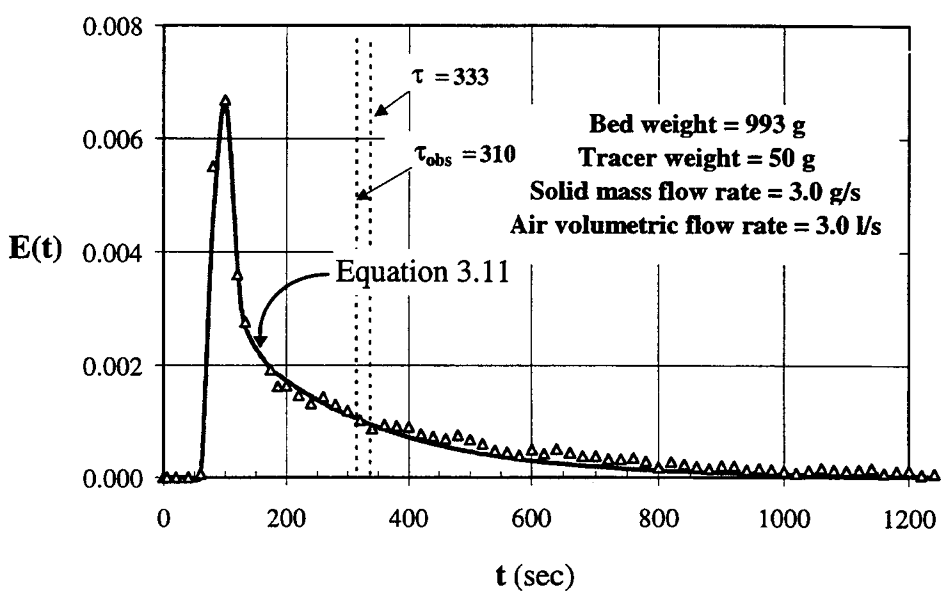


Figure 6.7 E(t) modeling of experiment #1035 (single-stage unit)

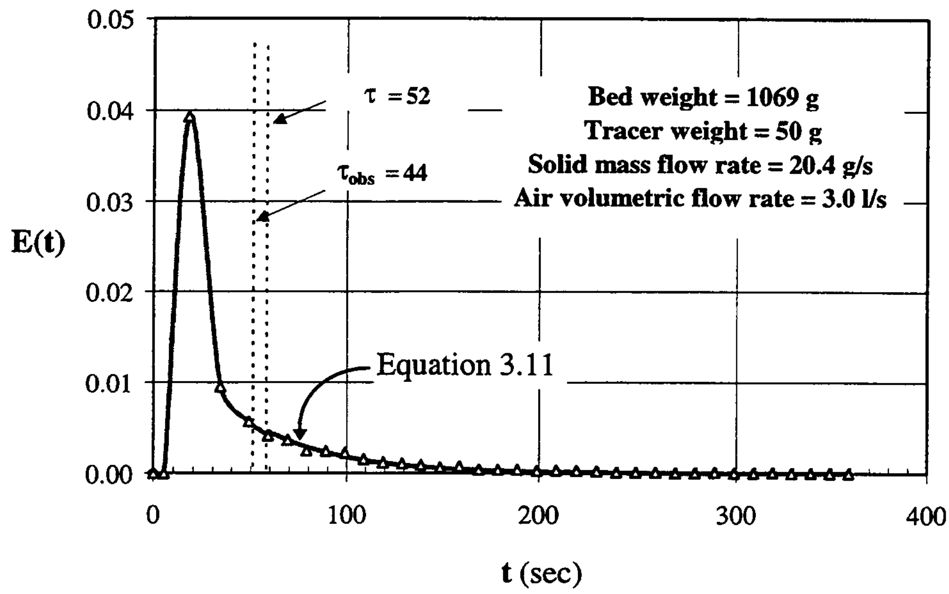


Figure 6.8 E(t) modeling of experiment #1036 (single-stage unit)

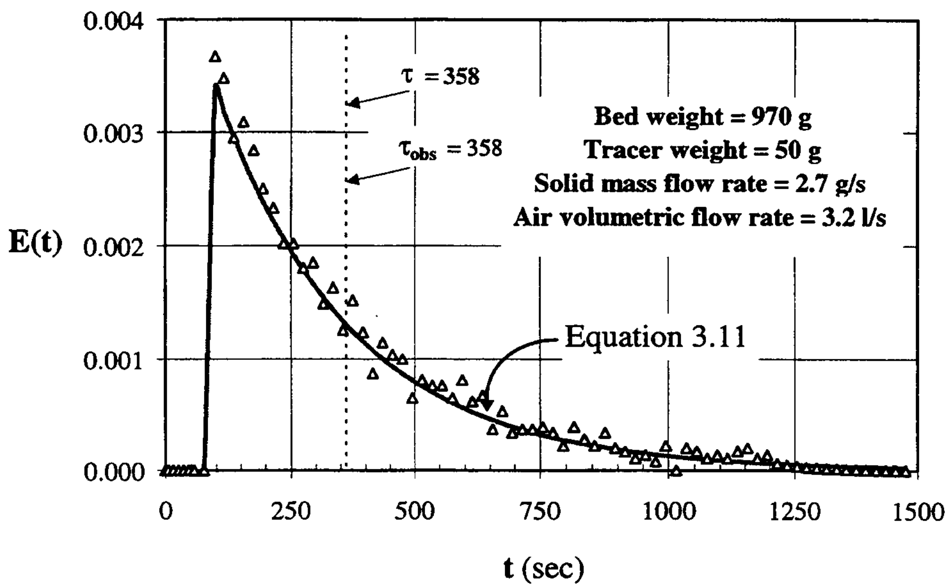


Figure 6.9 E(t) modeling of experiment #1037 (single-stage unit)

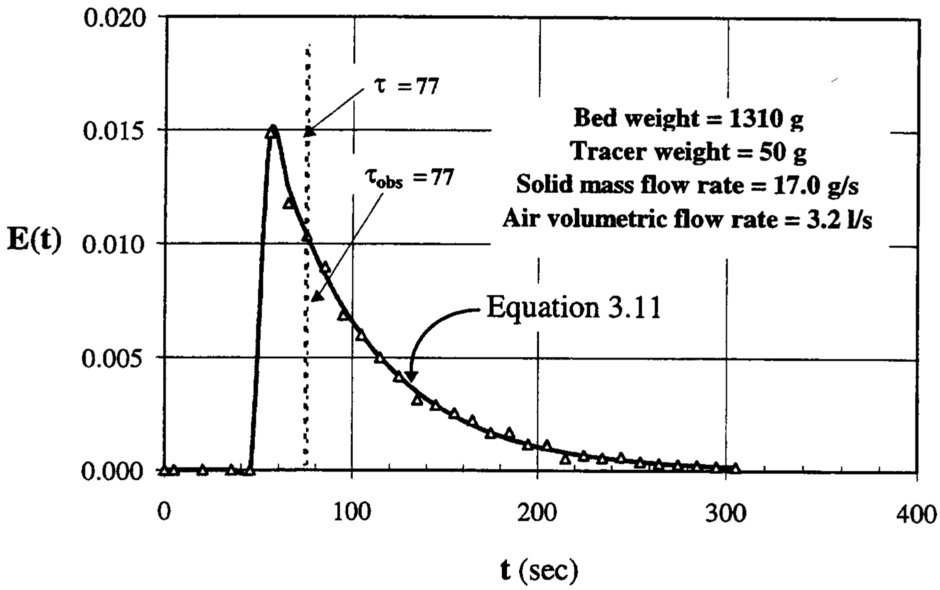


Figure 6.10 E(t) modeling of experiment #1038 (single-stage unit)

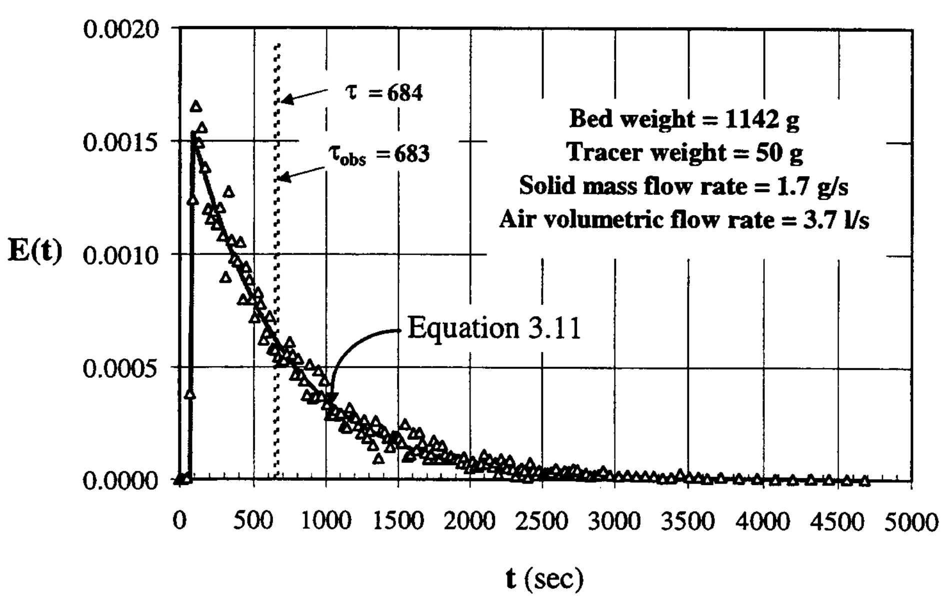


Figure 6.11 E(t) modeling of experiment #1039 (single-stage unit)

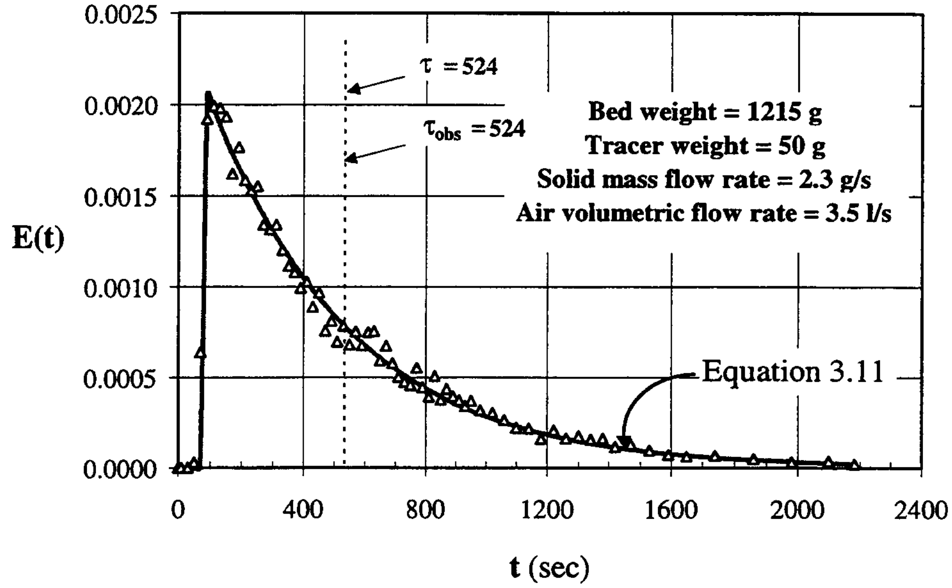


Figure 6.12 E(t) modeling of experiment #1040 (single-stage unit)

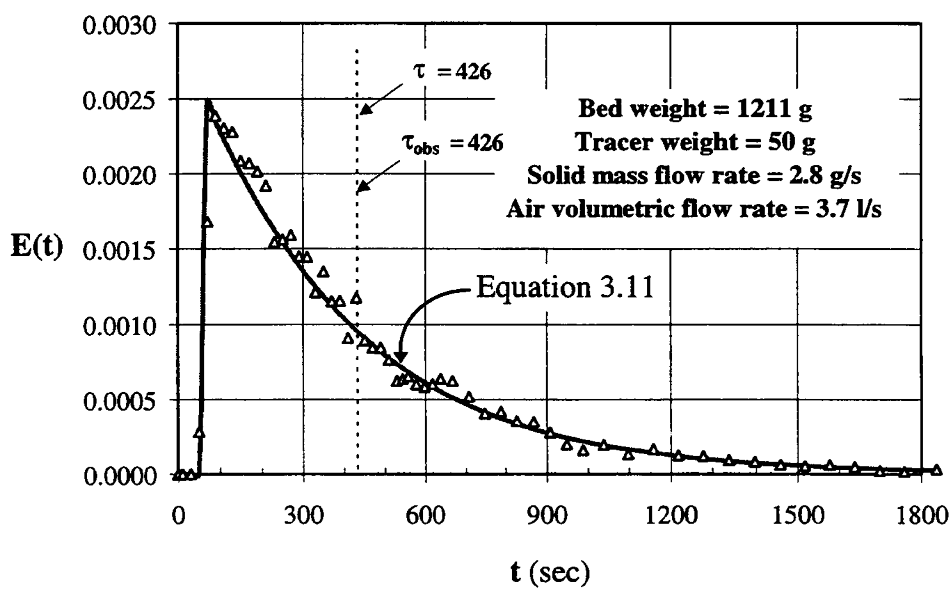


Figure 6.13 E(t) modeling of experiment #1041 (single-stage unit)

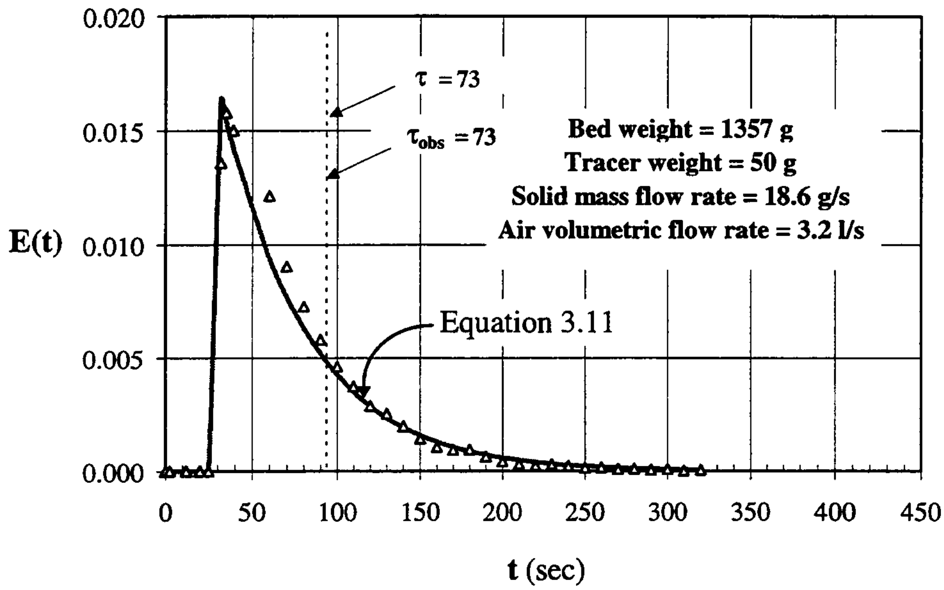


Figure 6.14 E(t) modeling of experiment #1042 (single-stage unit)

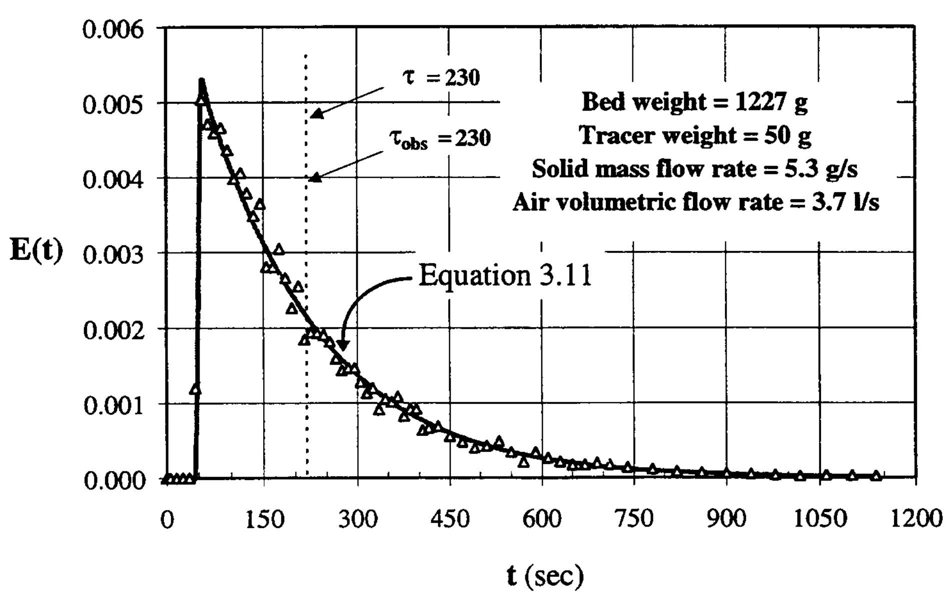


Figure 6.15 E(t) modeling of experiment #1043 (single-stage unit)

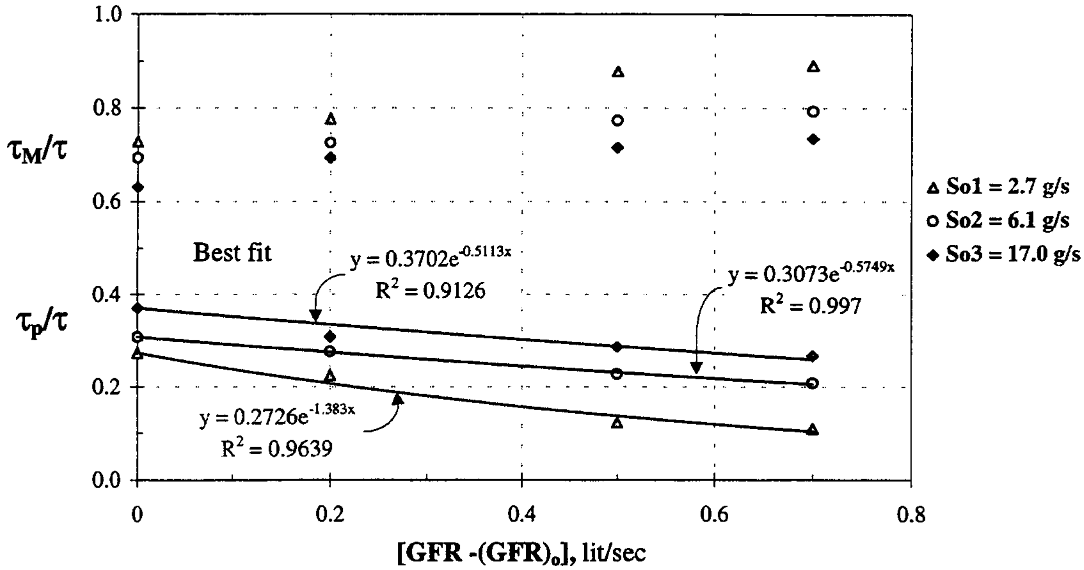


Figure 6.16 Plug and mixed flow behavior for the single-stage unit.

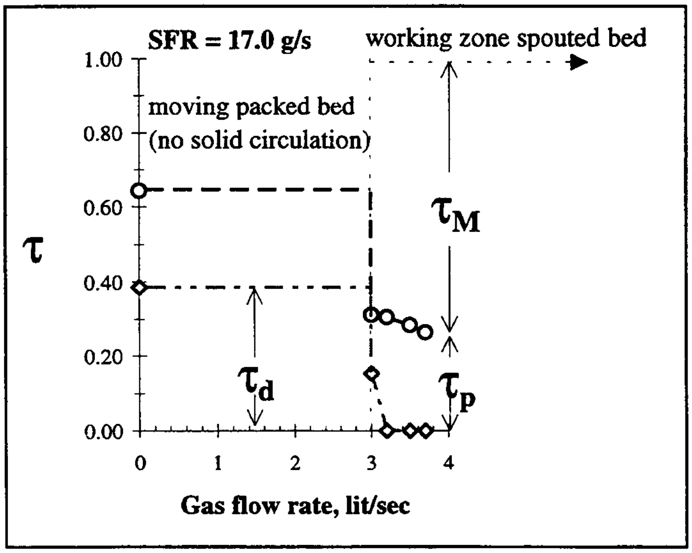


Figure 6.17 Plug, mixed flow and dead space for the single-stage unit.

From the plotted data in Figure 6.16 we observe that for constant solid flow rate, an increase of the gas flow rate causes also an increase in *mixing behavior* (τ_M/τ). Similarly, for constant solid flow rate, an increase in gas flow rate will reduce the *plug flow behavior* of the vessel (τ_p/τ) as expected. On the other hand, for constant gas flow rate, it can be observed that an increase of solid flow rate reduces the mixing of solids, since the particles flow faster through the system.

From the analysis of Figure 6.17, it is possible to conclude that the size of the dead volume is practically negligible for almost all working conditions. For low gas flow rate (below 3.0 liters/second) and in absence of reliable data, we assume that plug flow, mixed flow, and dead space remain practically constant, since for that range of gas flow rate, the solid particles cannot jump over the top of the draft tube.

τ_p/τ and τ_M/τ can also be plotted in terms of the recirculation time of solids, "t_R". This time, as it is shown in Figure 6.18, is obtained as a function of the gas flow rate.

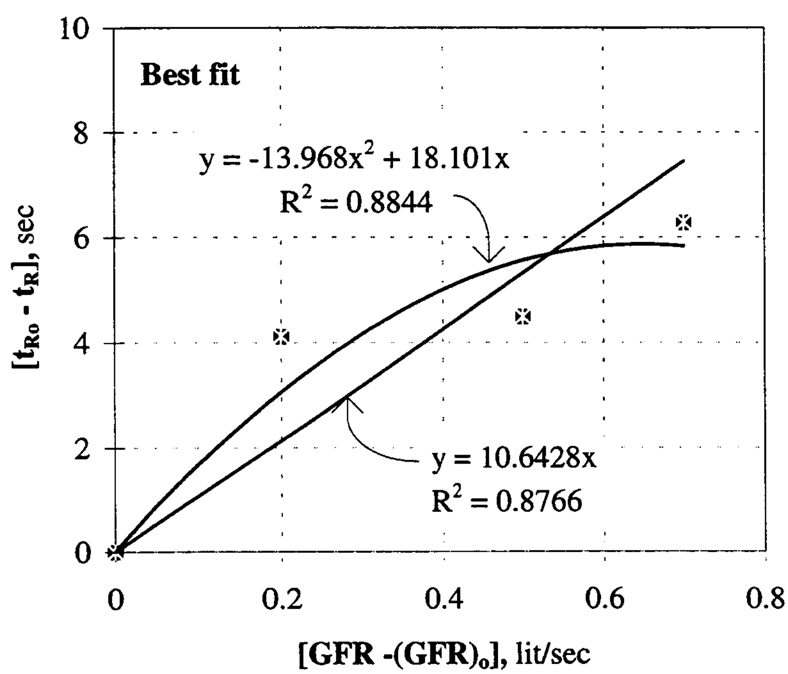


Figure 6.18 Recirculation time of solids.

Out of the proposed model we obtain the two model-parameters τ_M and τ_p. Figure 6.16 shows how these model-parameters change with the operating conditions, gas flow rate (GFR) and solid flow rate (SFR or "S_o"). τ_p/τ data are correlated and the resulting equations are shown in Table 6.1. All three correlations are of the general form

$$y = A \exp(-Bx) \tag{6.6}$$

where $y = \tau_p/\tau$, $x = [GFR - (GFR)_o]$ and A and B are constants for each SFR. This type of correlation has a physical meaning and it may well represent the actual behavior of the single-stage unit. Accordingly, when "x" goes to zero,

$$y = A = \left(\frac{\tau_p}{\tau}\right)_o \quad = \text{Fraction of plug-flow behavior at the lowest possible GFR}$$

Similarly, when "x" increases, the plug-flow behavior of the stage is reduced ($y \rightarrow 0$) due to the intensive agitation within the vessel.

SFR (g/s)	**Correlation for τ_p/τ**	**R^2**
2.7	$0.2726 \exp\{-1.383\ [GFR - (GFR)_o]\}$	0.964
6.1	$0.3073 \exp\{-0.5749\ [GFR - (GFR)_o]\}$	0.997
17.0	$0.3702 \exp\{-0.5113\ [GFR - (GFR)_o]\}$	0.913

Table 6.1 Correlations to predict τ_p/τ in the single-stage unit

The next step is to obtain a *single* correlation capable of predicting mixing flow behavior and plug flow behavior, as a function of both operating variables. A method, shown by Davis (1962), of correlating three variables "x" (S_o), "y" (GFR), and "z" (τ_p/τ or τ_M/τ), considers one variable, for example "x", as constant, temporarily, and relating "y" and "z" for each value of "x" by equations of the same type, as

$$\phi(z) = mF(y) + b \tag{6.6}$$

Where "m" is the slope of the line, and "b" is the intersection. Then "m" and "b" can be expressed as function of "x" (the third variable involved), as

$$m = \psi(x) \tag{6.7}$$

and

$$b = f(x) \tag{6.8}$$

so that the final equation becomes

$$\phi(z) = \psi(x)\,F(y) + f(x) \tag{6.9}$$

Following this procedure, from the correlations in Table 6.1 we obtain the values of "m" and "b" for constant S_o. Figures 6.19 and 6.20 show how these parameters change as a function of the solid flow rate S_o. From this information, the correspondent correlations, $m = \psi(x)$ and $b = f(x)$, also shown in these figures, are determined.

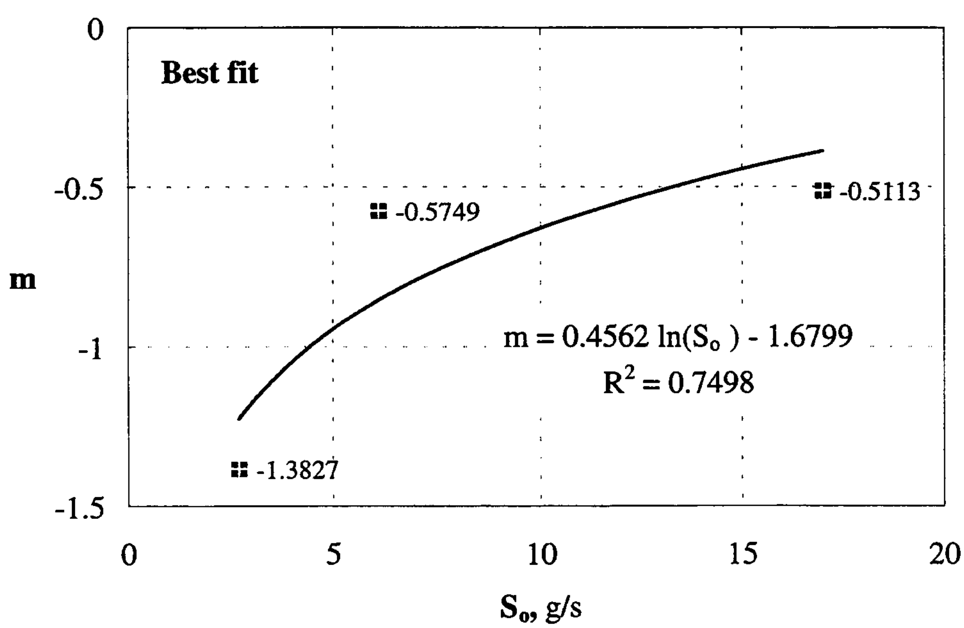


Figure 6.19 Correlation for τ_p/τ: "m" dependency on solid flow rate S_o.

Substitution of the correlations from Figures 6.19 and 6.20 in Equation 6.9 yields the desired model correlation:

$$\tau_p/\tau = (0.0066\ S_o + 0.26)\ \mathrm{EXP}\ \{-(0.46\ \ln S_o - 1.68)(GFR - GFR_o)\} \qquad (6.10)$$

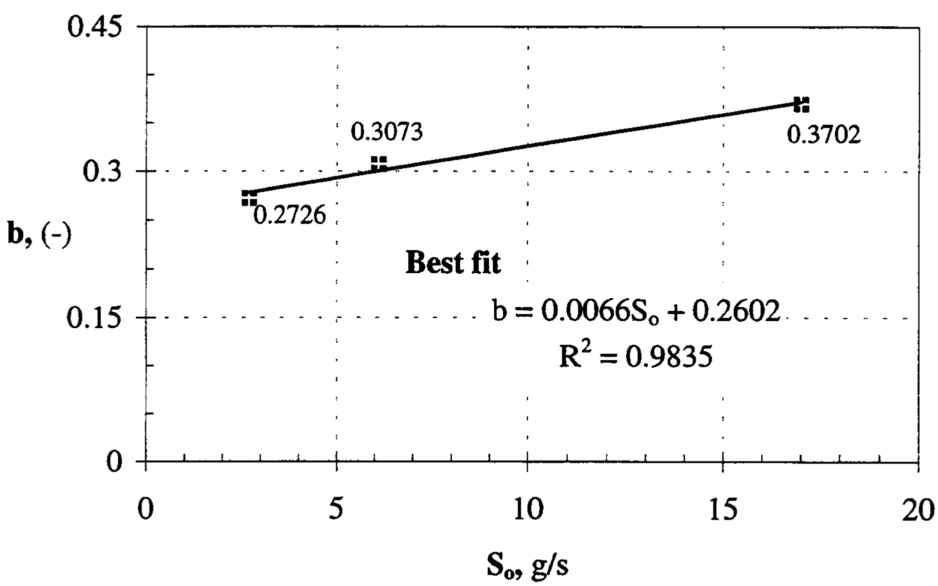


Figure 6.20 Correlation for τ_p/τ: "b" dependency on solid flow rate S_o.

If the linear correlation (y = 10.6428x) of Figure 6.18 is used, then Equation (6.10) can be written in terms of the *recirculation time* of solids,

$$\tau_p/\tau = (0.0066\ S_o + 0.26)\ \mathrm{EXP}\ \{-(0.043\ \ln S_o - 0.16)(t_{Ro} - t_R)\} \qquad (6.11)$$

These correlations have to be tested with an independent set of experimental data. The data used for that purpose are from the three-stage column experiments. Results are shown later in Section 6.3 of this thesis.

6.3 Three-stage Column

In Section 3.3 of this thesis, the mathematical model for the three-stage column that we believe may well describe the experimental situations depicted in Chapter 5 is presented. For this case, convolution of the E(t) equations (3.11) yield the E(t) expression [equation (3.12)] that is used to represent our data.

$$\left.\begin{aligned} &E(t) = 0 && t < 3\tau_{pi} \\ &E(t) = (1/2)(1/\tau_{Mi}^{3})(t - 3\tau_{pi})^{2} \exp\{-(t - 3\tau_{pi})/\tau_{Mi}\} && t \geq 3\tau_{pi} \end{aligned}\right\} \quad (3.12)$$

Figure 6.21 represents this combination of *ideal vessels.*

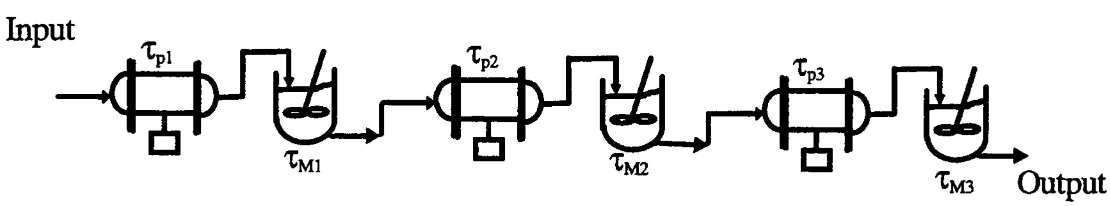


Figure 6.21 Compartment model for the three-stage column.

The least-square method is again used to determine model-parameters from the experimental data, and the best-fit optimization procedure, (quasi-Newton search algorithm) also yields satisfactory results for most experiments. Figures 6.22 to 6.33 show the results for the three-stage column.

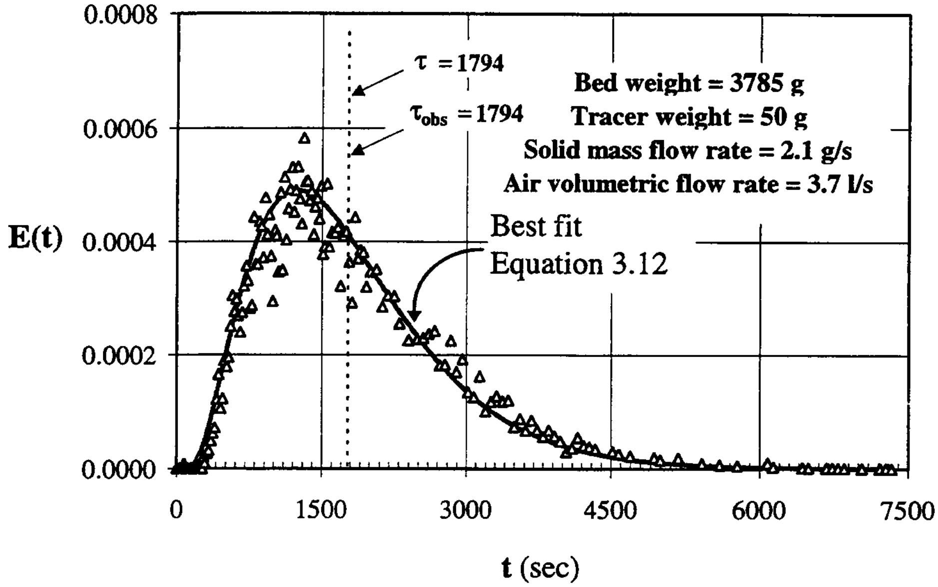


Figure 6.22 E(t) modeling of experiment #2000 (three-stage column)

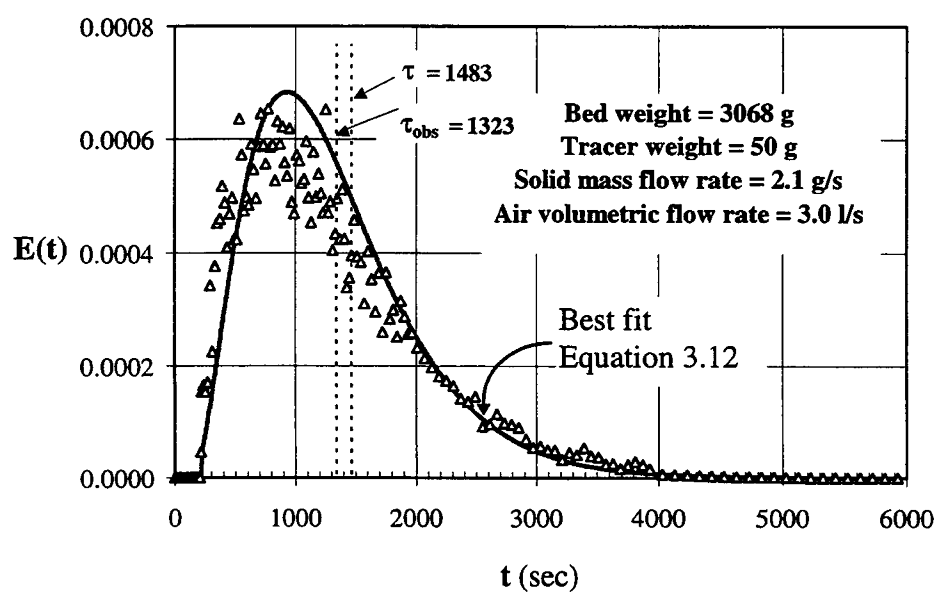


Figure 6.23 E(t) modeling of experiment #2001 (three-stage column)

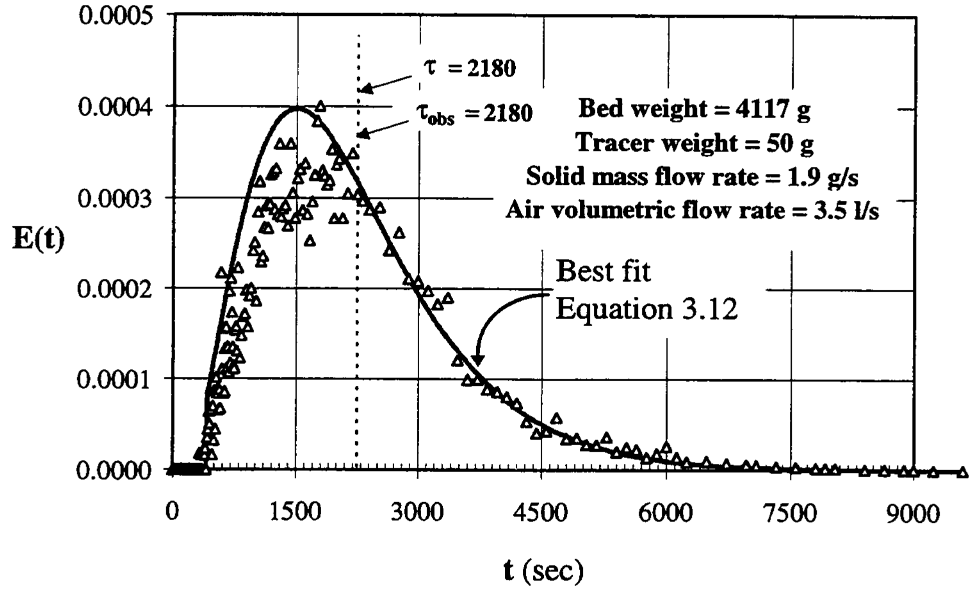


Figure 6.24 E(t) modeling of experiment #2002 (three-stage column)

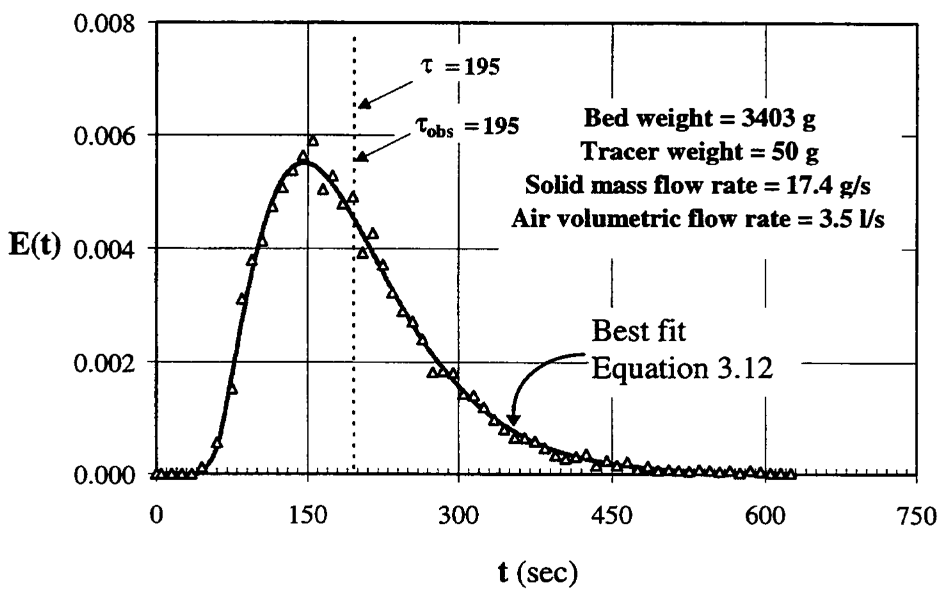


Figure 6.25 E(t) modeling of experiment #2003 (three-stage column)

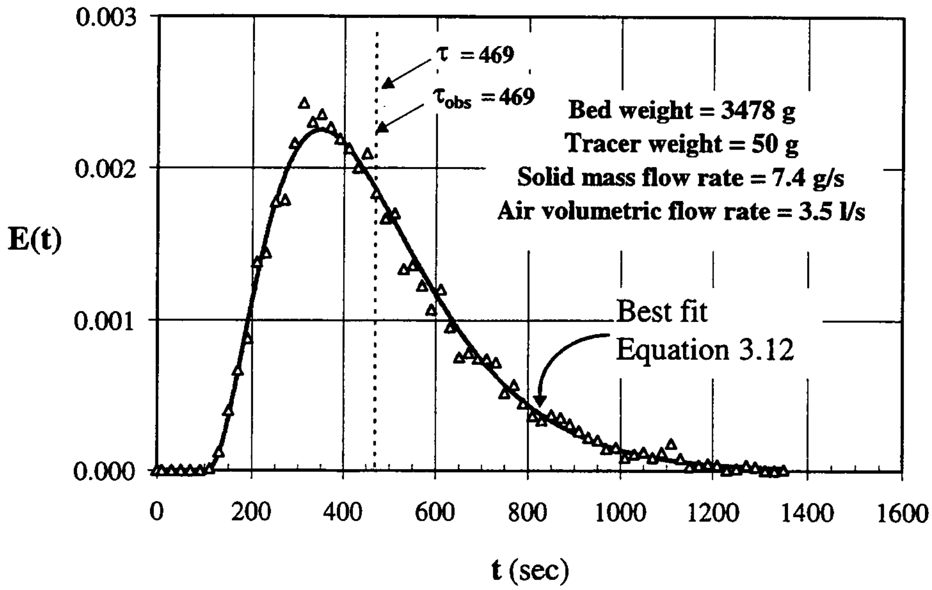


Figure 6.26 E(t) modeling of experiment #2004 (three-stage column)

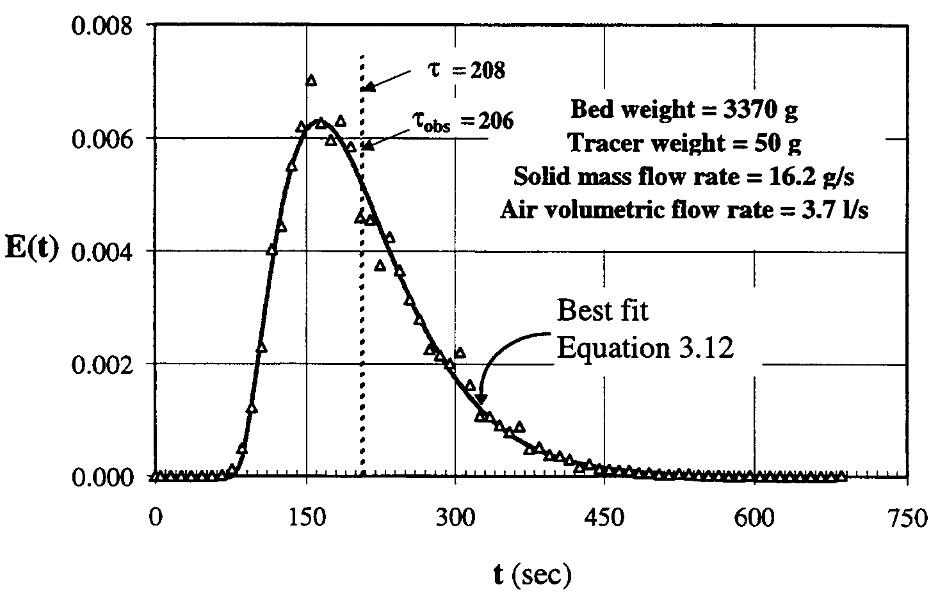


Figure 6.27 E(t) modeling of experiment #2005 (three-stage column)

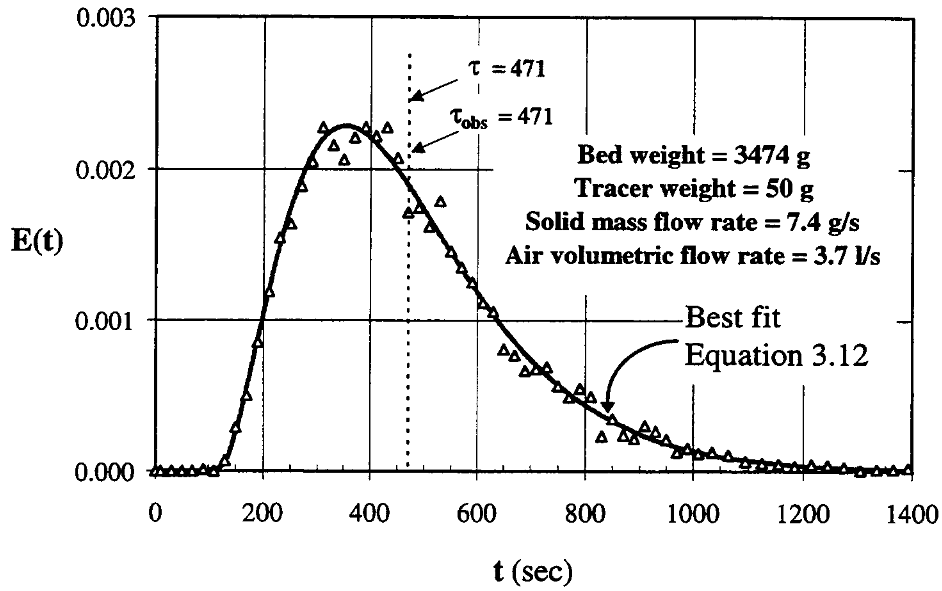


Figure 6.28 E(t) modeling of experiment #2006 (three-stage column)

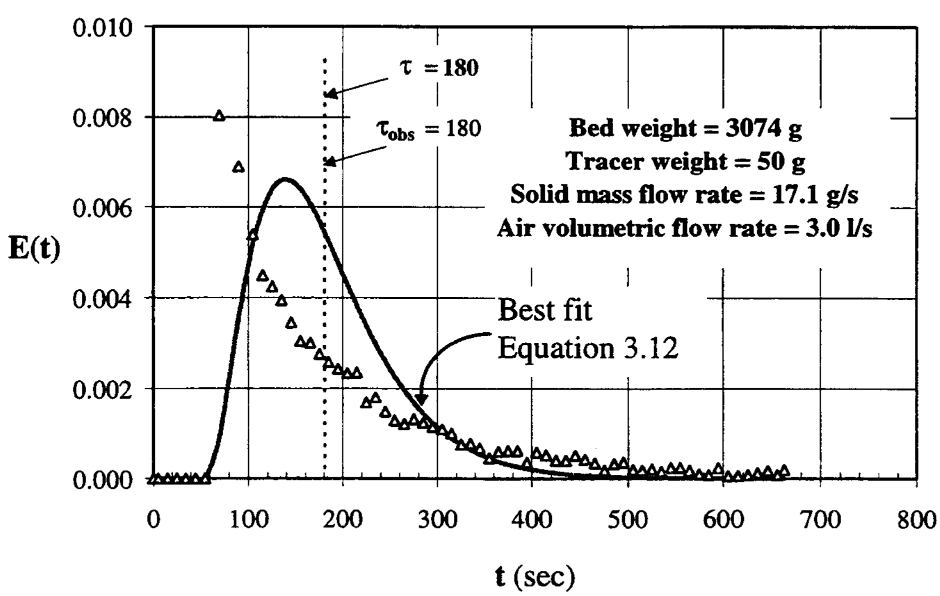


Figure 6.29 E(t) modeling of experiment #2007 (three-stage column)

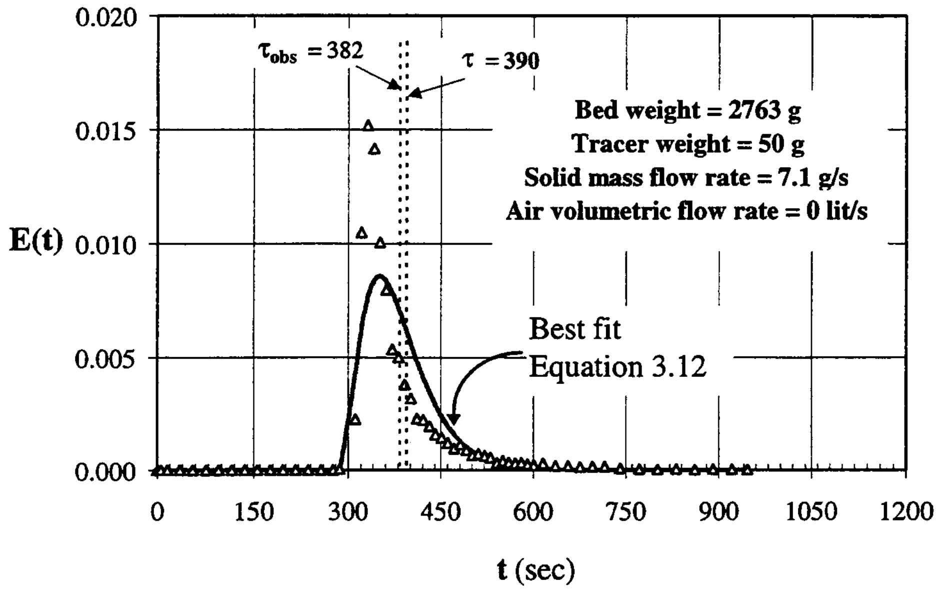


Figure 6.30 E(t) modeling of experiment #2008 (three-stage column)

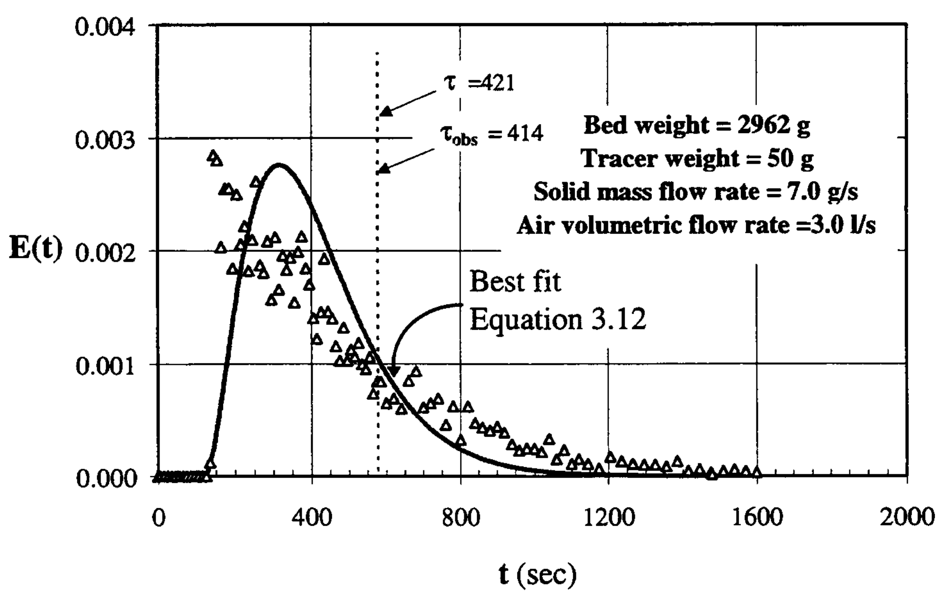


Figure 6.31 E(t) modeling of experiment #2009 (three-stage column)

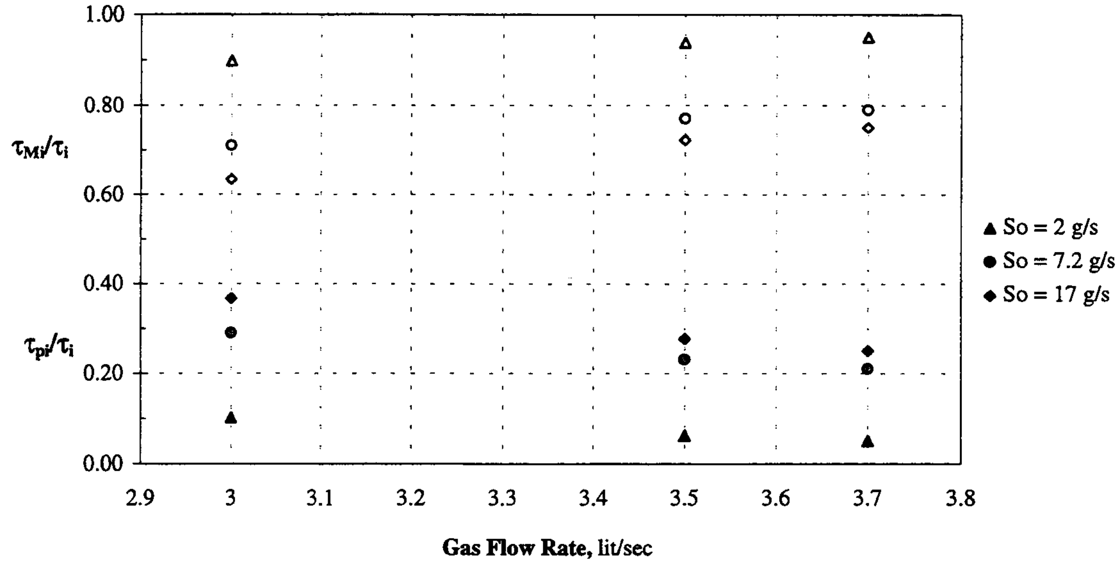


Figure 6.32 Plug and mixed flow behavior for the three-stage column.

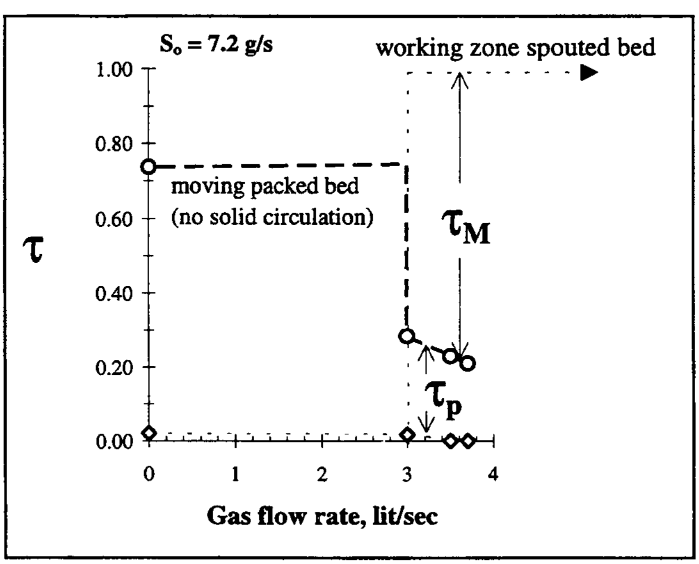


Figure 6.33 Plug, mixed flow and dead space for the three-stage column.

Once again, from the plotted data in Figure 6.32 we may confirm that for constant solid flow rate, an increase of the gas flow rate causes also an increase in *mixing behavior* (τ_M/τ). Similarly, for constant solid flow rate, an increase in gas flow rate will reduce the *plug flow behavior* of the vessel (τ_p/τ) as expected. Also in this case, for constant gas flow rate, an increase of solid flow rate reduces the mixing of solids.

Out of Figure 6.33, it is also possible to conclude that the size of the dead volume is practically negligible. Again, for low gas flow rate (below 3.0 liters/second), we assume that plug flow, mixed flow, and dead space remain practically constant, since as it was mentioned before, for that range of gas flow rate the solid particles cannot jump over the top of the draft tube.

Equations 6.10 and 6.11 can now be tested. Data from the three-stage column are used for that purpose since they are independently obtained. Figure 6.34 and 6.35 show the model predictions for the three-stage column. The experimental parameters are plotted against the predicted values in Figure 6.36. The predicted values are calculated using the correlations developed for the single-stage unit. The predictions are shown to be in very satisfactory agreement with the experimental results.

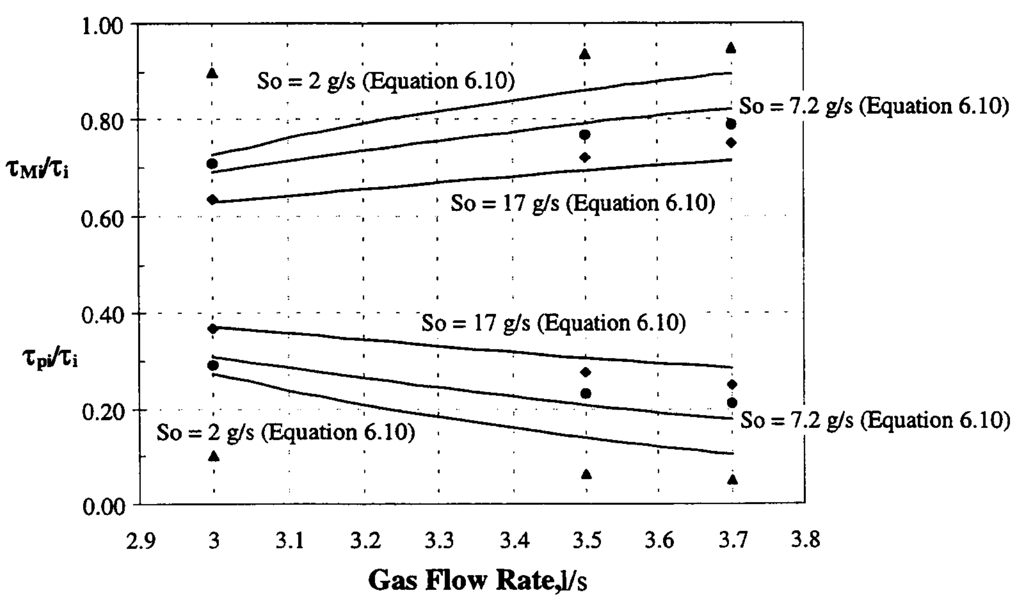


Figure 6.34 Model-parameters. Experimental and model predictions.

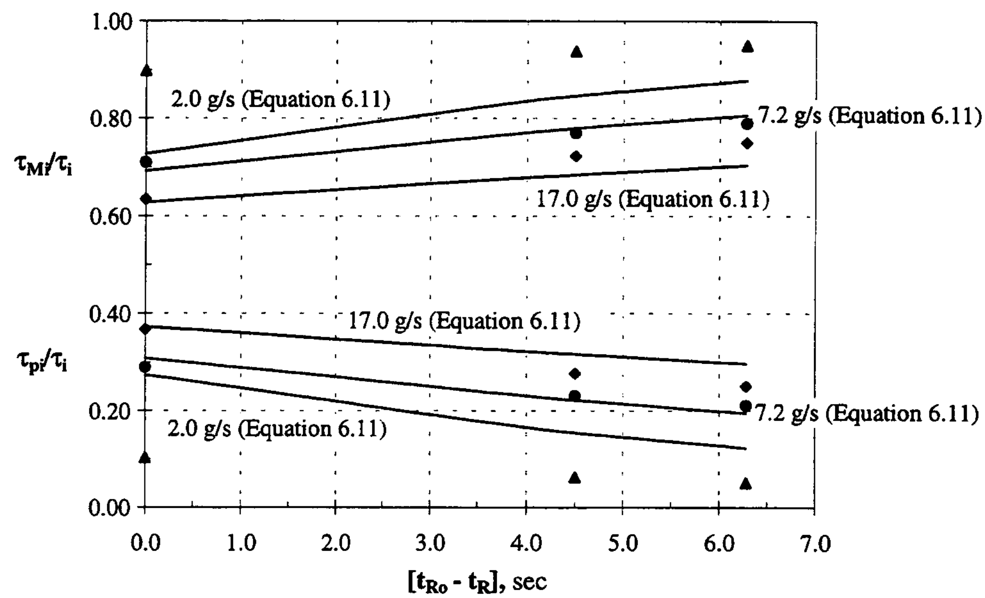


Figure 6.35 Model-parameters. Experimental and model predictions.

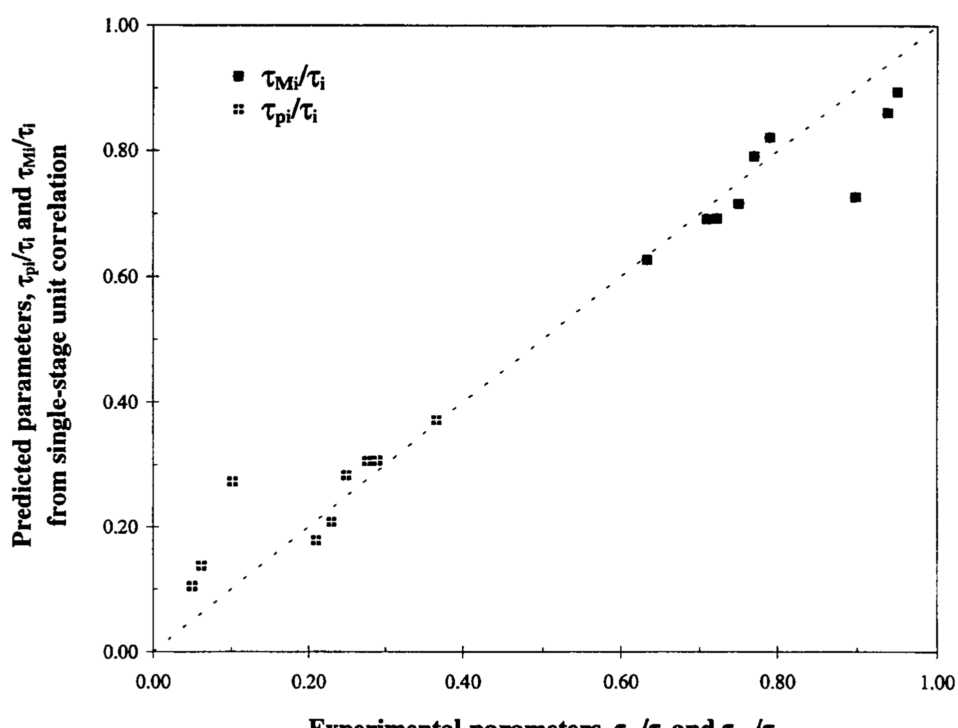


Figure 6.36 Measured versus predicted parameters.

Finally, using the predicted values coming from either Equation 6.10 or Equation 6.11, we generate the E(t) curves shown in Figures 6.37 to 6.45.

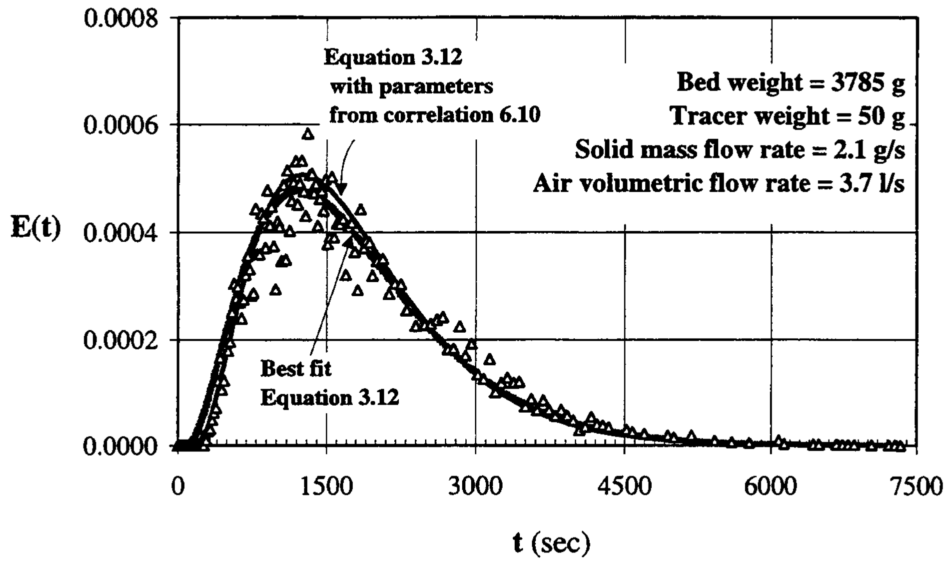


Figure 6.37 E(t) modeling of experiment #2000 (three-stage column).

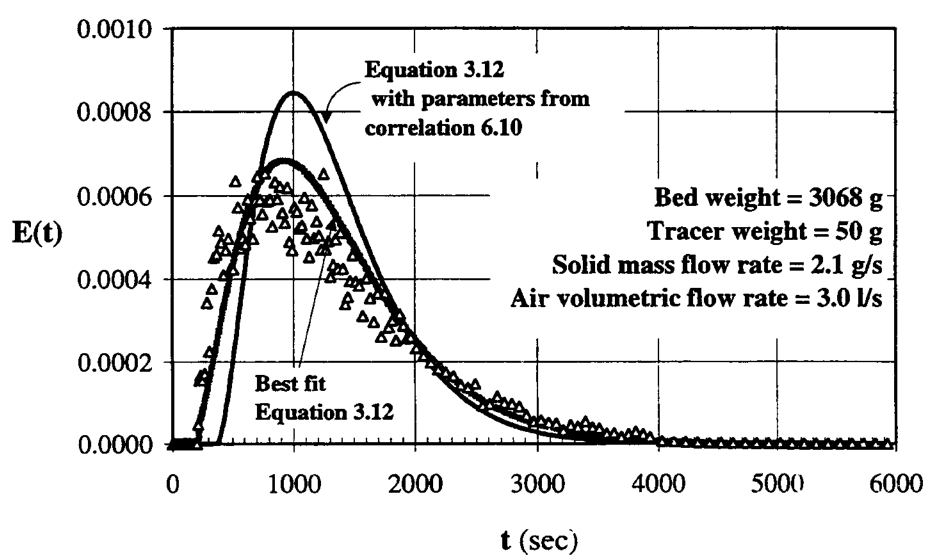


Figure 6.38 E(t) modeling of experiment #2001 (three-stage column).

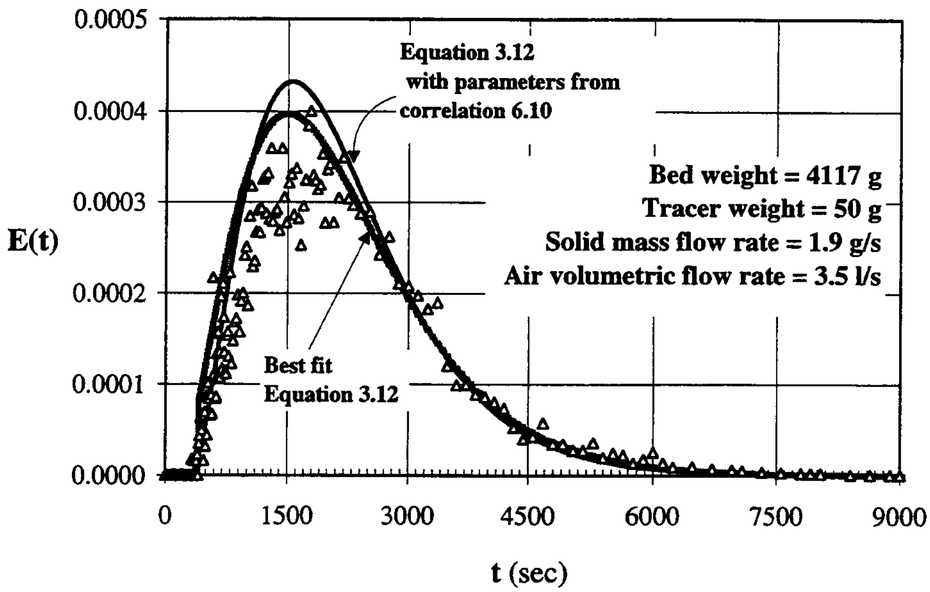


Figure 6.39 E(t) modeling of experiment #2002 (three-stage column).

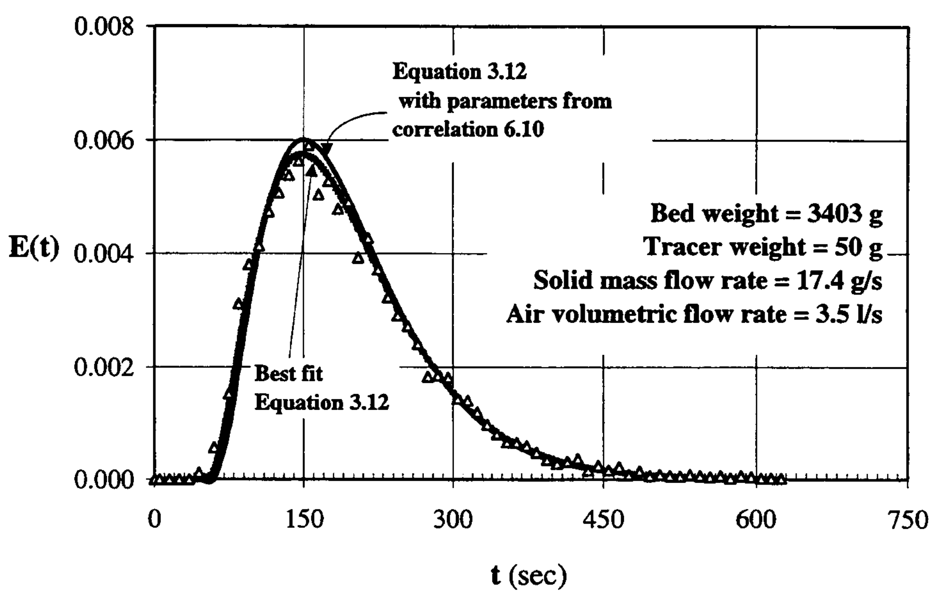


Figure 6.40 E(t) modeling of experiment #2003 (three-stage column).

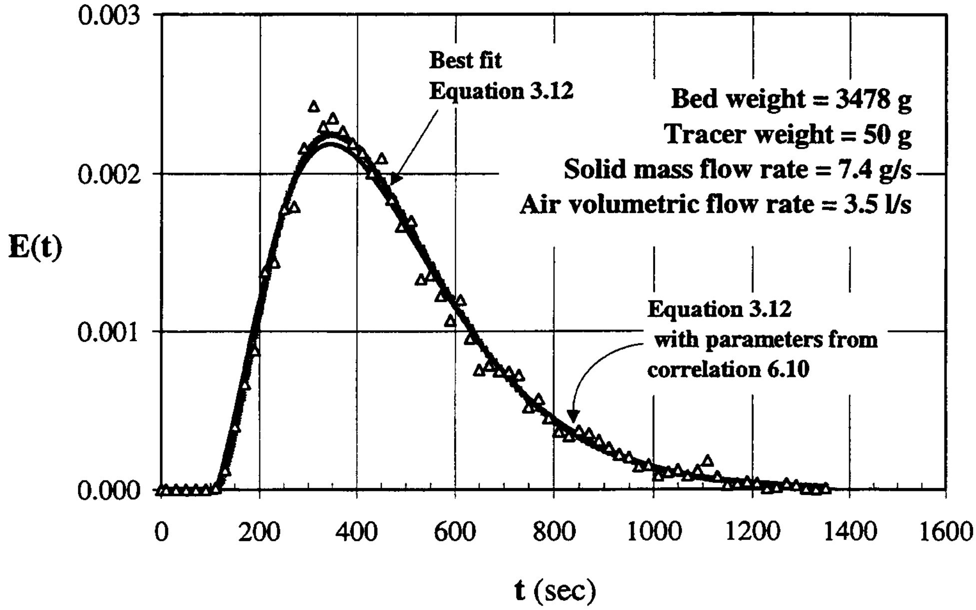


Figure 6.41 E(t) modeling of experiment #2004 (three-stage column).

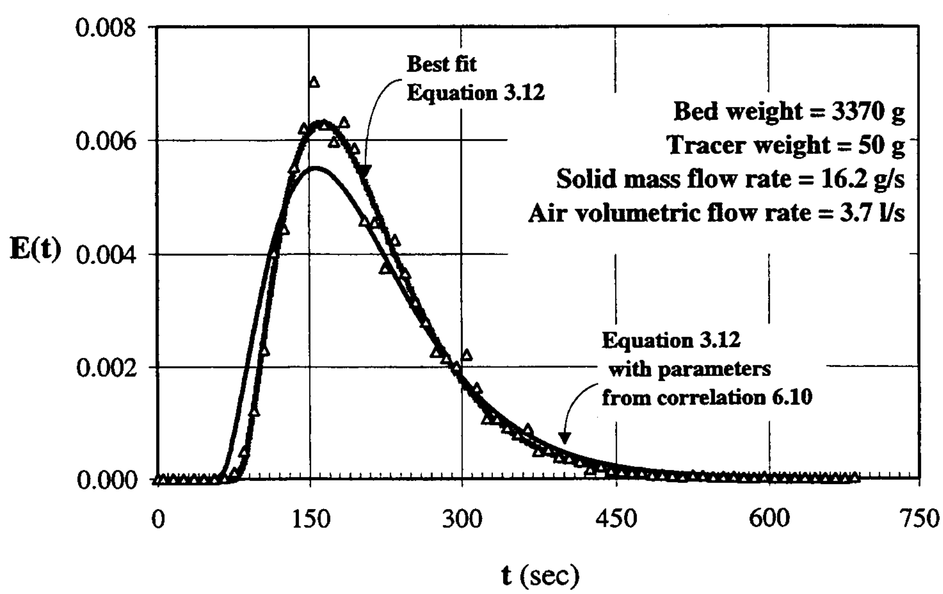


Figure 6.42 E(t) modeling of experiment #2005 (three-stage column).

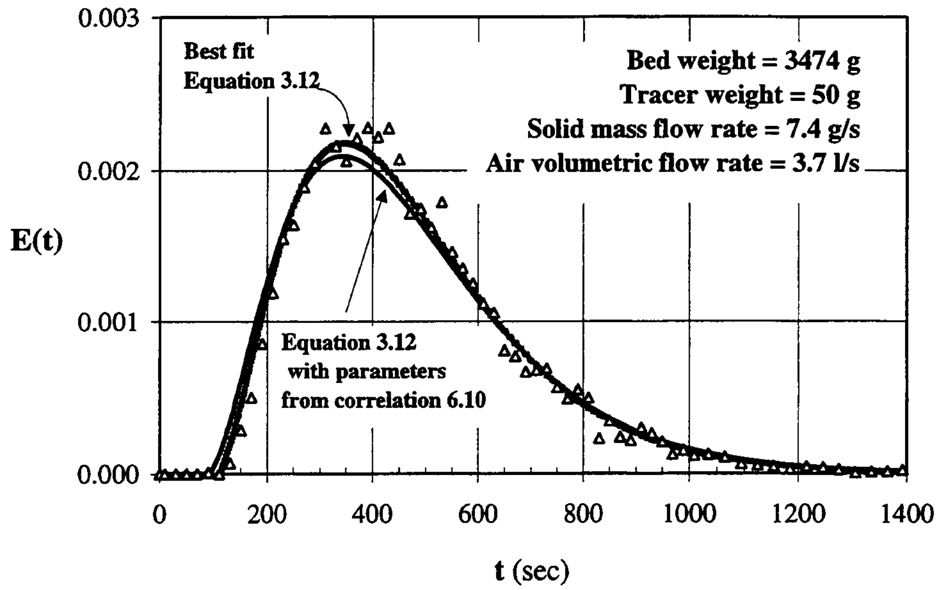


Figure 6.43 E(t) modeling of experiment #2006 (three-stage column).

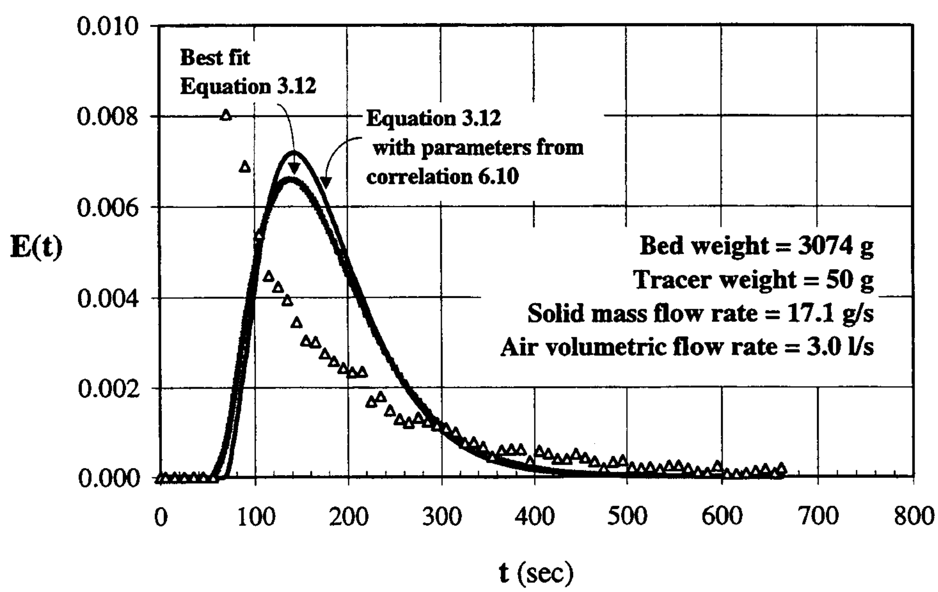


Figure 6.44 E(t) modeling of experiment #2007 (three-stage column).

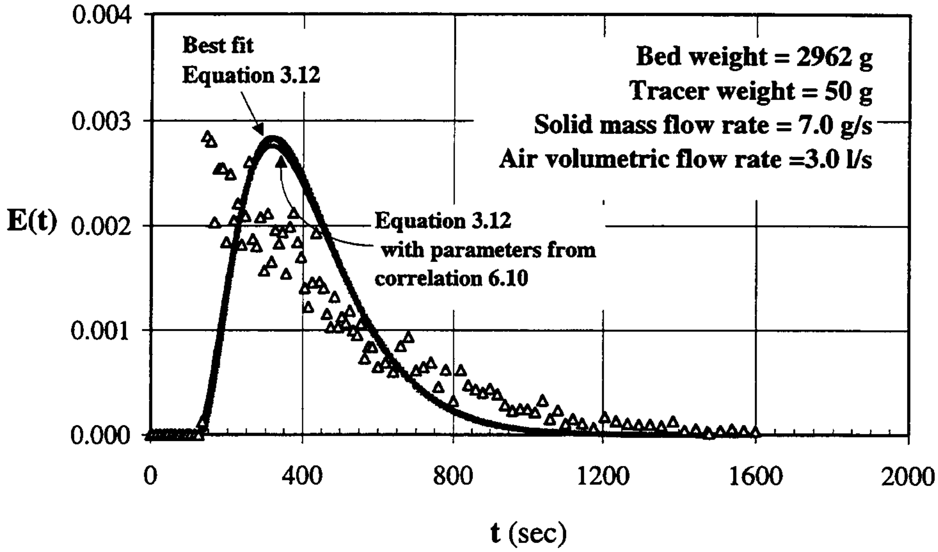


Figure 6.45 E(t) modeling of experiment #2009 (three-stage column).

6.4 Discussion

After looking all previous results, we conclude that the data corresponding to those experiments in the region of higher gas flow rates, are well modeled by both Equations 3.12 and 6.10. On the other hand, it is obvious that for lower gas flow rates, and any of the tested solid flow rates, both equations fail in predicting the experimental data. When gas flow is low, it seems that the solid circulating pattern does not develop because not all the particles have enough kinetic energy to rise to the top of the draft tube. Therefore, to get mixed flow behavior, we need high recirculation rates.

Certainly, with units of different size and geometry, this low gas flow limit will be different. We must say that we consider these conditions as the limit for bad behavior of the vessel. What causes this bad behavior?. We are not sure and consequently we can not give a satisfactory answer in this preliminary study. Most important is that we were not interested in studying bad behavior, rather we wanted to know the lower flow rate limits and good behavior. We found this limit to be above a GFR of 3.5 lit/sec for our particular design.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn based on the results obtained in this study:

1. The design of a staged spouted bed column used in this study has clear operating and scale-up advantages over designs reported in the literature. With the addition of a draft tube to each stage, internal recirculation of solids is improved, allowing operation with less gas and lower pressure drop. Under these conditions, there should be practically no limitation to the number of stages that could be used in such a column.
2. For high gas flow rates (above 3.5 liters/sec), the simple circulation model developed and tested predicts the data well.
    a) At a constant gas flow rate, an increase in solid flow rate will reduce the mixing of solids since solids spend less time within the vessel.
    b) Similarly, at a constant solid flow rate, an increase of gas flow rate will reduce the plug flow behavior of the vessel.
    c) The size of the dead volume is found to be negligible for almost all working conditions.
3. To start up an empty unit: turn on the gas, then pour in the solids. These will fill the bottom stage, then the ones above. To shut down, just let the solids pour out. Hardly any solids will be left behind in the unit. Thus the start-up and shut-down procedures for this column are easy to perform and do not require special devices with moving parts.
4. For low gas flow rates, the developed model is not a good representation of the experimental data. It is not clear in this preliminary study what could be the reasons behind this disagreement. One could speculate that one cause of disagreement may be found in the pressure drop difference. For the single-stage

unit a set of experiments were conducted just to show that the individual vessels, taken *one-by-one*, behave identically. It is proved, and we have no reasons to suspect any difference. But for the three-stage column, besides a possible interaction between the stages, merely a especulation, the actual total pressure is not the same for each stage.

5. A more general, and also probably more complex, circulation model could be developed. This model should include characteristics that allow prediction of all operating conditions such as zero and low spouting gas flow rates. For these situations, the present circulation model fails to represent the data properly. The reason behind this "failure" may be found on the assumption of *identical* stages for this column. Therefore, it can be speculated that a model coming from the convolution of Model 1, representing a single stage, with the assumption that all three stages are different, may produce better results than the model developed here.

6. Although we have not yet thoroughly documented this viewpoint, we believe that a pulsating valve should be used for feeding air to the L-valve. Visual observations show that a more uniform flow of solids is obtained when oscillating air pressure is used. This modification of the L-valve transforms it into a "*spitting valve*", which should be tested for further studies.

7. In order to have a better flow description of either the single-stage unit or the three-stage column, it would be convenient to obtain information on *gas* RTD.

8. The multistage, countercurrent, gas-solid spouted bed here presented, could be easily transformed in a cross-current multistage system. The various applications for this column become, in that case, even more interesting than the countercurent system, since different conditions could be easily achieved in each stage.

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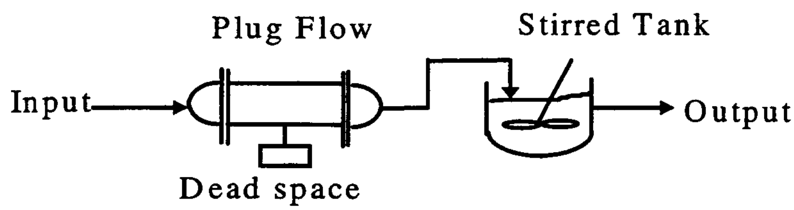
APPENDICES

APPENDIX A

DOCUMENTATION FOR SINGLE-STAGE UNIT MODEL



The mean residence time, τ, can be written as

$$\tau = \frac{W}{v} = \frac{W_p}{v} + \frac{W_M}{v} + \frac{W_d}{v} = \tau_p + \tau_M + \tau_d \tag{A1}$$

Since dead zone does not participate in the distribution of the tracer, one can write from a material balance of active vessel volume

$$v \cdot C_{out}(t) = v \cdot C_{in}(t) * E_1(t) * E_2(t) \tag{A2}$$

Taking Laplace transforms in both sides of equation (A2)

$$C_{out}(s) = C_{in}(s) \cdot E_1(s) \cdot E_2(s) \tag{A3}$$

or

$$\frac{C_{out}(s)}{C_{in}(s)} = E_1(s) \cdot E_2(s) \tag{A4}$$

In Laplace domain it can be shown that

$$E_1(s) = e^{-s\tau_p} \tag{A5}$$

similarly

$$E_2(s) = \frac{\frac{1}{\tau_M}}{s + \frac{1}{\tau_M}} \tag{A6}$$

Therefore, equation (A4) can be written as

$$\frac{C_{out}(s)}{C_{in}(s)} = \frac{1}{\tau_M} \frac{e^{-s\tau_p}}{s + \frac{1}{\tau_M}} \tag{A7}$$

Taking the inverse of the Laplace transform, we obtain the model equation

$$E(t) = \frac{C_{out}(t)}{C_{in}(t)} = \frac{1}{\tau_M} e^{-\frac{(t-\tau_p)}{\tau_M}} \tag{A8}$$

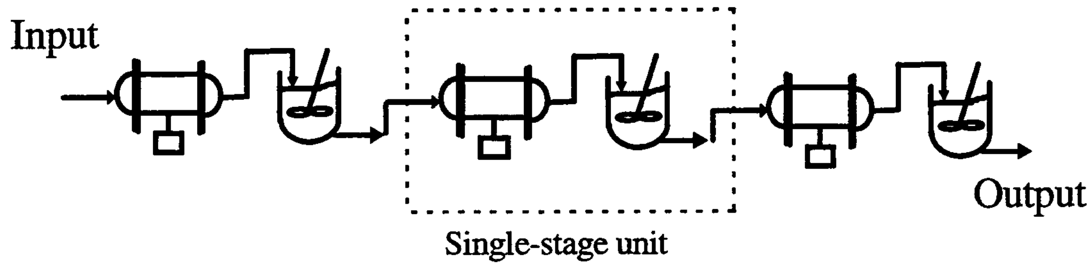
Equation (A1) reduces to

$$\tau = \tau_p + \tau_M \tag{A1'}$$

when there are not dead zones in the vessel. This is often the case when vigorous mixing is provided.

APPENDIX B

DOCUMENTATION FOR MULTISTAGE UNIT MODEL



For three-stage column

$$E(t) = E_1(t) * E_2(t) * E_3(t) \quad \text{(B1)}$$

where E(t) is the residence-time distribution of solids in the column, and $E_i(t)$ represent the residence-time distribution of solids in each single-stage unit.

From a material balance

$$v \cdot C_{out}(t) = v \cdot C_{in}(t) * E(t)$$

$$= v \cdot C_{in}(t) * E_1(t) * E_2(t) * E_3(t) \quad \text{(B2)}$$

Taking Laplace transforms in both sides of equation (B2)

$$C_{out}(s) = C_{in}(s) \cdot E_1(s) \cdot E_2(s) \cdot E_3(s)$$

or

$$\frac{C_{out}(s)}{C_{in}(s)} = E_1(s) \cdot E_2(s) \cdot E_3(s) \quad \text{(B3)}$$

where

$$E_1(s) = E_2(s) = E_3(s) = \frac{1}{\tau_M} \frac{e^{-s\tau_p}}{s + \frac{1}{\tau_M}} \tag{B4}$$

since we are assuming *identical* stages. Then,

$$\frac{C_{out}(s)}{C_{in}(s)} = \left(\frac{1}{\tau_{Mi}} \frac{e^{-s\tau_{Pi}}}{s + \frac{1}{\tau_{Mi}}} \right)^3$$

$$= \frac{1}{\tau_{Mi}^3} \frac{e^{-3s\tau_{Pi}}}{\left(s + \frac{1}{\tau_{Mi}}\right)^3} \tag{B5}$$

Taking the inverse of the Laplace transform, we obtain the residence-time distribution of solids for the entire column

$$E(t) = \frac{C_{out}(t)}{C_{in}(t)} = \frac{1}{2\tau_{Mi}^3}\left(t - 3\tau_{pi}\right)^2 \exp\left(-\left(t - 3\tau_{pi}\right)/\tau_{Mi}\right) \tag{B6}$$

Using equation (A1'), we finally obtain

$$E(t) = \frac{C_{out}(t)}{C_{in}(t)} = \frac{1}{2}\frac{\left(t - 3\tau_{pi}\right)^2}{\left(\tau_i - \tau_{pi}\right)^3} \exp\left(-\left(t - 3\tau_{pi}\right)/\left(\tau_i - \tau_{pi}\right)\right) \tag{B7}$$

APPENDIX C

OPTIMIZATION ROUTINE[1]

Newton's Method

The primary necessary condition for f(x) to have a local minimum is that f'(x) = 0. Consequently, we can solve the equation f'(x) = 0 by Newton's method to get

$$x^{k+1} = x^k - \frac{f'(x^k)}{f''(x^k)} \tag{C.1}$$

making sure on each k that $f(x^{k+1}) < f(x^k)$ for a minimum (see Figure C.1).

To see what Newton's method implies about f(x), suppose f(x) is approximated by a quadratic function at x^k

$$f(x) = f(x^k) + f'(x^k)(x - x^k) + \frac{1}{2} f''(x^k)(x - x^k)^2 \tag{C.2}$$

Find df(x)/dx = 0, a stationary point of the quadratic model of the function. The result by differentiating Equation (C.2) is

$$f'(x^k) + \left(\frac{1}{2}\right)(2) f''(x^k)(x - x^k) = 0 \tag{C.3}$$

which can be rearranged to yield Eq.(C.1). Consequently, Newton's method is equivalent to using a quadratic model for a function in minimization (or maximization) and applying the necessary conditions.

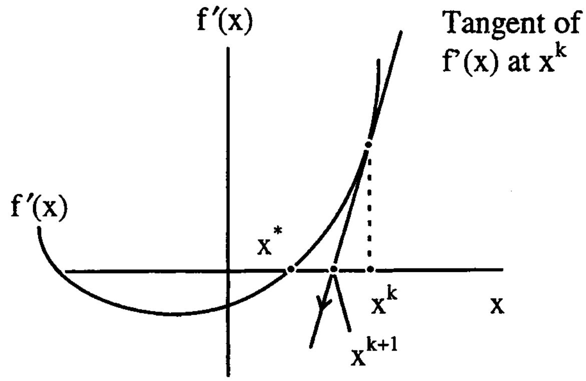


Figure C.1 Newton's method applied to solution of f'(x) = 0.

The advantages of Newton's method are:

1. The procedure is locally quadratically convergent to the extremum as long as f''(x) ≠ 0.
2. For a quadratic function, the minimum is obtained in one iteration.

The disadvantages of the method are:

1. We have to calculate both f'(x) and f''(x).
2. If f''(x) → 0, the method converges slowly.
3. If more than one extremum exist, the method may not converge to the desired estremum (the global one) and might oscillate.

Quasi-Newton's Method

A quasi-Newton method in general is one that imitates Newton's method. If f(x) is not given by a formula, or the formula is so complicated that analytical derivatives cannot be formulated, we can replace Eq.(C.1) with a finite difference approximation

$$x^{k+1} = x^k - \frac{[f(x+h)-f(x-h)]/2h}{[f(x+h)-2f(x)+f(x-h)]/h^2} \tag{C.4}$$

Central differences have been used in Eq.(C.4) but forward differences or any other difference scheme would suffice as long as the step size *h* is selected to match the difference formula and the computer (machine) precision for the computer on which the calculations are to be executed.

Other than selection of the value of *h*, the only additional disadvantage of the quasi-Newton method is that additional function evaluation are needed on each iteration *k* [three for formula (C.4) versus two for formula (C.1)].

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[1] Adapted from Edgar, T. F., and Himmelblau, D. M., "Optimization of Chemical Processes", McGraw-Hill, Inc., 1988.

APPENDIX D

EXPERIMENTAL DATA

Table D.1 Data Run# 1030

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	69.3	0.00	10	0	0.000000	0.00000	0.00000	0.0000	0.00
10	69.3	0.00	10	5	0.000000	0.00000	0.00000	0.0000	0.00
20	69.3	0.00	10	15	0.000000	0.00000	0.00000	0.0000	0.00
30	67.2	0.00	10	25	0.000000	0.00000	0.00000	0.0000	0.00
40	67.3	0.34	10	35	0.005053	0.00070	0.00700	0.0505	1.77
50	69.3	3.64	10	45	0.052495	0.00727	0.07272	0.5249	23.62
60	73.2	3.42	10	55	0.046731	0.00647	0.06474	0.4673	25.70
70	68.3	3.24	10	65	0.047445	0.00657	0.06573	0.4744	30.84
80	67.2	2.82	10	75	0.041964	0.00581	0.05813	0.4196	31.47
90	67.1	2.51	10	85	0.037401	0.00518	0.05181	0.3740	31.79
100	71.5	2.68	10	95	0.037503	0.00520	0.05195	0.3750	35.63
110	72.4	2.3	10	105	0.031786	0.00440	0.04403	0.3179	33.37
120	67.0	1.95	10	115	0.029087	0.00403	0.04030	0.2909	33.45
130	67.6	1.86	10	125	0.027535	0.00381	0.03815	0.2754	34.42
140	68.0	1.69	10	135	0.024860	0.00344	0.03444	0.2486	33.56
150	68.1	1.61	10	145	0.023656	0.00328	0.03277	0.2366	34.30
160	71.5	1.63	10	155	0.022813	0.00316	0.03160	0.2281	35.36
170	71.8	1.49	10	165	0.020758	0.00288	0.02876	0.2076	34.25
180	67.5	1.28	10	175	0.018957	0.00263	0.02626	0.1896	33.18
190	68.2	1.16	10	185	0.017004	0.00236	0.02356	0.1700	31.46
200	72.5	1.18	10	195	0.016267	0.00225	0.02253	0.1627	31.72
210	70.5	1.23	10	205	0.017458	0.00242	0.02418	0.1746	35.79
220	68.0	1.01	10	215	0.014859	0.00206	0.02059	0.1486	31.95
230	67.5	0.92	10	225	0.013634	0.00189	0.01889	0.1363	30.68
240	67.4	0.86	10	235	0.012769	0.00177	0.01769	0.1277	30.01
250	76.2	0.92	10	245	0.012072	0.00167	0.01672	0.1207	29.58
260	63.7	0.58	10	255	0.009099	0.00126	0.01261	0.0910	23.20
270	68.2	0.68	10	265	0.009972	0.00138	0.01381	0.0997	26.43
280	67.8	0.62	10	275	0.009140	0.00127	0.01266	0.0914	25.14
290	67.8	0.53	10	285	0.007818	0.00108	0.01083	0.0782	22.28
300	74.7	0.63	10	295	0.008434	0.00117	0.01168	0.0843	24.88
310	69.1	0.38	10	305	0.005502	0.00076	0.00762	0.0550	16.78
320	67.8	0.55	10	315	0.008113	0.00112	0.01124	0.0811	25.56
330	67.7	0.44	10	325	0.006504	0.00090	0.00901	0.0650	21.14
340	67.0	0.45	10	335	0.006712	0.00093	0.00930	0.0671	22.49
350	73.8	0.39	10	345	0.005287	0.00073	0.00732	0.0529	18.24
360	70.1	0.3	10	355	0.004278	0.00059	0.00593	0.0428	15.19
370	67.0	0.33	10	365	0.004924	0.00068	0.00682	0.0492	17.97
380	68.1	0.32	10	375	0.004696	0.00065	0.00651	0.0470	17.61
390	73.0	0.27	10	385	0.003700	0.00051	0.00513	0.0370	14.25
400	70.9	0.32	10	395	0.004514	0.00063	0.00625	0.0451	17.83
410	67.2	0.26	10	405	0.003871	0.00054	0.00536	0.0387	15.68
420	67.1	0.265	10	415	0.003952	0.00055	0.00547	0.0395	16.40
430	67.8	0.22	10	425	0.003247	0.00045	0.00450	0.0325	13.80
440	69.0	0.23	10	435	0.003331	0.00046	0.00462	0.0333	14.49
450	74.7	0.195	10	445	0.002610	0.00036	0.00362	0.0261	11.62
460	69.0	0.2	10	455	0.002897	0.00040	0.00401	0.0290	13.18
470	67.1	0.12	10	465	0.001788	0.00025	0.00248	0.0179	8.31
480	68.5	0.1	10	475	0.001460	0.00020	0.00202	0.0146	6.94
490	67.8	0.18	10	485	0.002654	0.00037	0.00368	0.0265	12.87
500	75.5	0.13	10	495	0.001722	0.00024	0.00239	0.0172	8.52
510	69.3	0.13	10	505	0.001876	0.00026	0.00260	0.0188	9.47
520	68.0	0.12	10	515	0.001766	0.00024	0.00245	0.0177	9.09
530	68.6	0.16	10	525	0.002333	0.00032	0.00323	0.0233	12.25

Run# 1030 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
540	75.0	0.10	10	535	0.001333	0.00018	0.00185	0.0133	7.13
550	67.5	0.06	10	545	0.000889	0.00012	0.00123	0.0089	4.85
560	68.1	0.06	10	555	0.000881	0.00012	0.00122	0.0088	4.89
570	73.3	0.04	10	565	0.000545	0.00008	0.00076	0.0055	3.08
580	68.5	0.03	10	575	0.000438	0.00006	0.00061	0.0044	2.52
590	69.2	0.07	10	585	0.001012	0.00014	0.00140	0.0101	5.92
600	67.9	0.05	10	595	0.000736	0.00010	0.00102	0.0074	4.38
610	67.6	0.05	10	605	0.000740	0.00010	0.00102	0.0074	4.47
620	66.8	0.04	10	615	0.000599	0.00008	0.00083	0.0060	3.68
630	73.9	0.06	10	625	0.000812	0.00011	0.00113	0.0081	5.08
640	69.5	0.04	10	635	0.000576	0.00008	0.00080	0.0058	3.66
650	66.8	0.04	10	645	0.000598	0.00008	0.00083	0.0060	3.86
660	66.6	0.02	10	655	0.000300	0.00004	0.00042	0.0030	1.97
670	67.7	0.04	10	665	0.000591	0.00008	0.00082	0.0059	3.93
680	75.0	0.05	10	675	0.000666	0.00009	0.00092	0.0067	4.50
690	66.3	0.02	10	685	0.000302	0.00004	0.00042	0.0030	2.07
700	68.1	0.03	10	695	0.000441	0.00006	0.00061	0.0044	3.06
710	68.4	0	10	705	0.000000	0.00000	0.00000	0.0000	0.00
720	73.2	0.03	10	715	0.000410	0.00006	0.00057	0.0041	2.93
730	68.9	0.02	10	725	0.000290	0.00004	0.00040	0.0029	2.11
740	68.3	0.02	10	735	0.000293	0.00004	0.00041	0.0029	2.15
750	67.2	0.04	10	745	0.000595	0.00008	0.00082	0.0060	4.44
760	67.6	0.01	10	755	0.000148	0.00002	0.00020	0.0015	1.12
770	75.8	0	10	765	0.000000	0.00000	0.00000	0.0000	0.00
780	67.8	0.02	10	775	0.000295	0.00004	0.00041	0.0030	2.29
790	67.1	0.04	10	785	0.000596	0.00008	0.00083	0.0060	4.68
800	68.0	0.04	10	795	0.000588	0.00008	0.00081	0.0059	4.68
810	67.9	0.01	10	805	0.000147	0.00002	0.00020	0.0015	1.19
820	74.7	0.01	10	815	0.000134	0.00002	0.00019	0.0013	1.09
830	68.6	0.01	10	825	0.000146	0.00002	0.00020	0.0015	1.20
840	67.9	0	10	835	0.000000	0.00000	0.00000	0.0000	0.00
850	68.5	0.02	10	845	0.000292	0.00004	0.00040	0.0029	2.47
860	72.4	0.01	10	855	0.000138	0.00002	0.00019	0.0014	1.18
870	72.0	0.01	10	865	0.000139	0.00002	0.00019	0.0014	1.20
880	66.7	0	10	875	0.000000	0.00000	0.00000	0.0000	0.00
890	67.0	0.01	10	885	0.000149	0.00002	0.00021	0.0015	1.32
900	67.2	0.02	10	895	0.000298	0.00004	0.00041	0.0030	2.66
910	73.9	0	10	905	0.000000	0.00000	0.00000	0.0000	0.00
920	69.0	0.01	10	915	0.000145	0.00002	0.00020	0.0014	1.33
930	66.6	0.01	10	925	0.000150	0.00002	0.00021	0.0015	1.39
940	67.4	0.01	10	935	0.000148	0.00002	0.00021	0.0015	1.39
950	70.0	0	10	945	0.000000	0.00000	0.00000	0.0000	0.00
960	73.1	0.01	10	955	0.000137	0.00002	0.00019	0.0014	1.31
970	68.2	0	10	965	0.000000	0.00000	0.00000	0.0000	0.00
980	66.8	0	10	975	0.000000	0.00000	0.00000	0.0000	0.00
990	68.5	0	10	985	0.000000	0.00000	0.00000	0.0000	0.00
1000	73.6	0	10	995	0.000000	0.00000	0.00000	0.0000	0.00
1010	68.9	0	10	1005	0.000000	0.00000	0.00000	0.0000	0.00
1020	68.5	0	10	1015	0.000000	0.00000	0.00000	0.0000	0.00
1030	67.5	0	10	1025	0.000000	0.00000	0.00000	0.0000	0.00
1040	69.0	0	10	1035	0.000000	0.00000	0.00000	0.0000	0.00
						ΣE(t)Δti =	0.9988		

So =	6.927	g/s
Bed weight =	1198.0	g
τ =	172.95	sec

τ_{obs}=	172.9	ΣCitiΔti =	1246.6
		ΣCiΔti =	7.21

Table D.2 Data Run #1031

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	58.8	0.00	10	0	0.00000	0.00000	0.00000	0.0000	0.00
20	58.8	0.00	10	10	0.00000	0.00000	0.00000	0.0000	0.00
30	58.8	0.00	10	25	0.00000	0.00000	0.00000	0.0000	0.00
40	57.1	0.00	10	35	0.00000	0.00000	0.00000	0.0000	0.00
50	65.9	4.61	10	45	0.06997	0.00823	0.08226	0.6997	31.48
60	57.5	9.13	10	55	0.15889	0.01868	0.18682	1.5889	87.39
70	58.1	4.30	10	65	0.07404	0.00870	0.08705	0.7404	48.12
80	58.0	2.69	10	75	0.04642	0.00546	0.05458	0.4642	34.81
90	64.6	2.19	10	85	0.03391	0.00399	0.03987	0.3391	28.82
100	57.2	1.56	10	95	0.02726	0.00321	0.03206	0.2726	25.90
110	56.7	1.15	10	105	0.02029	0.00239	0.02385	0.2029	21.30
120	58.6	1.28	10	115	0.02183	0.00257	0.02566	0.2183	25.10
130	60.3	1.15	10	125	0.01906	0.00224	0.02241	0.1906	23.82
140	62.4	1.16	10	135	0.01859	0.00219	0.02185	0.1859	25.09
150	58.3	0.98	10	145	0.01680	0.00198	0.01976	0.1680	24.36
160	64.2	0.88	10	155	0.01370	0.00161	0.01611	0.1370	21.24
170	51.8	0.81	10	165	0.01564	0.00184	0.01839	0.1564	25.81
180	57.4	0.87	10	175	0.01515	0.00178	0.01782	0.1515	26.52
190	63.2	0.74	10	185	0.01171	0.00138	0.01377	0.1171	21.67
200	57.9	0.56	10	195	0.00967	0.00114	0.01137	0.0967	18.86
210	57.5	0.62	10	205	0.01078	0.00127	0.01268	0.1078	22.10
220	57.1	0.59	10	215	0.01034	0.00122	0.01215	0.1034	22.22
230	62.5	0.66	10	225	0.01057	0.00124	0.01242	0.1057	23.78
240	53.5	0.58	10	235	0.01085	0.00128	0.01276	0.1085	25.49
250	58.1	0.71	10	245	0.01221	0.00144	0.01436	0.1221	29.92
260	58.8	0.62	10	255	0.01054	0.00124	0.01239	0.1054	26.87
270	63.3	0.63	10	265	0.00995	0.00117	0.01170	0.0995	26.38
280	58.7	0.52	10	275	0.00886	0.00104	0.01042	0.0886	24.36
290	58.8	0.48	10	285	0.00817	0.00096	0.00960	0.0817	23.27
300	57.7	0.44	10	295	0.00762	0.00090	0.00896	0.0762	22.49
310	60.3	0.45	10	305	0.00746	0.00088	0.00877	0.0746	22.75
320	61.2	0.4	10	315	0.00654	0.00077	0.00769	0.0654	20.61
330	57.1	0.29	10	325	0.00508	0.00060	0.00597	0.0508	16.50
340	57.5	0.37	10	335	0.00644	0.00076	0.00757	0.0644	21.57
350	57.5	0.32	10	345	0.00557	0.00065	0.00655	0.0557	19.21
360	58.4	0.47	10	355	0.00805	0.00095	0.00946	0.0805	28.56
370	60.8	0.46	10	365	0.00756	0.00089	0.00889	0.0756	27.60
380	58.2	0.31	10	375	0.00533	0.00063	0.00626	0.0533	19.97
390	62.9	0.33	10	385	0.00525	0.00062	0.00617	0.0525	20.20
400	53.4	0.34	10	395	0.00637	0.00075	0.00749	0.0637	25.17
410	59.0	0.33	10	405	0.00560	0.00066	0.00658	0.0560	22.67
420	58.2	0.22	10	415	0.00378	0.00044	0.00445	0.0378	15.70
430	57.9	0.24	10	425	0.00415	0.00049	0.00487	0.0415	17.62
440	56.8	0.25	10	435	0.00440	0.00052	0.00518	0.0440	19.15
450	57.9	0.23	10	445	0.00398	0.00047	0.00467	0.0398	17.69
460	65.6	0.25	10	455	0.00381	0.00045	0.00448	0.0381	17.34
470	55.7	0.195	10	465	0.00350	0.00041	0.00412	0.0350	16.29
480	57.1	0.22	10	475	0.00385	0.00045	0.00453	0.0385	18.29
490	61.0	0.18	10	485	0.00295	0.00035	0.00347	0.0295	14.31
500	58.6	0.205	10	495	0.00350	0.00041	0.00411	0.0350	17.32
510	58.4	0.16	10	505	0.00274	0.00032	0.00322	0.0274	13.83
520	55.0	0.14	10	515	0.00254	0.00030	0.00299	0.0254	13.104
530	57.3	0.16	10	525	0.00279	0.00033	0.00328	0.0279	14.66

Run #1031 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
540	59.3	0.18	10	535	0.00304	0.00036	0.00357	0.0304	16.25
550	63.4	0.16	10	545	0.00244	0.00029	0.00287	0.0244	13.32
560	58.4	0.14	10	555	0.00231	0.00027	0.00272	0.0231	12.82
570	53.1	0.15	10	565	0.00282	0.00033	0.00332	0.0282	15.95
580	63.4	0.12	10	575	0.00189	0.00022	0.00223	0.0189	10.89
590	58.9	0.16	10	585	0.00272	0.00032	0.00319	0.0272	15.89
600	57.8	0.09	10	595	0.00156	0.00018	0.00183	0.0156	9.27
610	57.8	0.10	10	605	0.00164	0.00019	0.00193	0.0164	9.95
620	57.7	0.08	10	615	0.00139	0.00016	0.00163	0.0139	8.52
630	64.1	0.12	10	625	0.00187	0.00022	0.00220	0.0187	11.71
640	58.6	0.07	10	635	0.00120	0.00014	0.00141	0.0120	7.59
650	57.8	0.10	10	645	0.00173	0.00020	0.00203	0.0173	11.16
660	55.8	0.11	10	655	0.00197	0.00023	0.00232	0.0197	12.92
670	59.3	0.09	10	665	0.00152	0.00018	0.00178	0.0152	10.09
680	60.8	0.07	10	675	0.00115	0.00014	0.00135	0.0115	7.77
690	58.2	0.07	10	685	0.00112	0.00013	0.00131	0.0112	7.65
700	56.7	0.09	10	695	0.00159	0.00019	0.00186	0.0159	11.02
710	58.7	0.08	10	705	0.00136	0.00016	0.00160	0.0136	9.61
720	64.7	0.10	10	715	0.00154	0.00018	0.00182	0.0154	11.05
730	58.3	0.06	10	725	0.00103	0.00012	0.00121	0.0103	7.47
740	56.3	0.03	10	735	0.00053	0.00006	0.00063	0.0053	3.92
750	58.6	0.14	10	745	0.00230	0.00027	0.00271	0.0230	17.15
760	58.1	0.04	10	755	0.00069	0.00008	0.00081	0.0069	5.20
770	63.4	0.07	10	765	0.00110	0.00013	0.00130	0.0110	8.45
780	57.2	0.04	10	775	0.00070	0.00008	0.00082	0.0070	5.42
790	56.9	0.05	10	785	0.00088	0.00010	0.00103	0.0088	6.90
800	60.8	0.07	10	795	0.00115	0.00014	0.00135	0.0115	9.16
810	59.5	0.03	10	805	0.00050	0.00006	0.00059	0.0050	4.06
820	58.1	0.05	10	815	0.00077	0.00009	0.00091	0.0077	6.31
830	58.4	0.05	10	825	0.00086	0.00010	0.00101	0.0086	7.07
840	58.4	0.05	10	835	0.00086	0.00010	0.00101	0.0086	7.14
850	60.2	0.08	10	845	0.00133	0.00016	0.00156	0.0133	11.23
860	59.5	0.04	10	855	0.00067	0.00008	0.00079	0.0067	5.75
870	57.8	0.02	10	865	0.00035	0.00004	0.00041	0.0035	3.00
880	57.9	0.02	10	875	0.00035	0.00004	0.00041	0.0035	3.03
890	51.6	0.03	10	885	0.00058	0.00007	0.00068	0.0058	5.15
900	62.1	0.05	10	895	0.00073	0.00009	0.00085	0.0073	6.49
910	58.1	0.02	10	905	0.00034	0.00004	0.00040	0.0034	3.12
920	57.2	0.04	10	915	0.00061	0.00007	0.00072	0.0061	5.60
930	58.2	0.01	10	925	0.00017	0.00002	0.00020	0.0017	1.59
940	63.7	0.04	10	935	0.00063	0.00007	0.00074	0.0063	5.87
950	59.5	0.03	10	945	0.00050	0.00006	0.00059	0.0050	4.76
960	57.7	0.03	10	955	0.00052	0.00006	0.00061	0.0052	4.97
970	53.7	0.01	10	965	0.00019	0.00002	0.00022	0.0019	1.80
980	63.9	0.02	10	975	0.00031	0.00004	0.00037	0.0031	3.05
990	58.2	0.02	10	985	0.00034	0.00004	0.00040	0.0034	3.38
1000	56.3	0.04	10	995	0.00071	0.00008	0.00084	0.0071	7.07
1010	56.7	0.01	10	1005	0.00018	0.00002	0.00021	0.0018	1.77
							ΣE(t)Δti =	0.99	

So =	5.88	g/s
Bed weight =	1200	g
τ =	204.08	sec

τ_{obs}=	185.6	ΣCitiΔti =	1556.6
		ΣCiΔti =	8.4

Table D.3 Data Run # 1032

Time(sec)	Total	Red	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	119.1	0.00	10	0	0.00000	0.00000	0.00000	0.0000	0.00
10	119.1	0.00	10	5	0.00000	0.00000	0.00000	0.0000	0.00
20	122.0	0.28	10	15	0.00230	0.00055	0.00547	0.3444	0.02
30	118.4	1.16	10	25	0.00979	0.00233	0.02333	2.4484	0.10
40	120.2	5.33	10	35	0.04433	0.01056	0.10561	15.5154	0.44
50	121.3	5.61	10	45	0.04625	0.01102	0.11019	20.8138	0.46
60	121.1	5.1	10	55	0.04213	0.01004	0.10037	23.1703	0.42
70	118.5	4.22	10	65	0.03562	0.00849	0.08486	23.1516	0.36
80	118.1	3.83	10	75	0.03242	0.00772	0.07725	24.3175	0.32
90	120.5	3.06	10	85	0.02539	0.00605	0.06049	21.5833	0.25
100	120.0	2.7	10	95	0.02250	0.00536	0.05360	21.3714	0.22
110	118.7	2.4	10	105	0.02022	0.00482	0.04817	21.2282	0.20
120	118.1	2.12	10	115	0.01796	0.00428	0.04278	20.6488	0.18
130	117.8	1.64	10	125	0.01392	0.00332	0.03317	17.4024	0.14
140	121.0	1.56	10	135	0.01289	0.00307	0.03071	17.3992	0.13
150	118.4	1.39	10	145	0.01174	0.00280	0.02796	17.0185	0.12
160	118.1	1.25	10	155	0.01059	0.00252	0.02522	16.4111	0.11
170	122.5	1.07	10	165	0.00873	0.00208	0.02081	14.4111	0.09
180	121.5	0.97	10	175	0.00798	0.00190	0.01902	13.9677	0.08
190	113.4	0.72	10	185	0.00635	0.00151	0.01512	11.7429	0.06
200	119.3	0.67	10	195	0.00562	0.00134	0.01338	10.9523	0.06
210	119.5	0.67	10	205	0.00561	0.00134	0.01336	11.4976	0.06
220	120.5	0.56	10	215	0.00465	0.00111	0.01108	9.9950	0.05
230	121.4	0.5	10	225	0.00412	0.00098	0.00981	9.2684	0.04
240	119.6	0.33	10	235	0.00276	0.00066	0.00658	6.4857	0.03
250	118.8	0.35	10	245	0.00295	0.00070	0.00702	7.2204	0.03
260	120.5	0.28	10	255	0.00232	0.00055	0.00554	5.9268	0.02
270	119.7	0.25	10	265	0.00209	0.00050	0.00497	5.5328	0.02
280	119.2	0.24	10	275	0.00201	0.00048	0.00480	5.5385	0.02
290	118.9	0.18	10	285	0.00151	0.00036	0.00361	4.3149	0.02
300	118.9	0.27	10	295	0.00227	0.00054	0.00541	6.7012	0.02
310	120.9	0.16	10	305	0.00132	0.00032	0.00315	4.0354	0.01
320	116.5	0.06	10	315	0.00051	0.00012	0.00123	1.6218	0.01
330	122.2	0.09	10	325	0.00074	0.00018	0.00175	2.3936	0.01
340	115.3	0.14	10	335	0.00121	0.00029	0.00289	4.0666	0.01
350	123.2	0.04	10	345	0.00032	0.00008	0.00077	1.1199	0.00
360	120.3	0.09	10	355	0.00075	0.00018	0.00178	2.6567	0.01
370	119.4	0.11	10	365	0.00092	0.00022	0.00219	3.3626	0.01
380	120.2	0.07	10	375	0.00058	0.00014	0.00139	2.1839	0.01
390	118.0	0.07	10	385	0.00059	0.00014	0.00141	2.2837	0.01
400	120.7	0.06	10	395	0.00050	0.00012	0.00118	1.9644	0.00
410	118.8	0.03	10	405	0.00025	0.00006	0.00060	1.0230	0.00
420	119.6	0.06	10	415	0.00050	0.00012	0.00120	2.0828	0.01
430	118.0	0.05	10	425	0.00042	0.00010	0.00101	1.8008	0.00
440	117.3	0.02	10	435	0.00017	0.00004	0.00041	0.7414	0.00
450	123.8	0.04	10	445	0.00032	0.00008	0.00077	1.4380	0.00
460	118.1	0.03	10	455	0.00025	0.00006	0.00061	1.1557	0.00
470	117.9	0	10	465	0.00000	0.00000	0.00000	0.0000	0.00
480	116.3	0.03	10	475	0.00026	0.00006	0.00061	1.2250	0.00
490	119.0	0.02	10	485	0.00017	0.00004	0.00040	0.8154	0.00
500	122.0	0	10	495	0.00000	0.00000	0.00000	0.0000	0.00
510	118.3	0	10	505	0.00000	0.00000	0.00000	0.0000	0.00
520	120.0	0.02	10	515	0.00017	0.00004	0.00040	0.8585	0.00
530	118.2	0.015	10	525	0.00013	0.00003	0.00030	0.6660	0.00

Run # 1032 (Cont..)

Time (sec)	Total	Red	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
540	120.1	0.00	10	535	0.00000	0.00000	0.00000	0.0000	0.00
550	119.5	0.00	10	545	0.00000	0.00000	0.00000	0.0000	0.00
560	119.4	0.00	10	555	0.00000	0.00000	0.00000	0.0000	0.00
570	115.2	0.00	10	565	0.00000	0.00000	0.00000	0.0000	0.00
580	120.6	0.00	10	575	0.00000	0.00000	0.00000	0.0000	0.00
590	117.1	0	10	585	0.00000	0.00000	0.00000	0.0000	0.00
600	118.7	0	10	595	0.00000	0.00000	0.00000	0.0000	0.00
610	117.2	0	10	605	0.00000	0.00000	0.00000	0.0000	0.00
620	120.1	0	10	615	0.00000	0.00000	0.00000	0.0000	0.00
630	114.4	0.01	10	625	0.00009	0.00002	0.00021	0.5464	0.00
640	119.7	0.05	10	635	0.00042	0.00010	0.00100	2.6522	0.00
650	114.4	0	10	645	0.00000	0.00000	0.00000	0.0000	0.00
660	117.0	0	10	655	0.00000	0.00000	0.00000	0.0000	0.00

ΣE(t)Δti = 0.9949

So =	11.91 g/s
Bed weight =	1218 g
τ =	102.30 sec

τ_{obs}=	102.3	ΣCitiΔti =	427.1
		ΣCiΔti =	4.18

Table D.4 Data Run#1033

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	48.38	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	48.38	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	48.38	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	48.37	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	44.73	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	47.68	0.00	10	40	0.00000	0.00000	0.00000	0.000	0.00
60	142.20	5.45	30	45	0.03833	0.00371	0.11131	1.150	51.74
70	45.78	2.00	10	55	0.04369	0.00423	0.04229	0.437	24.03
80	51.25	2.30	10	65	0.04488	0.00434	0.04345	0.449	29.17
90	47.72	2.03	10	75	0.04254	0.00412	0.04118	0.425	31.90
100	50.30	2.04	10	85	0.04056	0.00393	0.03926	0.406	34.47
110	50.90	2.01	10	95	0.03949	0.00382	0.03823	0.395	37.51
120	50.33	1.55	10	105	0.03080	0.00298	0.02981	0.308	32.34
130	45.57	1.52	10	115	0.03336	0.00323	0.03229	0.334	38.36
140	50.07	1.90	10	125	0.03795	0.00367	0.03674	0.379	47.43
150	50.68	1.50	10	135	0.02960	0.00287	0.02865	0.296	39.96
160	46.31	1.31	10	145	0.02829	0.00274	0.02739	0.283	41.02
170	51.72	1.40	10	155	0.02707	0.00262	0.02621	0.271	41.96
180	51.14	1.53	10	165	0.02992	0.00290	0.02896	0.299	49.36
190	46.62	1.09	10	175	0.02338	0.00226	0.02263	0.234	40.92
200	51.17	1.24	10	185	0.02423	0.00235	0.02346	0.242	44.83
210	51.05	1.14	10	195	0.02233	0.00216	0.02162	0.223	43.55
220	44.33	0.96	10	205	0.02166	0.00210	0.02096	0.217	44.39
230	50.72	1.03	10	215	0.02031	0.00197	0.01966	0.203	43.66
240	50.06	0.96	10	225	0.01918	0.00186	0.01857	0.192	43.15
250	43.44	0.76	10	235	0.01750	0.00169	0.01694	0.175	41.11
260	49.75	0.91	10	245	0.01829	0.00177	0.01771	0.183	44.81
270	46.70	0.80	10	255	0.01713	0.00166	0.01658	0.171	43.68
280	44.37	0.57	10	265	0.01285	0.00124	0.01244	0.128	34.04
290	49.53	0.62	10	275	0.01252	0.00121	0.01212	0.125	34.42
300	49.84	0.67	10	285	0.01344	0.00130	0.01301	0.134	38.31
310	47.55	0.65	10	295	0.01367	0.00132	0.01323	0.137	40.33
320	45.96	0.50	10	305	0.01088	0.00105	0.01053	0.109	33.18
330	50.08	0.56	10	315	0.01118	0.00108	0.01083	0.112	35.22
340	50.15	0.48	10	325	0.00957	0.00093	0.00927	0.096	31.11
350	43.56	0.42	10	335	0.00964	0.00093	0.00933	0.096	32.30
360	47.91	0.59	10	345	0.01231	0.00119	0.01192	0.123	42.49
370	49.40	0.38	10	355	0.00769	0.00074	0.00745	0.077	27.31
380	46.16	0.42	10	365	0.00910	0.00088	0.00881	0.091	33.21
390	46.59	0.38	10	375	0.00816	0.00079	0.00790	0.082	30.59
400	50.57	0.45	10	385	0.00890	0.00086	0.00861	0.089	34.26
410	49.78	0.44	10	395	0.00884	0.00086	0.00856	0.088	34.91
420	46.23	0.37	10	405	0.00800	0.00077	0.00775	0.080	32.41
430	53.14	0.32	10	415	0.00602	0.00058	0.00583	0.060	24.99
440	51.27	0.33	10	425	0.00644	0.00062	0.00623	0.064	27.36
450	49.05	0.31	10	435	0.00632	0.00061	0.00612	0.063	27.49
460	45.25	0.27	10	445	0.00597	0.00058	0.00578	0.060	26.55
470	51.80	0.37	10	455	0.00714	0.00069	0.00691	0.071	32.50
480	45.38	0.19	10	465	0.00419	0.00041	0.00405	0.042	19.47
490	51.50	0.28	10	475	0.00544	0.00053	0.00526	0.054	25.83
500	48.40	0.20	10	485	0.00413	0.00040	0.00400	0.041	20.04
510	47.35	0.19	10	495	0.00401	0.00039	0.00388	0.040	19.86
520	48.63	0.31	10	505	0.00637	0.00062	0.00617	0.064	32.19
530	51.08	0.23	10	515	0.00450	0.00044	0.00436	0.045	23.19
540	51.94	0.21	10	525	0.00404	0.00039	0.00391	0.040	21.23
550	45.64	0.18	10	535	0.00394	0.00038	0.00382	0.039	21.10
560	52.77	0.27	10	545	0.00512	0.00050	0.00495	0.051	27.89
570	50.91	0.18	10	555	0.00354	0.00034	0.00342	0.035	19.62
580	45.66	0.16	10	565	0.00350	0.00034	0.00339	0.035	19.80
590	49.04	0.20	10	575	0.00408	0.00039	0.00395	0.041	23.45
600	51.25	0.24	10	585	0.00468	0.00045	0.00453	0.047	27.40
610	45.53	0.15	10	595	0.00318	0.00031	0.00308	0.032	18.95
620	50.08	0.11	10	605	0.00220	0.00021	0.00213	0.022	13.29
630	51.97	0.12	10	615	0.00231	0.00022	0.00224	0.023	14.20
640	47.66	0.15	10	625	0.00315	0.00030	0.00305	0.031	19.67

Run#1033 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
650	47.78	0.17	10	635	0.00356	0.00034	0.00344	0.036	22.60
660	49.86	0.08	10	645	0.00160	0.00016	0.00155	0.016	10.35
670	49.42	0.10	10	655	0.00202	0.00020	0.00196	0.020	13.25
680	48.15	0.12	10	665	0.00249	0.00024	0.00241	0.025	16.57
690	51.39	0.07	10	675	0.00136	0.00013	0.00132	0.014	9.19
700	45.90	0.13	10	685	0.00283	0.00027	0.00274	0.028	19.40
710	52.60	0.08	10	695	0.00152	0.00015	0.00147	0.015	10.57
720	52.64	0.12	10	705	0.00228	0.00022	0.00221	0.023	16.07
730	46.00	0.14	10	715	0.00304	0.00029	0.00295	0.030	21.76
740	49.80	0.06	10	725	0.00120	0.00012	0.00117	0.012	8.73
750	48.11	0.04	10	735	0.00083	0.00008	0.00080	0.008	6.11
760	47.02	0.04	10	745	0.00085	0.00008	0.00082	0.009	6.34
770	49.43	0.07	10	755	0.00142	0.00014	0.00137	0.014	10.69
780	45.20	0.03	10	765	0.00066	0.00006	0.00064	0.007	5.08
790	46.40	0.03	10	775	0.00065	0.00006	0.00063	0.006	5.01
800	49.24	0.08	10	785	0.00162	0.00016	0.00157	0.016	12.75
810	48.35	0.02	10	795	0.00041	0.00004	0.00040	0.004	3.29
820	51.78	0.06	10	805	0.00116	0.00011	0.00112	0.012	9.33
830	45.71	0.01	10	815	0.00022	0.00002	0.00021	0.002	1.78
840	50.50	0.02	10	825	0.00040	0.00004	0.00038	0.004	3.27
850	46.02	0.03	10	835	0.00065	0.00006	0.00063	0.007	5.44
860	44.72	0.02	10	845	0.00045	0.00004	0.00043	0.004	3.78
870	52.20	0.03	10	855	0.00057	0.00006	0.00056	0.006	4.91
880	50.67	0.08	10	865	0.00158	0.00015	0.00153	0.016	13.66
890	46.70	0.02	10	875	0.00043	0.00004	0.00041	0.004	3.75
900	47.97	0.04	10	885	0.00083	0.00008	0.00081	0.008	7.38
910	48.22	0.01	10	895	0.00010	0.00001	0.00010	0.001	0.93
920	45.39	0.02	10	905	0.00044	0.00004	0.00043	0.004	3.99
930	44.00	0.03	10	915	0.00068	0.00007	0.00066	0.007	6.24
940	46.86	0.03	10	925	0.00064	0.00006	0.00062	0.006	5.92
950	47.54	0.01	10	935	0.00021	0.00002	0.00020	0.002	1.97
960	48.72	0.04	10	945	0.00082	0.00008	0.00079	0.008	7.76
970	49.50	0.02	10	955	0.00030	0.00003	0.00029	0.003	2.89
980	44.81	0.02	10	965	0.00045	0.00004	0.00043	0.004	4.31
990	49.54	0.02	10	975	0.00040	0.00004	0.00039	0.004	3.94
1000	51.25	0.01	10	985	0.00020	0.00002	0.00019	0.002	1.92
1010	47.57	0.02	10	995	0.00042	0.00004	0.00041	0.004	4.18
1020	43.45	0.02	10	1005	0.00046	0.00004	0.00045	0.005	4.63
1030	50.59	0.04	10	1015	0.00069	0.00007	0.00067	0.007	7.02
1040	47.98	0.01	10	1025	0.00010	0.00001	0.00010	0.001	1.07
1050	46.90	0.01	10	1035	0.00011	0.00001	0.00010	0.001	1.10
1060	51.24	0.01	10	1045	0.00010	0.00001	0.00009	0.001	1.02
1070	51.56	0.00	10	1055	0.00000	0.00000	0.00000	0.000	0.00
1080	46.81	0.01	10	1065	0.00011	0.00001	0.00010	0.001	1.14
1090	44.39	0.02	10	1075	0.00045	0.00004	0.00044	0.005	4.84
1100	46.68	0.01	10	1085	0.00021	0.00002	0.00021	0.002	2.32
1110	44.97	0.02	10	1095	0.00044	0.00004	0.00043	0.004	4.87
1120	50.49	0.01	10	1105	0.00020	0.00002	0.00019	0.002	2.19
1130	51.33	0.01	10	1115	0.00019	0.00002	0.00019	0.002	2.17
1140	44.45	0.01	10	1125	0.00022	0.00002	0.00022	0.002	2.53
1150	41.34	0.02	10	1135	0.00048	0.00005	0.00047	0.005	5.49
1160	50.67	0.02	10	1145	0.00039	0.00004	0.00038	0.004	4.52
1170	44.97	0.01	10	1155	0.00022	0.00002	0.00022	0.002	2.57
1180	51.97	0.00	10	1165	0.00000	0.00000	0.00000	0.000	0.00
1190	48.67	0.02	10	1175	0.00041	0.00004	0.00040	0.004	4.83
1200	46.43	0.01	10	1185	0.00022	0.00002	0.00021	0.002	2.55
1210	48.04	0.00	10	1195	0.00000	0.00000	0.00000	0.000	0.00
1220	49.93	0.01	10	1205	0.00020	0.00002	0.00019	0.002	2.41
1230	49.44	0.00	10	1215	0.00000	0.00000	0.00000	0.000	0.00
1240	41.00	0.00	10	1225	0.00000	0.00000	0.00000	0.000	0.00
1250	51.32	0.03	10	1235	0.00058	0.00006	0.00057	0.006	7.22

ΣE(t)Δti = **0.9964**

So =	**4.84**	g/s
Bed weight =	**1136**	g
τ =	**234.77**	sec

τ_{obs}=	220.5	ΣCitiΔti =	2269.1
		ΣCiΔti =	10.29

Table D.5 Data Run#1034

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	82.31	0.00	0	0	0.00000	0.00000	0.00000	0.000	0.00
10	82.31	0.08	10	5	0.00097	0.00016	0.00160	0.049	0.01
20	87.88	14.62	10	15	0.16636	0.02739	0.27386	24.954	1.66
30	87.93	10.92	10	25	0.12419	0.02044	0.20443	31.047	1.24
40	78.23	6.13	10	35	0.07835	0.01290	0.12898	27.424	0.78
50	81.91	4.48	10	45	0.05464	0.00899	0.08994	24.587	0.55
60	85.73	3.36	10	55	0.03914	0.00644	0.06443	21.525	0.39
70	86.42	3.00	10	65	0.03475	0.00572	0.05720	22.584	0.35
80	75.87	2.01	10	75	0.02655	0.00437	0.04370	19.911	0.27
90	81.93	1.39	10	85	0.01701	0.00280	0.02799	14.455	0.17
100	85.45	0.88	10	95	0.01033	0.00170	0.01700	9.812	0.10
110	86.02	0.63	10	105	0.00729	0.00120	0.01200	7.655	0.07
120	71.37	0.43	10	115	0.00602	0.00099	0.00992	6.929	0.06
130	85.57	0.35	10	125	0.00409	0.00067	0.00673	5.113	0.04
140	86.02	0.31	10	135	0.00360	0.00059	0.00593	4.865	0.04
150	84.56	0.25	10	145	0.00296	0.00049	0.00487	4.287	0.03
160	72.54	0.20	10	155	0.00276	0.00045	0.00454	4.274	0.03
170	84.21	0.22	10	165	0.00261	0.00043	0.00430	4.311	0.03
180	85.57	0.17	10	175	0.00199	0.00033	0.00327	3.477	0.02
190	85.64	0.12	10	185	0.00140	0.00023	0.00231	2.592	0.01
200	71.63	0.07	10	195	0.00098	0.00016	0.00161	1.906	0.01
210	85.28	0.09	10	205	0.00106	0.00017	0.00174	2.163	0.01
220	84.88	0.12	10	215	0.00141	0.00023	0.00233	3.040	0.01
230	83.30	0.09	10	225	0.00108	0.00018	0.00178	2.431	0.01
240	73.20	0.07	10	235	0.00096	0.00016	0.00157	2.247	0.01
250	85.31	0.01	10	245	0.00007	0.00001	0.00012	0.172	0.00
260	85.38	0.00	10	255	0.00000	0.00000	0.00000	0.000	0.00
270	79.26	0.00	10	265	0.00000	0.00000	0.00000	0.000	0.00
280	76.91	0.00	10	275	0.00000	0.00000	0.00000	0.000	0.00
290	85.20	0.00	10	285	0.00000	0.00000	0.00000	0.000	0.00
300	85.38	0.00	10	295	0.00000	0.00000	0.00000	0.000	0.00
310	82.06	0.00	10	305	0.00000	0.00000	0.00000	0.000	0.00
320	74.12	0.00	10	315	0.00000	0.00000	0.00000	0.000	0.00
330	85.96	0.00	10	325	0.00000	0.00000	0.00000	0.000	0.00
340	83.76	0.00	10	335	0.00000	0.00000	0.00000	0.000	0.00
350	83.96	0.00	10	345	0.00000	0.00000	0.00000	0.000	0.00

ΣE(t)Δti = 0.97

So =	**8.23**	g/s
Bed weight =	**977**	g
τ =	**118.76**	sec

τ_{obs}=	**42.6**	**ΣCitiΔti =**	**251.8**
		ΣCiΔti =	**5.91**

Table D.6 Data Run#1035

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	59.63	0.00	20	0	0.00000	0.00000	0.00000	0.00	0.00
10	59.63	0.00	20	5	0.00000	0.00000	0.00000	0.00	0.00
30	59.63	0.00	20	20	0.00000	0.00000	0.00000	0.00	0.00
50	59.63	0.00	20	40	0.00000	0.00000	0.00000	0.00	0.00
70	59.03	0.06	20	60	0.00102	0.00006	0.0012	0.02	1.22
90	63.78	5.89	20	80	0.09235	0.00551	0.1101	1.85	147.76
11	63.22	7.08	20	100	0.1119	0.00668	0.13355	2.24	223.98
130	60.13	3.63	20	120	0.06037	0.00360	0.07199	1.2	144.89
150	61.45	2.85	20	140	0.04638	0.00277	0.05531	0.93	129.86
170	61.98	1.76	20	160	0.02832	0.00169	0.03377	0.57	90.61
190	61.96	1.69	20	180	0.02728	0.00163	0.03253	0.55	98.19
210	61.42	1.64	20	200	0.02670	0.00159	0.03184	0.53	106.8
230	61.75	1.52	20	220	0.02462	0.00147	0.02935	0.49	108.3
250	61.60	1.36	20	240	0.02208	0.00132	0.02633	0.44	105.97
270	61.53	1.48	20	260	0.02405	0.00143	0.02868	0.48	125.08
290	60.50	1.32	20	280	0.02182	0.00130	0.02602	0.44	122.1
310	61.2	1.22	20	300	0.01993	0.0011	0.02377	0.40	119.5
330	58.38	0.99	20	320	0.01696	0.0010	0.02022	0.34	108.53
350	60.48	0.88	20	340	0.01455	0.00087	0.01735	0.29	98.94
370	62.08	0.97	20	360	0.01563	0.00093	0.01863	0.31	112.5
390	60.06	0.92	20	380	0.01523	0.00091	0.0181	0.30	115.7
410	54.1	0.81	20	400	0.01497	0.00089	0.01785	0.30	119.7
430	63.66	0.82	20	420	0.01288	0.00077	0.01536	0.26	108.20
450	56.59	0.69	20	440	0.0121	0.00073	0.01454	0.24	107.30
470	55.90	0.64	20	460	0.0114	0.00068	0.01365	0.23	105.33
490	47.53	0.60	20	480	0.01262	0.00075	0.01505	0.25	121.1
510	60.31	0.68	20	500	0.0112	0.00067	0.01345	0.23	112.7
530	59.57	0.60	20	520	0.01007	0.00060	0.0120	0.20	104.75
550	57.99	0.47	20	540	0.00810	0.00048	0.00967	0.16	87.53
570	60.29	0.45	20	560	0.00746	0.00045	0.00890	0.15	83.60
590	60.45	0.40	20	580	0.00662	0.00039	0.00789	0.13	76.76
610	57.95	0.48	20	600	0.00820	0.00049	0.00977	0.16	98.36
630	60.83	0.43	20	620	0.00707	0.00042	0.00843	0.14	87.65
650	59.95	0.51	20	640	0.00851	0.00051	0.0101	0.17	108.89
670	61.09	0.45	20	660	0.00737	0.00044	0.00878	0.15	97.23
690	60.67	0.38	20	680	0.00626	0.00037	0.00747	0.13	85.18
710	57.35	0.36	20	700	0.00628	0.00037	0.00749	0.13	87.88
730	60.41	0.33	20	720	0.00546	0.00033	0.00651	0.1	78.66
750	59.35	0.32	20	740	0.00539	0.00032	0.00643	0.1	79.80
770	60.07	0.35	20	760	0.00574	0.00034	0.00685	0.1	87.30
790	59.20	0.28	20	780	0.00473	0.00028	0.00564	0.09	73.78
810	58.51	0.17	20	800	0.00291	0.00017	0.00346	0.06	46.49
830	59.31	0.27	20	820	0.00455	0.00027	0.00543	0.09	74.66
850	59.35	0.23	20	840	0.00379	0.00023	0.00452	0.08	63.69
870	59.84	0.19	20	860	0.00318	0.00019	0.00379	0.06	54.61
890	59.62	0.15	20	880	0.00252	0.00015	0.00300	0.05	44.28
910	60.30	0.21	20	900	0.00348	0.00021	0.00415	0.07	62.69
930	59.74	0.20	20	920	0.00335	0.00020	0.00399	0.07	61.60
950	60.22	0.13	20	940	0.00216	0.00013	0.00257	0.04	40.58
970	58.1	0.15	20	960	0.00258	0.00015	0.00308	0.05	49.56
990	60.07	0.13	20	980	0.00216	0.00013	0.00258	0.04	42.42
101	59.74	0.1	20	1000	0.00184	0.0001	0.00220	0.04	36.83
1030	60.50	0.08	20	1020	0.00126	0.00007	0.00150	0.03	25.63
1050	59.45	0.12	20	1040	0.00202	0.00012	0.00241	0.04	41.98
1070	59.61	0.16	20	1060	0.00268	0.00016	0.00320	0.05	56.90
1090	59.33	0.13	20	1080	0.00219	0.00013	0.00261	0.04	47.33
111	59.48	0.12	20	110	0.00202	0.00012	0.00241	0.04	44.38
113	60.02	0.13	20	112	0.00217	0.00013	0.00258	0.04	48.52
115	59.32	0.16	20	114	0.00270	0.00016	0.00322	0.05	61.50
117	60.10	0.08	20	116	0.00125	0.00007	0.00149	0.02	28.95
119	59.91	0.1	20	118	0.00184	0.0001	0.00219	0.04	43.33
121	59.25	0.12	20	1200	0.00194	0.00012	0.00231	0.04	46.58
1230	60.09	0.05	20	1220	0.00083	0.00005	0.00099	0.02	20.30
1250	59.02	0.07	20	1240	0.0011	0.00007	0.0014	0.02	29.41

ΣE(t)Δti = 0.950

So =	2.98 g/s
Bed weight =	993 g
τ =	333.22 sec

τ_{obs}=	310.4	ΣCitiΔti =	4944.3
		ΣCiΔti =	15.93

Table D.7 Data Run#1036

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	204.3	0.0	10	0	0.00000	0.00000	0.00000	0.000	0.00
11	204.3	0.0	10	5.5	0.00000	0.00000	0.00000	0.000	0.00
24	262.8	25.3	13	17.5	0.09620	0.03928	0.51070	1.251	21.89
44	412.7	9.6	20	34	0.02328	0.00951	0.19016	0.466	15.83
54	203.7	2.8	10	49	0.01380	0.00563	0.05634	0.138	6.76
64	217.4	2.2	10	59	0.01003	0.00409	0.04094	0.100	5.92
74	209.6	1.9	10	69	0.00883	0.00360	0.03604	0.088	6.09
84	205.1	1.2	10	79	0.00600	0.00245	0.02449	0.060	4.74
94	204.3	1.2	10	89	0.00597	0.00244	0.02439	0.060	5.32
104	206.0	1.1	10	99	0.00539	0.00220	0.02201	0.054	5.34
114	204.6	0.8	10	109	0.00376	0.00154	0.01537	0.038	4.10
124	214.7	0.6	10	119	0.00293	0.00120	0.01198	0.029	3.49
134	205.4	0.5	10	129	0.00258	0.00105	0.01054	0.026	3.33
144	202.5	0.4	10	139	0.00217	0.00089	0.00887	0.022	3.02
154	211.2	0.3	10	149	0.00152	0.00062	0.00619	0.015	2.26
164	204.4	0.4	10	159	0.00181	0.00074	0.00739	0.018	2.88
174	204.4	0.2	10	169	0.00098	0.00040	0.00400	0.010	1.65
184	207.5	0.2	10	179	0.00101	0.00041	0.00413	0.010	1.81
194	209.1	0.2	10	189	0.00096	0.00039	0.00391	0.010	1.81
204	205.1	0.1	10	199	0.00068	0.00028	0.00279	0.007	1.36
214	201.7	0.2	10	209	0.00079	0.00032	0.00324	0.008	1.66
224	202.0	0.1	10	219	0.00069	0.00028	0.00283	0.007	1.52
234	201.0	0.1	10	229	0.00055	0.00022	0.00224	0.005	1.25
244	198.4	0.1	10	239	0.00030	0.00012	0.00124	0.003	0.72
254	206.1	0.1	10	249	0.00029	0.00012	0.00119	0.003	0.72
264	205.3	0.1	10	259	0.00029	0.00012	0.00119	0.003	0.76
274	203.0	0.0	10	269	0.00015	0.00006	0.00060	0.001	0.40
284	202.3	0.0	10	279	0.00015	0.00006	0.00061	0.001	0.41
294	198.6	0.1	10	289	0.00025	0.00010	0.00103	0.003	0.73
304	199.3	0.0	10	299	0.00015	0.00006	0.00061	0.002	0.45
314	198.2	0.0	10	309	0.00015	0.00006	0.00062	0.002	0.47
324	204.8	0.0	10	319	0.00020	0.00008	0.00080	0.002	0.62
334	203.8	0.0	10	329	0.00005	0.00002	0.00020	0.000	0.16
344	196.3	0.0	10	339	0.00015	0.00006	0.00062	0.002	0.52
354	201.5	0.0	10	349	0.00005	0.00002	0.00020	0.000	0.17
364	196.0	0.0	10	359	0.00005	0.00002	0.00021	0.001	0.18

ΣE(t)Δti = **0.998**

So =	**20.42**	g/s
Bed weight =	**1069**	g
τ =	**52.35**	sec

τ_{obs}=	**44.3**	**ΣCitiΔti =**	**108.3**
		ΣCiΔti =	**2.44**

Table D.8 Data Run# 1037

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	2.71	0.00	5	0	0.000000	0.00000	0.00000	0.0000	0.00
10	2.71	0.00	10	5	0.000000	0.00000	0.00000	0.0000	0.00
20	2.71	0.00	10	15	0.000000	0.00000	0.00000	0.0000	0.00
30	2.71	0.00	10	25	0.000000	0.00000	0.00000	0.0000	0.00
40	2.71	0.00	10	35	0.000000	0.00000	0.00000	0.0000	0.00
50	2.71	0.00	10	45	0.000000	0.00000	0.00000	0.0000	0.00
70	2.71	0.00	20	55	0.000000	0.00000	0.00000	0.0000	0.00
92	2.71	0.00	22	75	0.000000	0.00000	0.00000	0.0000	0.00
110	2.71	0.18	18	97	0.067796	0.00367	0.06548	0.0655	117.41
130	2.71	0.17	20	115	0.064207	0.00348	0.06960	0.0696	147.68
150	2.71	0.15	20	135	0.054428	0.00295	0.05900	0.0590	146.96
170	2.71	0.15	20	155	0.057011	0.00309	0.06180	0.0618	176.73
190	2.71	0.14	20	175	0.052399	0.00284	0.05680	0.0568	183.39
210	2.71	0.13	20	195	0.046125	0.00250	0.05000	0.0500	179.89
230	2.71	0.12	20	215	0.042989	0.00233	0.04660	0.0466	184.85
250	2.71	0.10	20	235	0.037269	0.00202	0.04040	0.0404	175.17
270	2.71	0.10	20	255	0.037269	0.00202	0.04040	0.0404	190.07
290	2.71	0.09	20	275	0.033210	0.00180	0.03600	0.0360	182.66
310	2.71	0.09	20	295	0.034133	0.00185	0.03700	0.0370	201.38
330	2.71	0.07	20	315	0.027491	0.00149	0.02980	0.0298	173.19
350	2.71	0.08	20	335	0.030074	0.00163	0.03260	0.0326	201.49
370	2.71	0.06	20	355	0.023247	0.00126	0.02520	0.0252	165.06
390	2.71	0.08	20	375	0.028044	0.00152	0.03040	0.0304	210.33
410	2.71	0.06	20	395	0.022878	0.00124	0.02480	0.0248	180.74
430	2.71	0.04	20	415	0.016052	0.00087	0.01740	0.0174	133.23
450	2.71	0.06	20	435	0.021218	0.00115	0.02300	0.0230	184.59
470	2.71	0.05	20	455	0.019188	0.00104	0.02080	0.0208	174.61
490	2.71	0.05	20	475	0.018450	0.00100	0.02000	0.0200	175.28
510	2.71	0.03	20	495	0.011993	0.00065	0.01300	0.0130	118.73
530	2.71	0.04	20	515	0.014945	0.00081	0.01620	0.0162	153.93
550	2.71	0.04	20	535	0.014022	0.00076	0.01520	0.0152	150.04
570	2.71	0.04	20	555	0.014022	0.00076	0.01520	0.0152	155.65
590	2.71	0.03	20	575	0.011993	0.00065	0.01300	0.0130	137.92
610	2.71	0.04	20	595	0.014945	0.00081	0.01620	0.0162	177.84
630	2.71	0.03	20	615	0.011439	0.00062	0.01240	0.0124	140.70
650	2.71	0.03	20	635	0.012362	0.00067	0.01340	0.0134	156.99
670	2.71	0.02	20	655	0.006827	0.00037	0.00740	0.0074	89.43
690	2.71	0.03	20	675	0.009779	0.00053	0.01060	0.0106	132.01
710	2.71	0.02	20	695	0.006273	0.00034	0.00680	0.0068	87.20
730	2.71	0.02	20	715	0.006827	0.00037	0.00740	0.0074	97.62
750	2.71	0.02	20	735	0.006827	0.00037	0.00740	0.0074	100.35
770	2.71	0.02	20	755	0.007196	0.00039	0.00780	0.0078	108.65
790	2.71	0.02	20	775	0.006273	0.00034	0.00680	0.0068	97.23
810	2.71	0.01	20	795	0.004059	0.00022	0.00440	0.0044	64.54
830	2.71	0.02	20	815	0.007196	0.00039	0.00780	0.0078	117.29
850	2.71	0.01	20	835	0.005166	0.00028	0.00560	0.0056	86.27
870	2.71	0.01	20	855	0.004059	0.00022	0.00440	0.0044	69.41
890	2.71	0.02	20	875	0.006273	0.00034	0.00680	0.0068	109.78
910	2.71	0.01	20	895	0.003690	0.00020	0.00400	0.0040	66.05
930	2.71	0.01	20	915	0.003137	0.00017	0.00340	0.0034	57.40
950	2.71	0.01	20	935	0.002030	0.00011	0.00220	0.0022	37.95
970	2.71	0.01	20	955	0.002583	0.00014	0.00280	0.0028	49.34
990	2.71	0.00	20	975	0.001476	0.00008	0.00160	0.0016	28.78

Run# 1037 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1010	2.7	0.01	20	995	0.004059	0.00022	0.00440	0.0812	80.77
1030	2.7	0.00	20	1015	0.000000	0.00000	0.00000	0.0000	0.00
1050	2.7	0.01	20	1035	0.003690	0.00020	0.00400	0.0738	76.38
1070	2.7	0.01	20	1055	0.003137	0.00017	0.00340	0.0627	66.18
1090	2.7	0.01	20	1075	0.002030	0.00011	0.00220	0.0406	43.63
1110	2.7	0.007	20	1095	0.002583	0.00014	0.00280	0.0517	56.57
1130	2.7	0.0055	20	1115	0.002030	0.00011	0.00220	0.0406	45.26
1150	2.7	0.0085874	20	1135	0.003169	0.00017	0.00343	0.0634	71.93
1170	2.7	0.01	20	1155	0.003690	0.00020	0.00400	0.0738	85.24
1190	2.7	0.0055	20	1175	0.002030	0.00011	0.00220	0.0406	47.69
1210	2.7	0.007	20	1195	0.002583	0.00014	0.00280	0.0517	61.73
1230	2.7	0.0031291	20	1215	0.001155	0.00006	0.00125	0.0231	28.06
1250	2.7	0.0024309	20	1235	0.000897	0.00005	0.00097	0.0179	22.16
1270	2.7	0.0018883	20	1255	0.000697	0.00004	0.00076	0.0139	17.49
1290	2.7	0.0014668	20	1275	0.000541	0.00003	0.00059	0.0108	13.80
1310	2.7	0.0011392	20	1295	0.000420	0.00002	0.00046	0.0084	10.89
1330	2.7	0.0008846	20	1315	0.000326	0.00002	0.00035	0.0065	8.59
1350	2.7	0.0006868	20	1335	0.000253	0.00001	0.00027	0.0051	6.77
1370	2.7	0.0005331	20	1355	0.000197	0.00001	0.00021	0.0039	5.33
1390	2.7	0.0004137	20	1375	0.000153	0.00001	0.00017	0.0031	4.20
1410	2.7	0.0003209	20	1395	0.000118	0.00001	0.00013	0.0024	3.30
1430	2.7	0.0002488	20	1415	0.000092	0.00000	0.00010	0.0018	2.60
1450	2.7	0.0001928	20	1435	0.000071	0.00000	0.00008	0.0014	2.04
1470	2.7	0.0001492	20	1455	0.000055	0.00000	0.00006	0.0011	1.60
1490	2.7	0.0001154	20	1475	0.000043	0.00000	0.00005	0.0009	1.26
						ΣE(t)Δti =	1.0		

So =	2.710	g/s
Bed weight =	969.89	g
τ =	357.89	sec

τ_{obs}=	357.9	ΣCitiΔti =	6839.3
		ΣCiΔti =	19.11

Table D.9 Data Run# 1038

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	169.90	0.00	10	0	0.000000	0.00000	0.00000	0.0000	0.00
10	169.90	0.00	10	5	0.000000	0.00000	0.00000	0.0000	0.00
30	169.90	0.00	20	20	0.000000	0.00000	0.00000	0.0000	0.00
40	169.90	0.00	10	35	0.000000	0.00000	0.00000	0.0000	0.00
50	169.90	0.00	10	45	0.000000	0.00000	0.00000	0.0000	0.00
60	169.85	7.43	10	55	0.043745	0.01486	0.14864	0.4374	14.44
70	167.63	5.88	10	65	0.034600	0.01176	0.11757	0.3460	14.88
80	169.58	5.17	10	75	0.030429	0.01034	0.10340	0.3043	16.13
90	166.67	4.49	10	85	0.026400	0.00897	0.08971	0.2640	16.63
100	168.32	3.43	10	95	0.020200	0.00686	0.06864	0.2020	14.75
110	169.37	3.00	10	105	0.017653	0.00600	0.05999	0.1765	14.65
120	169.80	2.50	10	115	0.014723	0.00500	0.05003	0.1472	13.69
130	169.39	2.09	10	125	0.012280	0.00417	0.04173	0.1228	12.65
140	169.89	1.58	10	135	0.009300	0.00316	0.03160	0.0930	10.51
150	169.75	1.45	10	145	0.008542	0.00290	0.02903	0.0854	10.51
160	169.33	1.27	10	155	0.007500	0.00255	0.02549	0.0750	9.98
170	169.70	1.12	10	165	0.006600	0.00224	0.02243	0.0660	9.44
180	169.51	0.84	10	175	0.004956	0.00168	0.01684	0.0496	7.58
190	170.00	0.85	10	185	0.005000	0.00170	0.01699	0.0500	8.15
200	171.16	0.59	10	195	0.003447	0.00117	0.01171	0.0345	5.96
210	170.59	0.58	10	205	0.003400	0.00116	0.01155	0.0340	6.22
220	168.75	0.27	10	215	0.001600	0.00054	0.00544	0.0160	3.09
230	169.98	0.34	10	225	0.002000	0.00068	0.00680	0.0200	4.06
240	167.87	0.28	10	235	0.001668	0.00057	0.00567	0.0167	3.55
250	166.67	0.31	10	245	0.001800	0.00061	0.00612	0.0180	4.01
260	172.44	0.20	10	255	0.001160	0.00039	0.00394	0.0116	2.70
270	167.09	0.16	10	265	0.000958	0.00033	0.00325	0.0096	2.33
280	172.49	0.14	10	275	0.000812	0.00028	0.00276	0.0081	2.05
290	163.40	0.11	10	285	0.000673	0.00023	0.00229	0.0067	1.77
300	162.76	0.09	10	295	0.000553	0.00019	0.00188	0.0055	1.51
310	171.02	0.08	10	305	0.000468	0.00016	0.00159	0.0047	1.32
						ΣE(t)Δti =	0.991		

So =	16.99 g/s
Bed weight =	1310.00 g
τ =	77.10 sec

τ_{obs} =	77.1	ΣCitiΔti =	200.8
		ΣCiΔti =	2.60

Table D.10 Data Run#1039

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	33.43	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
38	35.16	0.00	20	19	0.00000	0.00000	0.00000	0.000	0.00
58	35.05	0.01	20	48	0.00017	0.00001	0.0001	0.003	0.16
78	32.95	0.38	20	68	0.0115	0.00039	0.00771	0.231	15.68
98	33.04	1.23	20	88	0.03723	0.00124	0.02489	0.745	65.52
11	33.16	1.64	20	108	0.04946	0.00165	0.03307	0.989	106.83
138	33.46	1.50	20	128	0.04468	0.00149	0.02987	0.894	114.3
158	36.22	1.69	20	148	0.04666	0.00156	0.03120	0.933	138.1
178	34.03	1.4	20	168	0.04143	0.00139	0.02770	0.829	139.22
198	33.66	1.2	20	188	0.03595	0.00120	0.02403	0.719	135.1
218	33.49	1.1	20	208	0.03464	0.0011	0.02316	0.693	144.09
238	33.53	1.20	20	228	0.03564	0.0011	0.02383	0.713	162.52
258	33.38	1.1	20	248	0.03385	0.0011	0.02263	0.677	167.9
278	36.56	1.32	20	268	0.0361	0.0012	0.02414	0.722	193.52
298	33.99	1.1	20	288	0.03236	0.00108	0.02164	0.647	186.4
318	33.16	0.89	20	308	0.02684	0.00090	0.01794	0.537	165.33
338	32.97	1.26	20	328	0.03822	0.00128	0.02555	0.764	250.70
358	33.04	1.05	20	348	0.03178	0.00106	0.02125	0.636	221.1
378	33.00	0.97	20	368	0.02939	0.00098	0.01965	0.588	216.34
398	35.62	1.03	20	388	0.02892	0.00097	0.01933	0.578	224.39
418	32.38	1.02	20	408	0.03150	0.00105	0.02106	0.630	257.05
438	33.28	0.80	20	428	0.02389	0.00080	0.01597	0.478	204.48
458	33.36	0.94	20	448	0.02818	0.00094	0.01884	0.564	252.47
478	32.07	0.85	20	468	0.02650	0.00089	0.01772	0.530	248.08
498	32.63	0.78	20	488	0.02390	0.00080	0.01598	0.478	233.31
518	36.73	0.79	20	508	0.0215	0.00072	0.01438	0.430	218.52
538	33.01	0.82	20	528	0.02484	0.00083	0.0166	0.497	262.32
558	33.03	0.77	20	548	0.02331	0.00078	0.01559	0.466	255.50
578	32.51	0.61	20	568	0.0186	0.00062	0.01244	0.372	211.4
598	32.83	0.64	20	588	0.01949	0.00065	0.01303	0.390	229.25
618	32.73	0.71	20	608	0.02169	0.00073	0.01450	0.434	263.78
638	36.77	0.64	20	628	0.0174	0.00058	0.0116	0.348	218.6
658	33.04	0.57	20	648	0.01725	0.00058	0.0115	0.345	223.58
678	32.45	0.53	20	668	0.01633	0.00055	0.01092	0.327	218.2
698	32.68	0.51	20	688	0.0156	0.00052	0.01043	0.312	214.74
718	32.75	0.52	20	708	0.01588	0.00053	0.01062	0.318	224.83
738	32.88	0.55	20	728	0.01673	0.00056	0.0111	0.335	243.55
758	36.21	0.66	20	748	0.01823	0.00061	0.0121	0.365	272.68
778	32.50	0.54	20	768	0.01662	0.00056	0.0111	0.332	255.21
798	32.26	0.45	20	788	0.01395	0.00047	0.00933	0.279	219.84
818	33.03	0.53	20	808	0.01605	0.00054	0.01073	0.321	259.30
838	32.32	0.45	20	828	0.01392	0.00047	0.00931	0.278	230.57
858	33.04	0.44	20	848	0.0131	0.00044	0.00880	0.263	223.29
878	36.30	0.41	20	868	0.0112	0.00038	0.00755	0.226	196.08
898	32.00	0.49	20	888	0.0153	0.00051	0.01024	0.306	271.95
918	32.36	0.35	20	908	0.01082	0.00036	0.00723	0.216	196.42
938	32.43	0.36	20	928	0.0111	0.00037	0.00742	0.222	206.03
958	32.45	0.47	20	948	0.01448	0.00048	0.00968	0.290	274.61
978	32.31	0.36	20	968	0.0111	0.00037	0.00745	0.223	215.7
998	31.77	0.42	20	988	0.01322	0.00044	0.00884	0.264	261.23
101	36.77	0.37	20	1008	0.01006	0.00034	0.00673	0.201	202.86
1038	33.85	0.29	20	1028	0.00857	0.00029	0.00573	0.17	176.1
1058	32.63	0.28	20	1048	0.00858	0.00029	0.00574	0.172	179.86
1078	32.87	0.31	20	1068	0.00928	0.00031	0.00620	0.186	198.20
1098	32.91	0.28	20	1088	0.00851	0.00028	0.00569	0.170	185.1
111	34.08	0.30	20	110	0.00880	0.00029	0.00589	0.176	195.07
113	35.04	0.25	20	112	0.00713	0.00024	0.00477	0.143	160.96
115	31.8	0.22	20	114	0.00692	0.00023	0.00462	0.138	158.79
117	33.28	0.32	20	116	0.00962	0.00032	0.00643	0.192	224.62
119	33.17	0.28	20	118	0.00844	0.00028	0.00564	0.169	200.57
121	31.7	0.26	20	1208	0.00820	0.00027	0.00548	0.164	198.1
1238	36.14	0.26	20	1228	0.00719	0.00024	0.00481	0.144	176.69
1258	32.64	0.20	20	1248	0.00613	0.00020	0.00410	0.123	152.94
1278	32.86	0.26	20	1268	0.00791	0.00026	0.00529	0.158	200.66
1298	32.45	0.18	20	1288	0.00555	0.00019	0.00371	0.11	142.89
131	32.58	0.21	20	1308	0.00645	0.00022	0.00431	0.129	168.62
1338	32.84	0.15	20	1328	0.00457	0.00015	0.00305	0.091	121.3
1358	36.67	0.29	20	1348	0.00777	0.00026	0.00520	0.155	209.53

Run#1039 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1378	31.94	0.09	20	1368	0.00282	0.00009	0.00188	0.056	77.09
1398	31.98	0.21	20	1388	0.00657	0.00022	0.00439	0.131	182.29
1418	33.12	0.21	20	1408	0.00634	0.00021	0.00424	0.127	178.55
1438	32.39	0.18	20	1428	0.00556	0.00019	0.00372	0.111	158.72
1458	34.68	0.15	20	1448	0.00433	0.00014	0.00289	0.087	125.26
1478	33.13	0.19	20	1468	0.00573	0.00019	0.00383	0.115	168.38
1498	33.35	0.19	20	1488	0.00570	0.00019	0.00381	0.114	169.55
1518	32.79	0.18	20	1508	0.00549	0.00018	0.00367	0.110	165.56
1538	32.88	0.16	20	1528	0.00487	0.00016	0.00325	0.097	148.71
1558	32.67	0.24	20	1548	0.00735	0.00025	0.00491	0.147	227.44
1578	36.43	0.11	20	1568	0.00302	0.00010	0.00202	0.060	94.69
1598	33.18	0.11	20	1588	0.00332	0.00011	0.00222	0.066	105.29
1618	32.48	0.20	20	1608	0.00616	0.00021	0.00412	0.123	198.03
1638	32.93	0.13	20	1628	0.00395	0.00013	0.00264	0.079	128.54
1658	31.99	0.20	20	1648	0.00625	0.00021	0.00418	0.125	206.06
1678	32.72	0.16	20	1668	0.00489	0.00016	0.00327	0.098	163.13
1698	36.58	0.13	20	1688	0.00355	0.00012	0.00238	0.071	119.98
1718	33.01	0.09	20	1708	0.00273	0.00009	0.00182	0.055	93.14
1738	33.15	0.11	20	1728	0.00332	0.00011	0.00222	0.066	114.68
1758	32.59	0.17	20	1748	0.00522	0.00017	0.00349	0.104	182.36
1778	32.49	0.15	20	1768	0.00462	0.00015	0.00309	0.092	163.25
1798	36.34	0.10	20	1788	0.00275	0.00009	0.00184	0.055	98.40
1818	33.34	0.15	20	1808	0.00450	0.00015	0.00301	0.090	162.69
1838	33.14	0.11	20	1828	0.00332	0.00011	0.00222	0.066	121.35
1858	32.54	0.09	20	1848	0.00277	0.00009	0.00185	0.055	102.22
1878	33.47	0.11	20	1868	0.00314	0.00010	0.00210	0.063	117.20
1908	36.71	0.10	20	1893	0.00272	0.00009	0.00273	0.082	154.70
1928	33.29	0.09	20	1918	0.00270	0.00009	0.00181	0.054	103.71
1948	37.02	0.08	20	1938	0.00216	0.00007	0.00144	0.043	83.76
1968	33.21	0.10	20	1958	0.00301	0.00010	0.00201	0.060	117.92
1988	32.83	0.07	20	1978	0.00213	0.00007	0.00143	0.043	84.35
2008	33.14	0.05	20	1998	0.00151	0.00005	0.00101	0.030	60.29
2028	32.88	0.08	20	2018	0.00243	0.00008	0.00163	0.049	98.20
2048	34.37	0.07	20	2038	0.00189	0.00006	0.00126	0.038	77.08
2068	35.05	0.06	20	2058	0.00171	0.00006	0.00114	0.034	70.46
2088	33.30	0.07	20	2078	0.00210	0.00007	0.00141	0.042	87.36
2108	33.15	0.11	20	2098	0.00332	0.00011	0.00222	0.066	139.23
2128	32.86	0.07	20	2118	0.00213	0.00007	0.00142	0.043	90.24
2148	32.99	0.09	20	2138	0.00273	0.00009	0.00182	0.055	116.65
2168	34.42	0.06	20	2158	0.00174	0.00006	0.00117	0.035	75.24
2188	34.87	0.08	20	2178	0.00229	0.00008	0.00153	0.046	99.94
2208	33.09	0.03	20	2198	0.00076	0.00003	0.00051	0.015	33.21
2228	32.80	0.09	20	2218	0.00274	0.00009	0.00183	0.055	121.72
2248	33.39	0.07	20	2238	0.00210	0.00007	0.00140	0.042	93.84
2268	33.10	0.05	20	2258	0.00151	0.00005	0.00101	0.030	68.22
2288	32.93	0.09	20	2278	0.00258	0.00009	0.00173	0.052	117.60
2308	36.27	0.05	20	2298	0.00138	0.00005	0.00092	0.028	63.37
2328	32.89	0.02	20	2318	0.00046	0.00002	0.00030	0.009	21.14
2348	32.90	0.04	20	2338	0.00122	0.00004	0.00081	0.024	56.85
2368	32.67	0.05	20	2358	0.00153	0.00005	0.00102	0.031	72.18
2388	33.16	0.04	20	2378	0.00121	0.00004	0.00081	0.024	57.37
2408	32.88	0.01	20	2398	0.00030	0.00001	0.00020	0.006	14.59
2428	35.54	0.08	20	2418	0.00225	0.00008	0.00150	0.045	108.86
2448	32.26	0.04	20	2438	0.00124	0.00004	0.00083	0.025	60.46
2468	32.88	0.02	20	2458	0.00061	0.00002	0.00041	0.012	29.90
2488	32.30	0.04	20	2478	0.00124	0.00004	0.00083	0.025	61.37
2508	33.03	0.02	20	2498	0.00061	0.00002	0.00040	0.012	30.25
2528	35.70	0.03	20	2518	0.00084	0.00003	0.00056	0.017	42.32
2548	33.21	0.03	20	2538	0.00090	0.00003	0.00060	0.018	45.85
2578	51.13	0.05	30	2563	0.00098	0.00003	0.00098	0.029	50.13
2608	46.87	0.07	30	2593	0.00149	0.00005	0.00150	0.045	77.45
2638	51.03	0.04	30	2623	0.00078	0.00003	0.00079	0.024	41.12
2668	50.32	0.06	30	2653	0.00119	0.00004	0.00120	0.036	63.27
2698	47.48	0.05	30	2683	0.00105	0.00004	0.00106	0.032	56.51

Run#1039 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
2728	50.30	0.07	30	2713	0.00139	0.00005	0.00140	0.042	75.51
2758	50.18	0.07	30	2743	0.00130	0.00004	0.00130	0.039	71.06
2788	50.16	0.03	30	2773	0.00060	0.00002	0.00060	0.018	33.17
2818	47.31	0.04	30	2803	0.00085	0.00003	0.00085	0.025	47.40
2848	50.35	0.03	30	2833	0.00050	0.00002	0.00050	0.015	28.13
2878	51.50	0.03	30	2863	0.00058	0.00002	0.00058	0.017	33.36
2908	50.59	0.04	30	2893	0.00069	0.00002	0.00069	0.021	40.03
2938	50.10	0.06	30	2923	0.00120	0.00004	0.00120	0.036	70.01
2998	98.65	0.06	60	2968	0.00061	0.00002	0.00122	0.036	36.10
3058	101.35	0.05	60	3028	0.00049	0.00002	0.00099	0.030	29.88
3118	97.82	0.06	60	3088	0.00061	0.00002	0.00123	0.037	37.88
3178	101.44	0.05	60	3148	0.00049	0.00002	0.00099	0.030	31.03
3238	97.93	0.05	60	3208	0.00051	0.00002	0.00102	0.031	32.76
3298	101.75	0.05	60	3268	0.00049	0.00002	0.00099	0.029	32.12
3358	97.40	0.02	60	3328	0.00021	0.00001	0.00041	0.012	13.67
3418	101.99	0.03	60	3388	0.00025	0.00001	0.00049	0.015	16.61
3478	97.97	0.08	60	3448	0.00082	0.00003	0.00164	0.049	56.31
3538	101.13	0.04	60	3508	0.00040	0.00001	0.00079	0.024	27.75
3598	99.11	0.03	60	3568	0.00030	0.00001	0.00061	0.018	21.60
3658	101.82	0.02	60	3628	0.00015	0.00000	0.00030	0.009	10.69
3778	200.65	0.06	120	3718	0.00030	0.00001	0.00120	0.036	22.24
3898	199.58	0.04	120	3838	0.00020	0.00001	0.00080	0.024	15.38
4018	201.47	0.04	120	3958	0.00020	0.00001	0.00080	0.024	15.72
4138	201.40	0.02	120	4078	0.00010	0.00000	0.00040	0.012	8.10
4258	202.72	0.02	120	4198	0.00010	0.00000	0.00040	0.012	8.28
4378	202.33	0.03	120	4318	0.00015	0.00000	0.00059	0.018	12.80
4498	204.18	0.03	120	4438	0.00015	0.00000	0.00059	0.018	13.04
4618	202.19	0.02	120	4558	0.00010	0.00000	0.00040	0.012	9.02
4738	202.76	0.01	120	4678	0.00005	0.00000	0.00020	0.006	4.61

ΣE(t)Δti = 1.00

So =	**1.67**	g/s
Bed weight =	**1142**	g
τ =	**683.83**	sec

τ_{obs}=	**682.6**	**ΣCitiΔti =**	**20436.6**
		ΣCiΔti =	**29.94**

Table D.11 Data Run#1040

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	46.20	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
20	46.20	0.00	20	10	0.00000	0.00000	0.00000	0.000	0.00
40	46.20	0.00	20	30	0.00000	0.00000	0.00000	0.000	0.00
60	46.33	0.03	20	50	0.00065	0.00003	0.00060	0.013	0.65
80	46.43	0.64	20	70	0.01378	0.00064	0.01279	0.276	19.30
100	46.15	1.91	20	90	0.04139	0.00192	0.03839	0.828	74.50
120	46.11	1.98	20	110	0.04294	0.00199	0.03983	0.859	94.47
140	46.16	1.97	20	130	0.04268	0.00198	0.03959	0.854	110.96
160	45.75	1.91	20	150	0.04164	0.00193	0.03862	0.833	124.92
180	46.39	1.62	20	170	0.03493	0.00162	0.03239	0.699	118.75
200	45.97	1.75	20	190	0.03807	0.00177	0.03531	0.761	144.66
220	53.81	1.84	20	210	0.03419	0.00159	0.03172	0.684	143.62
240	39.17	1.29	20	230	0.03293	0.00153	0.03055	0.659	151.49
260	58.51	1.96	20	250	0.03350	0.00155	0.03107	0.670	167.49
280	48.09	1.39	20	270	0.02890	0.00134	0.02681	0.578	156.08
300	46.59	1.32	20	290	0.02833	0.00131	0.02628	0.567	164.33
320	46.01	1.33	20	310	0.02891	0.00134	0.02681	0.578	179.22
340	45.95	1.19	20	330	0.02590	0.00120	0.02402	0.518	170.92
360	46.78	1.13	20	350	0.02405	0.00112	0.02231	0.481	168.34
380	46.38	1.08	20	370	0.02329	0.00108	0.02160	0.466	172.32
400	46.21	0.99	20	390	0.02142	0.00099	0.01987	0.428	167.11
420	46.53	1.03	20	410	0.02214	0.00103	0.02053	0.443	181.52
440	46.37	0.89	20	430	0.01919	0.00089	0.01780	0.384	165.06
460	46.40	0.97	20	450	0.02091	0.00097	0.01939	0.418	188.15
480	45.87	0.75	20	470	0.01635	0.00076	0.01517	0.327	153.70
500	46.22	0.81	20	490	0.01752	0.00081	0.01626	0.350	171.74
520	45.89	0.69	20	510	0.01504	0.00070	0.01395	0.301	153.37
540	46.13	0.78	20	530	0.01691	0.00078	0.01568	0.338	179.23
560	46.22	0.68	20	550	0.01471	0.00068	0.01365	0.294	161.83
580	45.53	0.74	20	570	0.01625	0.00075	0.01508	0.325	185.28
600	45.82	0.67	20	590	0.01462	0.00068	0.01356	0.292	172.54
620	46.30	0.75	20	610	0.01620	0.00075	0.01503	0.324	197.62
640	45.44	0.74	20	630	0.01629	0.00076	0.01511	0.326	205.19
660	46.05	0.59	20	650	0.01281	0.00059	0.01188	0.256	166.56
680	46.06	0.67	20	670	0.01455	0.00067	0.01349	0.291	194.92
700	46.40	0.58	20	690	0.01250	0.00058	0.01159	0.250	172.50
720	45.77	0.50	20	710	0.01081	0.00050	0.01003	0.216	153.57
740	46.24	0.48	20	730	0.01027	0.00048	0.00953	0.205	149.98
760	46.55	0.46	20	750	0.00988	0.00046	0.00917	0.198	148.23
780	45.40	0.54	20	770	0.01189	0.00055	0.01103	0.238	183.17
800	45.97	0.44	20	790	0.00957	0.00044	0.00888	0.191	151.23
820	45.95	0.39	20	810	0.00849	0.00039	0.00787	0.170	137.51
840	45.75	0.50	20	830	0.01093	0.00051	0.01014	0.219	181.42
860	45.36	0.37	20	850	0.00816	0.00038	0.00757	0.163	138.67
880	45.78	0.43	20	870	0.00939	0.00044	0.00871	0.188	163.43
900	45.64	0.39	20	890	0.00855	0.00040	0.00793	0.171	152.10
920	45.83	0.37	20	910	0.00807	0.00037	0.00749	0.161	146.93
940	45.93	0.34	20	930	0.00740	0.00034	0.00687	0.148	137.69
960	46.23	0.37	20	950	0.00800	0.00037	0.00742	0.160	152.07
1000	91.77	0.63	40	980	0.00686	0.00032	0.01274	0.275	269.11
1040	104.91	0.69	40	1020	0.00658	0.00031	0.01220	0.263	268.34
1080	94.50	0.54	40	1060	0.00571	0.00027	0.01060	0.229	242.29
1120	91.94	0.44	40	1100	0.00479	0.00022	0.00888	0.191	210.57
1160	91.77	0.43	40	1140	0.00469	0.00022	0.00869	0.187	213.66

Run#1040 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
650	92.09	0.32	40	1180	0.00347	0.00016	0.00645	0.139	164.01
660	92.31	0.41	40	1220	0.00444	0.00021	0.00824	0.178	216.75
670	91.51	0.32	40	1260	0.00350	0.00016	0.00649	0.140	176.24
680	92.06	0.35	40	1300	0.00380	0.00018	0.00705	0.152	197.70
690	91.67	0.31	40	1340	0.00338	0.00016	0.00627	0.135	181.26
700	91.61	0.32	40	1380	0.00349	0.00016	0.00648	0.140	192.82
710	91.60	0.23	40	1420	0.00251	0.00012	0.00466	0.100	142.62
720	137.92	0.39	60	1470	0.00283	0.00013	0.00787	0.170	249.41
730	138.10	0.29	60	1530	0.00210	0.00010	0.00584	0.126	192.77
740	138.36	0.22	60	1590	0.00159	0.00007	0.00442	0.095	151.69
750	138.74	0.19	60	1650	0.00137	0.00006	0.00381	0.082	135.58
760	290.89	0.43	120	1740	0.00148	0.00007	0.00823	0.177	308.65
770	275.21	0.30	120	1860	0.00109	0.00005	0.00607	0.131	243.31
780	274.73	0.19	120	1980	0.00069	0.00003	0.00385	0.083	164.32
790	273.82	0.22	120	2100	0.00080	0.00004	0.00447	0.096	202.47
800	106.93	0.05	45	2183	0.00047	0.00002	0.00098	0.021	45.92

ΣE(t)Δti = 0.9836

So =	2.32	g/s
Bed weight =	1215	g
τ =	523.59	sec

τ_{obs}=	523.6	ΣCitiΔti =	11097.9
		ΣCiΔti =	21.19

Table D.12 Data Run#1041

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	28.40	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
20	28.40	0.00	20	10	0.00000	0.00000	0.00000	0.000	0.00
40	28.40	0.00	20	30	0.00000	0.00000	0.00000	0.000	0.00
60	57.98	0.29	20	50	0.00500	0.00028	0.00568	0.100	5.00
80	58.44	1.73	20	70	0.02960	0.00168	0.03362	0.592	41.44
100	58.52	2.46	20	90	0.04204	0.00239	0.04774	0.841	75.67
120	58.21	2.36	20	110	0.04054	0.00230	0.04604	0.811	89.19
140	58.69	2.36	20	130	0.04013	0.00228	0.04557	0.803	104.33
160	58.80	2.16	20	150	0.03673	0.00209	0.04172	0.735	110.20
180	58.67	2.14	20	170	0.03648	0.00207	0.04142	0.730	124.02
200	48.46	1.72	20	190	0.03549	0.00202	0.04031	0.710	134.87
220	48.45	1.64	20	210	0.03385	0.00192	0.03844	0.677	142.17
240	59.17	1.61	20	230	0.02721	0.00155	0.03090	0.544	125.16
260	58.60	1.61	20	250	0.02747	0.00156	0.03120	0.549	137.37
280	59.27	1.66	20	270	0.02801	0.00159	0.03181	0.560	151.24
300	59.96	1.53	20	290	0.02552	0.00145	0.02898	0.510	148.00
320	59.25	1.51	20	310	0.02549	0.00145	0.02894	0.510	158.01
340	59.02	1.26	20	330	0.02135	0.00121	0.02425	0.427	140.90
360	58.91	1.40	20	350	0.02377	0.00135	0.02699	0.475	166.36
380	59.21	1.20	20	370	0.02027	0.00115	0.02302	0.405	149.97
400	58.93	1.20	20	390	0.02036	0.00116	0.02313	0.407	158.83
420	59.28	0.95	20	410	0.01603	0.00091	0.01820	0.321	131.41
440	59.90	1.24	20	430	0.02070	0.00118	0.02351	0.414	178.03
460	59.73	0.94	20	450	0.01574	0.00089	0.01787	0.315	141.64
480	48.94	0.73	20	470	0.01492	0.00085	0.01694	0.298	140.21
500	49.09	0.73	20	490	0.01487	0.00084	0.01689	0.297	145.73
520	58.61	0.79	20	510	0.01348	0.00077	0.01531	0.270	137.49
540	59.04	0.65	20	530	0.01101	0.00063	0.01250	0.220	116.70
548	22.26	0.25	8	543.9	0.01123	0.00064	0.00500	0.088	47.88
568	52.04	0.60	20	557.8	0.01153	0.00065	0.01309	0.231	128.63
588	46.22	0.49	20	577.8	0.01060	0.00060	0.01204	0.212	122.52
608	59.26	0.61	20	597.8	0.01029	0.00058	0.01169	0.206	123.08
628	59.26	0.63	20	617.8	0.01063	0.00060	0.01207	0.213	131.37
648	59.55	0.67	20	637.8	0.01125	0.00064	0.01278	0.225	143.53
688	118.12	1.30	40	667.8	0.01101	0.00062	0.02500	0.440	294.00
728	117.93	1.08	40	707.8	0.00916	0.00052	0.02080	0.366	259.29
768	117.21	0.84	40	747.8	0.00717	0.00041	0.01628	0.287	214.38
808	117.57	0.87	40	787.8	0.00740	0.00042	0.01681	0.296	233.20
848	97.61	0.61	40	827.8	0.00625	0.00035	0.01419	0.250	206.94
888	117.74	0.73	40	867.8	0.00620	0.00035	0.01408	0.248	215.23
928	118.15	0.58	40	907.8	0.00491	0.00028	0.01115	0.196	178.26
968	117.40	0.41	40	947.8	0.00349	0.00020	0.00793	0.140	132.41
1008	116.84	0.33	40	987.8	0.00282	0.00016	0.00642	0.113	111.60
1068	176.01	0.61	60	1038	0.00347	0.00020	0.01181	0.208	215.81
1128	155.17	0.37	60	1098	0.00238	0.00014	0.00812	0.143	157.07
1188	174.88	0.52	60	1158	0.00297	0.00017	0.01013	0.178	206.57
1248	175.27	0.39	60	1218	0.00223	0.00013	0.00758	0.134	162.59
1308	177.27	0.38	60	1278	0.00214	0.00012	0.00730	0.129	164.35
1368	174.85	0.29	60	1338	0.00166	0.00009	0.00565	0.100	133.13
1428	156.72	0.23	60	1398	0.00147	0.00008	0.00500	0.088	123.09
1488	174.82	0.19	60	1458	0.00109	0.00006	0.00370	0.065	95.07
1548	173.34	0.16	60	1518	0.00092	0.00005	0.00314	0.055	84.06
1608	173.45	0.19	60	1578	0.00110	0.00006	0.00373	0.066	103.70
1668	174.27	0.15	60	1638	0.00086	0.00005	0.00293	0.052	84.58
1728	155.84	0.06	60	1698	0.00039	0.00002	0.00131	0.023	39.22
1788	175.04	0.05	60	1758	0.00029	0.00002	0.00097	0.017	30.13
1884	272.56	0.15	96	1836	0.00055	0.00003	0.00300	0.053	96.96

ΣE(t)Δti = **0.98**

So =	2.84 g/s
Bed weight =	1211 g
τ =	426.41 sec

τ_{obs}=	426.3	ΣCitiΔti =	7392.6
		ΣCiΔti =	17.34

Table D.13 Data Run#1042

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	18.62	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
5	18.62	0.00	10	2.5	0.00000	0.00000	0.00000	0.000	0.00
15	18.62	0.00	10	10	0.00000	0.00000	0.00000	0.000	0.00
25	18.62	0.00	10	20	0.00000	0.00000	0.00000	0.000	0.00
35	187.25	6.84	10	30	0.03651	0.01360	0.13596	0.365	10.95
45	186.61	7.92	10	40	0.04243	0.01580	0.15800	0.424	16.97
55	188.57	7.61	10	45	0.04033	0.01502	0.15019	0.403	18.15
65	184.35	6.02	10	60	0.03263	0.01215	0.12151	0.326	19.58
75	185.93	4.52	10	70	0.02431	0.00905	0.09053	0.243	17.02
85	186.21	3.64	10	80	0.01955	0.00728	0.07280	0.195	15.64
95	184.60	2.88	10	90	0.01560	0.00581	0.05810	0.156	14.04
105	184.51	2.29	10	100	0.01238	0.00461	0.04612	0.124	12.38
115	183.13	1.84	10	110	0.01002	0.00373	0.03732	0.100	11.02
125	185.67	1.44	10	120	0.00776	0.00289	0.02888	0.078	9.31
135	181.83	1.24	10	130	0.00682	0.00254	0.02540	0.068	8.87
145	187.72	1.00	10	140	0.00533	0.00198	0.01984	0.053	7.46
155	182.77	0.70	10	150	0.00383	0.00143	0.01426	0.038	5.74
165	186.24	0.53	10	160	0.00285	0.00106	0.01060	0.028	4.55
175	185.56	0.47	10	170	0.00253	0.00094	0.00943	0.025	4.31
185	182.00	0.47	10	180	0.00255	0.00095	0.00951	0.026	4.60
195	187.04	0.32	10	190	0.00171	0.00064	0.00637	0.017	3.25
205	185.55	0.21	10	200	0.00113	0.00042	0.00421	0.011	2.26
215	190.07	0.16	10	210	0.00084	0.00031	0.00313	0.008	1.77
225	183.53	0.12	10	220	0.00065	0.00024	0.00243	0.007	1.44
235	183.02	0.15	10	230	0.00082	0.00031	0.00305	0.008	1.89
245	185.42	0.11	10	240	0.00059	0.00022	0.00221	0.006	1.42
255	186.02	0.07	10	250	0.00038	0.00014	0.00140	0.004	0.94
265	184.70	0.08	10	260	0.00043	0.00016	0.00161	0.004	1.13
275	186.81	0.04	10	270	0.00021	0.00008	0.00080	0.002	0.58
285	186.21	0.05	10	280	0.00027	0.00010	0.00100	0.003	0.75
295	185.68	0.03	10	290	0.00016	0.00006	0.00060	0.002	0.47
305	187.94	0.04	10	300	0.00021	0.00008	0.00079	0.002	0.64
315	184.75	0.01	10	310	0.00005	0.00002	0.00020	0.001	0.17
325	189.18	0.00	10	320	0.00016	0.00006	0.00059	0.002	0.51

ΣE(t)Δti = 1.0

So =	18.62	g/s
Bed weight =	1357	g
τ =	73	sec

τ_{obs}=	72.9	ΣCitiΔti =	199.0
		ΣCiΔti =	2.73

Table D.14 Data Run#1043

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	53.45	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	53.45	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	53.45	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	52.45	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	53.61	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	54.30	0.61	10	45	0.01123	0.00120	0.01201	0.112	5.06
60	53.44	2.52	10	55	0.04716	0.00504	0.05040	0.472	25.94
70	53.68	2.37	10	65	0.04415	0.00472	0.04719	0.442	28.70
80	53.02	2.28	10	75	0.04300	0.00460	0.04596	0.430	32.25
90	55.94	2.44	10	85	0.04362	0.00466	0.04662	0.436	37.08
100	52.39	2.14	10	95	0.04085	0.00437	0.04366	0.408	38.81
110	52.66	1.96	10	105	0.03722	0.00398	0.03978	0.372	39.08
120	53.95	2.05	10	115	0.03800	0.00406	0.04062	0.380	43.70
130	54.14	1.92	10	125	0.03546	0.00379	0.03791	0.355	44.33
140	52.36	1.71	10	135	0.03266	0.00349	0.03491	0.327	44.09
150	55.06	1.88	10	145	0.03414	0.00365	0.03650	0.341	49.51
160	52.86	1.39	10	155	0.02630	0.00281	0.02811	0.263	40.76
170	53.35	1.40	10	165	0.02624	0.00280	0.02805	0.262	43.30
180	53.30	1.52	10	175	0.02852	0.00305	0.03048	0.285	49.91
190	53.83	1.34	10	185	0.02489	0.00266	0.02661	0.249	46.05
200	52.39	1.11	10	195	0.02119	0.00226	0.02265	0.212	41.32
210	55.33	1.32	10	205	0.02386	0.00255	0.02550	0.239	48.91
220	53.24	0.92	10	215	0.01728	0.00185	0.01847	0.173	37.15
230	52.40	0.95	10	225	0.01813	0.00194	0.01938	0.181	40.79
240	53.03	0.96	10	235	0.01810	0.00193	0.01935	0.181	42.54
250	51.52	0.92	10	245	0.01786	0.00191	0.01909	0.179	43.75
260	54.14	0.92	10	255	0.01699	0.00182	0.01816	0.170	43.33
270	53.76	0.80	10	265	0.01488	0.00159	0.01591	0.149	39.43
280	54.28	0.73	10	275	0.01345	0.00144	0.01438	0.134	36.98
290	54.80	0.75	10	285	0.01369	0.00146	0.01463	0.137	39.01
300	52.44	0.72	10	295	0.01373	0.00147	0.01468	0.137	40.50
310	54.28	0.65	10	305	0.01197	0.00128	0.01280	0.120	36.52
320	52.98	0.56	10	315	0.01057	0.00113	0.01130	0.106	33.30
330	53.58	0.60	10	325	0.01120	0.00120	0.01197	0.112	36.39
340	52.42	0.45	10	335	0.00858	0.00092	0.00918	0.086	28.76
350	53.78	0.53	10	345	0.00985	0.00105	0.01053	0.099	34.00
360	53.49	0.51	10	355	0.00953	0.00102	0.01019	0.095	33.85
370	53.19	0.54	10	365	0.01015	0.00109	0.01085	0.102	37.06
380	53.00	0.41	10	375	0.00774	0.00083	0.00827	0.077	29.01
390	53.18	0.46	10	385	0.00865	0.00092	0.00925	0.086	33.30
400	53.50	0.46	10	395	0.00860	0.00092	0.00919	0.086	33.96
410	53.27	0.32	10	405	0.00601	0.00064	0.00642	0.060	24.33
420	52.73	0.33	10	415	0.00626	0.00067	0.00669	0.063	25.97
440	107.10	0.69	20	430	0.00644	0.00069	0.01377	0.129	55.41
460	107.15	0.56	20	450	0.00523	0.00056	0.01117	0.105	47.04
480	106.20	0.48	20	470	0.00452	0.00048	0.00966	0.090	42.49
500	106.03	0.40	20	490	0.00377	0.00040	0.00806	0.075	36.97
520	104.65	0.42	20	510	0.00401	0.00043	0.00858	0.080	40.94
540	106.64	0.49	20	530	0.00459	0.00049	0.00982	0.092	48.71
560	108.95	0.35	20	550	0.00321	0.00034	0.00687	0.064	35.34
580	105.71	0.21	20	570	0.00199	0.00021	0.00425	0.040	22.65
600	107.86	0.35	20	590	0.00324	0.00035	0.00694	0.065	38.29
620	107.59	0.27	20	610	0.00251	0.00027	0.00536	0.050	30.62
640	107.49	0.22	20	630	0.00205	0.00022	0.00438	0.041	25.79

Run#1043 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
660	108.69	0.18	20	650	0.00166	0.00018	0.00354	0.033	21.53
680	105.86	0.17	20	670	0.00161	0.00017	0.00343	0.032	21.52
700	106.89	0.20	20	690	0.00187	0.00020	0.00400	0.037	25.82
720	107.73	0.18	20	710	0.00167	0.00018	0.00357	0.033	23.73
760	214.00	0.28	40	740	0.00131	0.00014	0.00559	0.052	38.73
800	215.06	0.23	40	780	0.00107	0.00011	0.00457	0.043	33.37
840	215.25	0.17	40	820	0.00079	0.00008	0.00338	0.032	25.90
880	214.71	0.14	40	860	0.00065	0.00007	0.00279	0.026	22.43
920	212.58	0.12	40	900	0.00056	0.00006	0.00241	0.023	20.32
960	211.80	0.10	40	940	0.00047	0.00005	0.00202	0.019	17.75
1000	214.80	0.08	40	980	0.00037	0.00004	0.00159	0.015	14.60
1040	213.14	0.05	40	1020	0.00023	0.00003	0.00100	0.009	9.57
1080	211.41	0.07	40	1060	0.00033	0.00004	0.00142	0.013	14.04
1120	214.06	0.06	40	1100	0.00028	0.00003	0.00120	0.011	12.33
1154.2	181.04	0.04	34	1137	0.00022	0.00002	0.00081	0.008	8.59

ΣE(t)Δti = 0.9700

So =	**5.344**	g/s
Bed weight =	**1227**	g
τ =	**229.57**	sec

τ_{obs}=	**229.6**	**ΣCitiΔti =**	**2143.2**
		ΣCiΔti =	**9.34**

Table D.15 Data Run#2000

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	21.1	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	21.1	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	21.1	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	21.1	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	21.1	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	21.1	0.00	10	45	0.00000	0.00000	0.00000	0.000	0.00
60	21.1	0.00	10	55	0.00000	0.00000	0.00000	0.000	0.00
70	21.1	0.00	10	65	0.00000	0.00000	0.00000	0.000	0.00
80	21.1	0.00	10	75	0.00000	0.00000	0.00000	0.000	0.00
90	21.1	0.00	10	85	0.00000	0.00000	0.00000	0.000	0.00
100	21.1	0.00	10	95	0.00000	0.00000	0.00000	0.000	0.00
11	21.1	0.00	10	105	0.00000	0.00000	0.00000	0.000	0.00
120	21.1	0.00	10	11	0.00000	0.00000	0.00000	0.000	0.00
130	21.1	0.00	10	125	0.00000	0.00000	0.00000	0.000	0.00
140	21.1	0.00	10	135	0.00000	0.00000	0.00000	0.000	0.00
150	21.1	0.00	10	145	0.00000	0.00000	0.00000	0.000	0.00
160	21.1	0.00	10	155	0.00000	0.00000	0.00000	0.000	0.00
170	21.1	0.00	10	165	0.00000	0.00000	0.00000	0.000	0.00
180	21.1	0.00	10	175	0.00000	0.00000	0.00000	0.000	0.00
190	21.08	0.00	10	185	0.00000	0.00000	0.00000	0.000	0.00
200	23.28	0.00	10	195	0.00000	0.00000	0.00000	0.000	0.00
210	23.88	0.00	10	205	0.00000	0.00000	0.00000	0.000	0.00
220	23.92	0.00	10	215	0.00000	0.00000	0.00000	0.000	0.00
230	21.1	0.00	10	225	0.00000	0.00000	0.00000	0.000	0.00
240	21.75	0.01	10	235	0.00046	0.00002	0.00020	0.005	1.08
250	21.69	0.00	10	245	0.00000	0.00000	0.00000	0.000	0.00
260	20.84	0.00	10	255	0.00000	0.00000	0.00000	0.000	0.00
270	21.04	0.00	10	265	0.00000	0.00000	0.00000	0.000	0.00
280	21.1	0.01	10	275	0.00047	0.00002	0.00020	0.005	1.30
300	42.34	0.01	20	290	0.00024	0.00001	0.00020	0.005	1.37
320	47.97	0.03	20	310	0.00063	0.00003	0.00054	0.013	3.88
340	40.97	0.03	20	330	0.00073	0.00003	0.00063	0.015	4.83
360	44.26	0.05	20	350	0.0011	0.00005	0.00097	0.023	7.91
380	41.32	0.06	20	370	0.00145	0.00006	0.00125	0.029	10.75
400	42.02	0.07	20	390	0.00167	0.00007	0.00144	0.033	12.99
420	42.05	0.12	20	410	0.00285	0.00012	0.00246	0.057	23.40
440	41.59	0.16	20	430	0.00385	0.00017	0.00331	0.077	33.08
460	48.57	0.12	20	450	0.00247	0.0001	0.00213	0.049	22.24
480	41.9	0.12	20	470	0.00286	0.00012	0.00247	0.057	26.91
500	40.86	0.18	20	490	0.00441	0.00019	0.00379	0.088	43.17
520	40.89	0.17	20	510	0.00416	0.00018	0.00358	0.083	42.41
540	41.80	0.19	20	530	0.00455	0.00020	0.00392	0.091	48.18
560	43.05	0.25	20	550	0.00581	0.00025	0.00500	0.11	63.88
580	46.66	0.33	20	570	0.00707	0.00030	0.00609	0.14	80.63
600	40.54	0.26	20	590	0.00641	0.00028	0.00552	0.128	75.68
620	41.84	0.29	20	610	0.00693	0.00030	0.00597	0.139	84.56
640	41.64	0.26	20	630	0.00624	0.00027	0.00538	0.125	78.67
660	41.36	0.23	20	650	0.00556	0.00024	0.00479	0.11	72.29
680	48.69	0.31	20	670	0.00637	0.00027	0.00548	0.127	85.32
700	41.58	0.31	20	690	0.00746	0.00032	0.00642	0.149	102.89
720	42.36	0.35	20	710	0.00826	0.00036	0.00712	0.165	117.3
740	37.74	0.29	20	730	0.00768	0.00033	0.00662	0.154	112.1
760	39.72	0.26	20	750	0.00655	0.00028	0.00564	0.13	98.19
780	42.06	0.28	20	770	0.00666	0.00029	0.00573	0.133	102.52
800	48.58	0.50	20	790	0.01029	0.00044	0.00887	0.206	162.62
820	41.99	0.35	20	810	0.00834	0.00036	0.00718	0.167	135.03
840	41.99	0.35	20	830	0.00834	0.00036	0.00718	0.167	138.37
860	41.55	0.42	20	850	0.0101	0.00044	0.00871	0.202	171.8
880	41.38	0.41	20	870	0.00991	0.00043	0.00854	0.198	172.40
900	37.16	0.32	20	890	0.00861	0.00037	0.00742	0.172	153.28
920	48.68	0.54	20	910	0.0110	0.00048	0.00956	0.222	201.89
940	42.29	0.41	20	930	0.00958	0.00041	0.00825	0.192	178.1
960	41.42	0.43	20	950	0.01038	0.00045	0.00894	0.208	197.25
980	41.48	0.36	20	970	0.00868	0.00037	0.00748	0.174	168.37
1000	42.47	0.29	20	990	0.00683	0.00029	0.00588	0.137	135.20
1020	37.96	0.37	20	101	0.00975	0.00042	0.00840	0.195	196.89
1040	45.17	0.43	20	1030	0.00952	0.00041	0.00820	0.190	196.1
1060	44.77	0.36	20	1050	0.00804	0.00035	0.00693	0.16	168.86

Run#2000 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1080	39.80	0.45	20	1070	0.01131	0.00049	0.00974	0.226	241.99
1100	41.33	0.34	20	1090	0.00811	0.00035	0.00698	0.162	176.70
1120	39.38	0.47	20	1110	0.01194	0.00051	0.01028	0.239	264.99
1140	38.51	0.36	20	1130	0.00935	0.00040	0.00805	0.187	211.27
1160	47.97	0.51	20	1150	0.01063	0.00046	0.00916	0.213	244.53
1180	42.02	0.48	20	1170	0.01142	0.00049	0.00984	0.228	267.30
1200	41.35	0.51	20	1190	0.01233	0.00053	0.01062	0.247	293.54
1220	41.01	0.43	20	1210	0.01049	0.00045	0.00903	0.210	253.74
1240	40.41	0.46	20	1230	0.01138	0.00049	0.00981	0.228	280.03
1260	41.24	0.51	20	1250	0.01237	0.00053	0.01065	0.247	309.17
1280	43.48	0.48	20	1270	0.01104	0.00048	0.00951	0.221	280.40
1300	45.02	0.45	20	1290	0.01000	0.00043	0.00861	0.200	257.89
1320	40.65	0.55	20	1310	0.01353	0.00058	0.01166	0.271	354.49
1340	40.88	0.48	20	1330	0.01174	0.00051	0.01011	0.235	312.33
1360	42.42	0.50	20	1350	0.01179	0.00051	0.01015	0.236	318.25
1380	41.05	0.45	20	1370	0.01096	0.00047	0.00944	0.219	300.37
1400	42.30	0.48	20	1390	0.01135	0.00049	0.00977	0.227	315.46
1420	47.05	0.45	20	1410	0.00956	0.00041	0.00824	0.191	269.71
1440	41.06	0.44	20	1430	0.01072	0.00046	0.00923	0.214	306.48
1460	41.58	0.46	20	1450	0.01106	0.00048	0.00953	0.221	320.83
1480	42.10	0.43	20	1470	0.01021	0.00044	0.00880	0.204	300.29
1500	40.68	0.47	20	1490	0.01155	0.00050	0.00995	0.231	344.30
1520	45.09	0.40	20	1510	0.00876	0.00038	0.00755	0.175	264.56
1540	41.84	0.38	20	1530	0.00908	0.00039	0.00782	0.182	277.92
1560	39.46	0.46	20	1550	0.01166	0.00050	0.01004	0.233	361.38
1590	60.65	0.55	30	1575	0.00907	0.00039	0.01172	0.272	428.48
1620	62.09	0.60	30	1605	0.00966	0.00042	0.01249	0.290	465.29
1650	66.42	0.64	30	1635	0.00964	0.00042	0.01245	0.289	472.63
1680	58.83	0.58	30	1665	0.00986	0.00042	0.01274	0.296	492.45
1710	60.36	0.45	30	1695	0.00746	0.00032	0.00963	0.224	379.10
1740	59.87	0.57	30	1725	0.00952	0.00041	0.01230	0.286	492.69
1770	65.98	0.64	30	1755	0.00970	0.00042	0.01253	0.291	510.70
1800	59.28	0.50	30	1785	0.00843	0.00036	0.01090	0.253	451.67
1830	58.96	0.40	30	1815	0.00678	0.00029	0.00877	0.204	369.40
1860	63.25	0.65	30	1845	0.01028	0.00044	0.01328	0.308	568.81
1890	60.03	0.52	30	1875	0.00858	0.00037	0.01109	0.257	482.57
1920	57.01	0.51	30	1905	0.00895	0.00039	0.01156	0.268	511.25
1950	58.83	0.52	30	1935	0.00884	0.00038	0.01142	0.265	513.11
1980	59.33	0.44	30	1965	0.00742	0.00032	0.00958	0.222	437.18
2040	120.66	0.97	60	2010	0.00804	0.00035	0.02078	0.482	969.52
2100	120.58	0.98	60	2070	0.00813	0.00035	0.02100	0.488	1009.42
2160	121.00	0.80	60	2130	0.00661	0.00028	0.01709	0.397	844.96
2220	118.77	0.84	60	2190	0.00707	0.00030	0.01828	0.424	929.33
2280	126.39	0.89	60	2250	0.00704	0.00030	0.01820	0.423	950.63
2340	121.80	0.72	60	2310	0.00591	0.00025	0.01528	0.355	819.31
2460	252.18	1.32	120	2400	0.00523	0.00023	0.02705	0.628	1507.49
2520	128.65	0.68	60	2490	0.00529	0.00023	0.01366	0.317	789.68
2580	125.96	0.67	60	2550	0.00532	0.00023	0.01375	0.319	813.83
2640	127.45	0.70	60	2610	0.00549	0.00024	0.01419	0.330	860.10
2700	124.69	0.70	60	2670	0.00561	0.00024	0.01451	0.337	899.35
2747	99.59	0.42	47	2724	0.00422	0.00018	0.00854	0.198	539.83
2807	125.24	0.53	60	2777	0.00423	0.00018	0.01094	0.254	705.11
2867	130.36	0.68	60	2837	0.00522	0.00022	0.01348	0.313	887.92
2927	137.15	0.54	60	2897	0.00394	0.00017	0.01017	0.236	684.38
2987	136.70	0.61	60	2957	0.00446	0.00019	0.01153	0.268	791.71
3047	121.82	0.38	60	3017	0.00312	0.00013	0.00806	0.187	564.67
3107	135.20	0.40	60	3077	0.00292	0.00013	0.00755	0.175	539.39
3167	129.83	0.49	60	3137	0.00377	0.00016	0.00975	0.226	710.37
3227	135.62	0.32	60	3197	0.00236	0.00010	0.00610	0.142	452.61
3287	130.90	0.36	60	3257	0.00275	0.00012	0.00711	0.165	537.44
3347	137.78	0.41	60	3317	0.00298	0.00013	0.00769	0.179	592.24
3407	130.55	0.36	60	3377	0.00276	0.00012	0.00713	0.165	558.74
3467	135.66	0.38	60	3437	0.00280	0.00012	0.00724	0.168	577.65
3527	128.70	0.22	60	3497	0.00171	0.00007	0.00442	0.103	358.67

Run#2000 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
3587	136.52	0.28	60	3557	0.00205	0.00009	0.00530	0.123	437.72
3647	128.17	0.20	60	3617	0.00156	0.00007	0.00403	0.094	338.64
3707	130.73	0.26	60	3677	0.00199	0.00009	0.00514	0.119	438.78
3767	126.54	0.20	60	3737	0.00158	0.00007	0.00408	0.095	354.39
3827	136.97	0.18	60	3797	0.00131	0.00006	0.00340	0.079	299.39
3887	127.25	0.20	60	3857	0.00157	0.00007	0.00406	0.094	363.72
3947	135.81	0.18	60	3917	0.00133	0.00006	0.00343	0.080	311.49
4007	125.09	0.14	60	3977	0.00112	0.00005	0.00289	0.067	267.06
4067	131.30	0.09	60	4037	0.00069	0.00003	0.00177	0.041	166.03
4127	121.37	0.10	60	4097	0.00082	0.00004	0.00213	0.049	202.54
4187	125.28	0.16	60	4157	0.00128	0.00006	0.00330	0.077	318.54

ΣE(t)Δti = 0.9600

So =	**2.11**	g/s
Bed weight =	**3785**	g
τ =	**1794**	sec

$$\tau_{obs} = 1793.6 \qquad \frac{\Sigma C_i t_i \Delta t_i = 39829.8}{\Sigma C_i \Delta t_i = 22.21}$$

Table D.16 Data Run#2001

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	20.70	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	20.70	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	20.70	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	20.70	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	20.70	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	20.70	0.00	10	45	0.00000	0.00000	0.00000	0.000	0.00
60	20.70	0.00	10	55	0.00000	0.00000	0.00000	0.000	0.00
70	20.70	0.00	10	65	0.00000	0.00000	0.00000	0.000	0.00
80	20.70	0.00	10	75	0.00000	0.00000	0.00000	0.000	0.00
90	20.70	0.00	10	85	0.00000	0.00000	0.00000	0.000	0.00
100	20.70	0.00	10	95	0.00000	0.00000	0.00000	0.000	0.00
11	20.70	0.00	10	105	0.00000	0.00000	0.00000	0.000	0.00
120	20.70	0.00	10	11	0.00000	0.00000	0.00000	0.000	0.00
130	20.70	0.00	10	125	0.00000	0.00000	0.00000	0.000	0.00
140	20.70	0.00	10	135	0.00000	0.00000	0.00000	0.000	0.00
150	20.70	0.00	10	145	0.00000	0.00000	0.00000	0.000	0.00
160	20.70	0.00	10	155	0.00000	0.00000	0.00000	0.000	0.00
170	20.70	0.00	10	165	0.00000	0.00000	0.00000	0.000	0.00
180	20.70	0.00	10	175	0.00000	0.00000	0.00000	0.000	0.00
190	22.74	0.00	10	185	0.00000	0.00000	0.00000	0.000	0.00
200	17.06	0.00	10	195	0.00000	0.00000	0.00000	0.000	0.00
210	23.73	0.00	10	205	0.00000	0.00000	0.00000	0.000	0.00
220	17.72	0.02	10	215	0.0011	0.00005	0.00047	0.01	2.43
230	24.14	0.09	10	225	0.00373	0.00015	0.00154	0.037	8.39
240	17.46	0.07	10	235	0.00401	0.00017	0.00166	0.040	9.42
260	40.38	0.15	20	250	0.00371	0.00015	0.00307	0.074	18.57
280	46.08	0.19	20	270	0.00412	0.00017	0.00341	0.082	22.27
300	41.02	0.34	20	290	0.00829	0.00034	0.00686	0.166	48.07
320	40.38	0.22	20	310	0.00545	0.00023	0.00451	0.109	33.78
340	40.61	0.37	20	330	0.0091	0.00038	0.00754	0.182	60.13
360	42.08	0.46	20	350	0.01093	0.00045	0.00904	0.219	76.52
380	40.54	0.45	20	370	0.0111	0.00046	0.00918	0.222	82.14
400	40.45	0.51	20	390	0.01248	0.00052	0.01033	0.250	97.38
420	41.54	0.49	20	410	0.0118	0.00049	0.00976	0.236	96.74
440	46.47	0.46	20	430	0.00990	0.00041	0.00819	0.198	85.13
460	40.60	0.46	20	450	0.0113	0.00047	0.00937	0.227	101.9
480	40.82	0.49	20	470	0.01200	0.00050	0.00993	0.240	112.8
500	41.96	0.43	20	490	0.01025	0.00042	0.00848	0.205	100.44
520	41.08	0.42	20	510	0.01022	0.00042	0.00846	0.204	104.28
540	40.69	0.63	20	530	0.01536	0.00064	0.0127	0.307	162.82
560	39.78	0.55	20	550	0.01383	0.00057	0.0114	0.277	152.09
580	41.0	0.47	20	570	0.0114	0.00047	0.00948	0.229	130.65
600	41.54	0.50	20	590	0.01204	0.00050	0.00996	0.241	142.03
620	46.20	0.54	20	610	0.0116	0.00048	0.00967	0.234	142.6
640	40.59	0.58	20	630	0.01429	0.00059	0.0118	0.286	180.04
660	42.47	0.56	20	650	0.0131	0.00055	0.0109	0.264	171.4
680	41.70	0.50	20	670	0.0119	0.00050	0.00992	0.240	160.67
700	40.51	0.58	20	690	0.0141	0.00059	0.0117	0.284	195.88
720	41.0	0.64	20	710	0.0156	0.00065	0.0129	0.312	221.60
740	39.95	0.57	20	730	0.01427	0.00059	0.0118	0.285	208.31
760	41.68	0.56	20	750	0.01344	0.00056	0.0111	0.269	201.54
780	43.05	0.68	20	770	0.01580	0.00065	0.01307	0.316	243.25
800	46.60	0.66	20	790	0.0141	0.00059	0.0117	0.283	223.78
820	41.39	0.59	20	810	0.01425	0.00059	0.0117	0.285	230.93
840	40.10	0.51	20	830	0.01272	0.00053	0.01052	0.254	211.1
860	41.25	0.63	20	850	0.01527	0.00063	0.01264	0.305	259.67
880	37.77	0.54	20	870	0.01430	0.00059	0.0118	0.286	248.77
900	40.62	0.61	20	890	0.01502	0.00062	0.01242	0.300	267.31
920	40.01	0.54	20	910	0.01350	0.00056	0.0111	0.270	245.64
940	46.41	0.60	20	930	0.01293	0.00053	0.01070	0.259	240.47
960	40.78	0.61	20	950	0.01496	0.00062	0.01238	0.299	284.21
980	40.60	0.48	20	970	0.0118	0.00049	0.00978	0.236	229.36
1000	40.58	0.46	20	990	0.0113	0.00047	0.00938	0.227	224.45
1020	41.29	0.57	20	101	0.01380	0.00057	0.0114	0.276	278.86
1040	41.25	0.56	20	1030	0.01358	0.00056	0.0112	0.272	279.66
1060	42.02	0.53	20	1050	0.0126	0.00052	0.01044	0.252	264.87
1080	40.69	0.52	20	1070	0.01278	0.00053	0.01057	0.256	273.48
110	43.75	0.63	20	1090	0.01440	0.00060	0.0119	0.288	313.92

Run#2001 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1120	46.61	0.56	20	1110	0.01201	0.00050	0.00994	0.240	266.72
1140	41.06	0.45	20	1130	0.01096	0.00045	0.00907	0.219	247.69
1160	40.86	0.57	20	1150	0.01395	0.00058	0.01154	0.279	320.85
1180	40.31	0.49	20	1170	0.01203	0.00050	0.00995	0.241	281.54
1200	41.48	0.54	20	1190	0.01302	0.00054	0.01077	0.260	309.84
1220	41.84	0.51	20	1210	0.01219	0.00050	0.01008	0.244	294.98
1240	41.34	0.47	20	1230	0.01137	0.00047	0.00941	0.227	279.68
1260	41.85	0.66	20	1250	0.01577	0.00065	0.01305	0.315	394.27
1280	46.62	0.53	20	1270	0.01137	0.00047	0.00941	0.227	288.76
1300	41.35	0.49	20	1290	0.01185	0.00049	0.00980	0.237	305.73
1320	41.89	0.41	20	1310	0.00979	0.00040	0.00810	0.196	256.43
1340	41.03	0.43	20	1330	0.01048	0.00043	0.00867	0.210	278.77
1360	40.95	0.49	20	1350	0.01197	0.00049	0.00990	0.239	323.08
1380	40.97	0.42	20	1370	0.01025	0.00042	0.00848	0.205	280.89
1400	41.27	0.51	20	1390	0.01236	0.00051	0.01022	0.247	343.54
1420	43.87	0.45	20	1410	0.01026	0.00042	0.00849	0.205	289.26
1440	45.07	0.37	20	1430	0.00821	0.00034	0.00679	0.164	234.79
1460	40.68	0.35	20	1450	0.00860	0.00036	0.00712	0.172	249.51
1480	40.81	0.39	20	1470	0.00956	0.00040	0.00791	0.191	280.96
1500	42.49	0.47	20	1490	0.01106	0.00046	0.00915	0.221	329.67
1530	63.06	0.60	30	1515	0.00951	0.00039	0.01181	0.285	432.45
1560	58.17	0.54	30	1545	0.00928	0.00038	0.01152	0.278	430.27
1590	63.85	0.48	30	1575	0.00752	0.00031	0.00933	0.226	355.21
1620	63.71	0.62	30	1605	0.00973	0.00040	0.01208	0.292	468.58
1650	62.04	0.53	30	1635	0.00854	0.00035	0.01060	0.256	419.03
1680	58.59	0.42	30	1665	0.00717	0.00030	0.00890	0.215	358.06
1710	64.63	0.57	30	1695	0.00882	0.00036	0.01094	0.265	448.47
1740	64.32	0.41	30	1725	0.00630	0.00026	0.00781	0.189	325.85
1770	58.83	0.52	30	1755	0.00884	0.00037	0.01097	0.265	465.37
1800	61.26	0.42	30	1785	0.00686	0.00028	0.00851	0.206	367.14
1830	64.80	0.47	30	1815	0.00725	0.00030	0.00900	0.218	394.93
1860	57.47	0.35	30	1845	0.00609	0.00025	0.00756	0.183	337.09
1890	64.20	0.49	30	1875	0.00763	0.00032	0.00947	0.229	429.32
1920	64.65	0.45	30	1905	0.00696	0.00029	0.00864	0.209	397.80
1950	59.60	0.37	30	1935	0.00621	0.00026	0.00770	0.186	360.38
1980	65.38	0.41	30	1965	0.00627	0.00026	0.00778	0.188	369.68
2040	123.67	0.70	60	2010	0.00562	0.00023	0.01395	0.337	677.75
2100	131.22	0.68	60	2070	0.00518	0.00021	0.01286	0.311	643.62
2160	125.53	0.60	60	2130	0.00478	0.00020	0.01186	0.287	610.85
2220	130.35	0.57	60	2190	0.00437	0.00018	0.01085	0.262	574.59
2280	123.78	0.52	60	2250	0.00420	0.00017	0.01043	0.252	567.14
2340	123.29	0.49	60	2310	0.00397	0.00016	0.00986	0.238	550.85
2400	128.54	0.44	60	2370	0.00342	0.00014	0.00850	0.205	486.76
2460	124.43	0.41	60	2430	0.00330	0.00014	0.00818	0.198	480.41
2520	122.57	0.43	60	2490	0.00351	0.00015	0.00871	0.210	524.12
2580	130.08	0.29	60	2550	0.00223	0.00009	0.00553	0.134	341.10
2640	124.92	0.29	60	2610	0.00232	0.00010	0.00576	0.139	363.54
2700	126.94	0.35	60	2670	0.00276	0.00011	0.00684	0.165	441.70
2760	125.87	0.30	60	2730	0.00238	0.00010	0.00592	0.143	390.40
2820	125.27	0.29	60	2790	0.00231	0.00010	0.00575	0.139	387.53
2880	133.34	0.29	60	2850	0.00217	0.00009	0.00540	0.130	371.91
2940	125.50	0.21	60	2910	0.00167	0.00007	0.00415	0.100	292.16
3000	125.59	0.17	60	2970	0.00131	0.00005	0.00326	0.079	234.12
3060	131.33	0.18	60	3030	0.00137	0.00006	0.00340	0.082	249.17
3120	122.09	0.15	60	3090	0.00123	0.00005	0.00305	0.074	227.78
3180	132.98	0.16	60	3150	0.00120	0.00005	0.00299	0.072	227.40
3240	125.81	0.10	60	3210	0.00079	0.00003	0.00197	0.048	153.09
3300	123.33	0.14	60	3270	0.00109	0.00005	0.00272	0.066	214.77
3360	129.85	0.13	60	3330	0.00100	0.00004	0.00248	0.060	200.03
3420	122.37	0.16	60	3390	0.00131	0.00005	0.00325	0.078	265.95
3480	125.54	0.12	60	3450	0.00096	0.00004	0.00237	0.057	197.87
3540	131.32	0.12	60	3510	0.00091	0.00004	0.00227	0.055	192.45
3600	125.09	0.08	60	3570	0.00060	0.00002	0.00149	0.036	128.43
3660	129.23	0.08	60	3630	0.00062	0.00003	0.00154	0.037	134.83

Run#2001 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
3720	124.75	0.05	60	3690	0.00040	0.00002	0.00099	0.024	88.74
3780	123.28	0.07	60	3750	0.00057	0.00002	0.00141	0.034	127.76
3840	128.06	0.09	60	3810	0.00070	0.00003	0.00174	0.042	160.66
3900	125.29	0.07	60	3870	0.00056	0.00002	0.00139	0.034	129.73
3954	129.26	0.05	54	3927	0.00039	0.00002	0.00086	0.021	82.03

$\Sigma E(t)\Delta ti$ = **0.9600**

So =	**2.068** g/s
Bed weight =	**3068** g
τ =	**1483.3** sec

τ_{obs}=	**1323**	$\Sigma Citi\Delta ti$ =	**30402.5**
		$\Sigma Ci\Delta ti$ =	**22.98**

Table D.17 Data Run#2002

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	18.90	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	18.90	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	18.90	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	18.90	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	18.90	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	18.90	0.00	10	45	0.00000	0.00000	0.00000	0.000	0.00
60	18.90	0.00	10	55	0.00000	0.00000	0.00000	0.000	0.00
70	18.90	0.00	10	65	0.00000	0.00000	0.00000	0.000	0.00
80	18.90	0.00	10	75	0.00000	0.00000	0.00000	0.000	0.00
90	18.90	0.00	10	85	0.00000	0.00000	0.00000	0.000	0.00
100	18.90	0.00	10	95	0.00000	0.00000	0.00000	0.000	0.00
11	18.90	0.00	10	105	0.00000	0.00000	0.00000	0.000	0.00
120	18.90	0.00	10	11	0.00000	0.00000	0.00000	0.000	0.00
130	18.90	0.00	10	125	0.00000	0.00000	0.00000	0.000	0.00
140	18.90	0.00	10	135	0.00000	0.00000	0.00000	0.000	0.00
150	18.90	0.00	10	145	0.00000	0.00000	0.00000	0.000	0.00
160	18.90	0.00	10	155	0.00000	0.00000	0.00000	0.000	0.00
170	18.90	0.00	10	165	0.00000	0.00000	0.00000	0.000	0.00
180	18.90	0.00	10	175	0.00000	0.00000	0.00000	0.000	0.00
190	18.90	0.00	10	185	0.00000	0.00000	0.00000	0.000	0.00
200	18.90	0.00	10	195	0.00000	0.00000	0.00000	0.000	0.00
210	17.1	0.00	10	205	0.00000	0.00000	0.00000	0.000	0.00
220	23.12	0.00	10	215	0.00000	0.00000	0.00000	0.000	0.00
230	16.90	0.00	10	225	0.00000	0.00000	0.00000	0.000	0.00
240	17.74	0.00	10	235	0.00000	0.00000	0.00000	0.000	0.00
250	22.53	0.00	10	245	0.00000	0.00000	0.00000	0.000	0.00
260	16.94	0.00	10	255	0.00000	0.00000	0.00000	0.000	0.00
270	17.53	0.00	10	265	0.00000	0.00000	0.00000	0.000	0.00
280	22.56	0.00	10	275	0.00000	0.00000	0.00000	0.000	0.00
290	17.29	0.00	10	285	0.00000	0.00000	0.00000	0.000	0.00
300	16.94	0.00	10	295	0.00000	0.00000	0.00000	0.000	0.00
310	23.82	0.00	10	305	0.00000	0.00000	0.00000	0.000	0.00
320	16.82	0.00	10	315	0.00000	0.00000	0.00000	0.000	0.00
330	21.32	0.01	10	325	0.00047	0.00002	0.00021	0.005	1.52
340	19.47	0.00	10	335	0.00000	0.00000	0.00000	0.000	0.00
350	17.1	0.00	10	345	0.00000	0.00000	0.00000	0.000	0.00
360	23.12	0.01	10	355	0.00043	0.00002	0.00020	0.004	1.54
370	17.27	0.00	10	365	0.00000	0.00000	0.00000	0.000	0.00
380	17.55	0.01	10	375	0.00057	0.00002	0.00026	0.006	2.14
390	23.75	0.01	10	385	0.00042	0.00002	0.00019	0.004	1.62
400	16.42	0.01	10	395	0.00061	0.00002	0.00027	0.006	2.41
410	13.95	0.00	10	405	0.00000	0.00000	0.00000	0.000	0.00
420	21.46	0.02	10	415	0.00093	0.00004	0.00042	0.009	3.87
430	17.23	0.02	10	425	0.0011	0.00004	0.00052	0.012	4.93
440	17.78	0.03	10	435	0.00169	0.00006	0.00076	0.017	7.34
450	22.64	0.03	10	445	0.00133	0.00005	0.00060	0.013	5.90
460	17.49	0.03	10	455	0.00172	0.00006	0.00077	0.017	7.80
470	17.1	0.03	10	465	0.00175	0.00007	0.00079	0.017	8.14
480	22.93	0.01	10	475	0.00044	0.00002	0.00020	0.004	2.07
490	16.24	0.03	10	485	0.00185	0.00007	0.00083	0.018	8.96
500	23.44	0.02	10	495	0.00085	0.00003	0.00039	0.009	4.22
510	17.30	0.04	10	505	0.00231	0.00009	0.00104	0.023	11.6
520	17.03	0.02	10	515	0.0011	0.00004	0.00053	0.012	6.05
530	22.36	0.06	10	525	0.00268	0.00010	0.0012	0.027	14.09
540	17.9	0.04	10	535	0.00223	0.00008	0.0010	0.022	11.9
550	17.06	0.04	10	545	0.00234	0.00009	0.00106	0.023	12.78
560	22.83	0.04	10	555	0.00175	0.00007	0.00079	0.018	9.72
570	17.1	0.04	10	565	0.00234	0.00009	0.00105	0.023	13.1
580	16.77	0.03	10	575	0.00179	0.00007	0.00081	0.018	10.29
590	22.57	0.13	10	585	0.00576	0.00022	0.00260	0.058	33.70
600	17.06	0.05	10	595	0.00293	0.0001	0.00132	0.029	17.44
610	16.95	0.07	10	605	0.00413	0.00016	0.00186	0.041	24.99
620	22.48	0.05	10	615	0.00222	0.00008	0.00100	0.022	13.68
630	17.59	0.04	10	625	0.00227	0.00009	0.00103	0.023	14.2
640	22.60	0.08	10	635	0.00354	0.00013	0.00160	0.035	22.48
650	16.8	0.07	10	645	0.00416	0.00016	0.00188	0.042	26.86
660	16.9	0.05	10	655	0.00296	0.0001	0.00133	0.030	19.37
670	22.30	0.08	10	665	0.00359	0.00014	0.00162	0.036	23.86

Run#2002 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
680	17.59	0.05	10	675	0.00284	0.00011	0.00128	0.028	19.19
690	17.26	0.09	10	685	0.00521	0.00020	0.00235	0.052	35.72
700	22.56	0.07	10	695	0.00310	0.00012	0.00140	0.031	21.56
710	16.10	0.09	10	705	0.00559	0.00021	0.00252	0.056	39.41
720	17.39	0.08	10	715	0.00460	0.00017	0.00208	0.046	32.89
730	22.35	0.08	10	725	0.00358	0.00014	0.00162	0.036	25.95
740	16.51	0.05	10	735	0.00303	0.00011	0.00137	0.030	22.27
750	16.98	0.05	10	745	0.00294	0.00011	0.00133	0.029	21.94
760	22.09	0.09	10	755	0.00407	0.00015	0.00184	0.041	30.76
770	16.75	0.07	10	765	0.00418	0.00016	0.00189	0.042	31.97
780	17.34	0.06	10	775	0.00346	0.00013	0.00156	0.035	26.82
800	39.02	0.23	20	790	0.00589	0.00022	0.00532	0.118	93.13
820	38.47	0.13	20	810	0.00325	0.00012	0.00293	0.065	52.64
840	38.34	0.15	20	830	0.00391	0.00015	0.00353	0.078	64.95
860	33.59	0.15	20	850	0.00447	0.00017	0.00403	0.089	75.92
880	39.55	0.18	20	870	0.00455	0.00017	0.00411	0.091	79.19
900	39.97	0.21	20	890	0.00525	0.00020	0.00474	0.105	93.53
920	33.60	0.14	20	910	0.00417	0.00016	0.00376	0.083	75.83
940	39.39	0.20	20	930	0.00508	0.00019	0.00458	0.102	94.45
960	39.63	0.21	20	950	0.00530	0.00020	0.00478	0.106	100.69
980	39.01	0.25	20	970	0.00641	0.00024	0.00578	0.128	124.33
1000	33.88	0.23	20	990	0.00664	0.00025	0.00599	0.133	131.49
1020	40.48	0.20	20	1010	0.00494	0.00019	0.00446	0.099	99.80
1040	39.82	0.30	20	1030	0.00753	0.00028	0.00680	0.151	155.22
1060	33.86	0.29	20	1050	0.00842	0.00032	0.00760	0.168	176.76
1080	39.52	0.24	20	1070	0.00607	0.00023	0.00548	0.121	129.96
1100	40.08	0.25	20	1090	0.00624	0.00024	0.00563	0.125	135.98
1120	39.55	0.28	20	1110	0.00708	0.00027	0.00639	0.142	157.17
1140	33.71	0.26	20	1130	0.00771	0.00029	0.00696	0.154	174.31
1160	39.66	0.28	20	1150	0.00706	0.00027	0.00637	0.141	162.38
1180	39.91	0.31	20	1170	0.00777	0.00029	0.00701	0.155	181.76
1200	33.65	0.29	20	1190	0.00862	0.00033	0.00778	0.172	205.11
1220	33.93	0.30	20	1210	0.00869	0.00033	0.00785	0.174	210.40
1240	40.74	0.31	20	1230	0.00761	0.00029	0.00687	0.152	187.19
1260	37.52	0.33	20	1250	0.00880	0.00033	0.00794	0.176	219.88
1280	36.22	0.27	20	1270	0.00745	0.00028	0.00673	0.149	189.34
1300	39.92	0.38	20	1290	0.00952	0.00036	0.00859	0.190	245.59
1320	40.63	0.30	20	1310	0.00738	0.00028	0.00666	0.148	193.48
1350	56.33	0.43	30	1335	0.00763	0.00029	0.01033	0.229	305.73
1380	56.92	0.44	30	1365	0.00773	0.00029	0.01046	0.232	316.55
1410	56.12	0.40	30	1395	0.00713	0.00027	0.00965	0.214	298.29
1440	56.73	0.54	30	1425	0.00952	0.00036	0.01289	0.286	406.93
1470	58.09	0.47	30	1455	0.00809	0.00031	0.01095	0.243	353.17
1500	57.15	0.42	30	1485	0.00735	0.00028	0.00995	0.220	327.40
1530	56.38	0.48	30	1515	0.00851	0.00032	0.01153	0.255	386.95
1560	55.84	0.49	30	1545	0.00878	0.00033	0.01188	0.263	406.72
1590	55.46	0.42	30	1575	0.00757	0.00029	0.01025	0.227	357.83
1620	55.90	0.50	30	1605	0.00894	0.00034	0.01211	0.268	430.68
1650	57.56	0.43	30	1635	0.00747	0.00028	0.01011	0.224	366.43
1680	56.77	0.38	30	1665	0.00669	0.00025	0.00906	0.201	334.35
1710	61.33	0.48	30	1695	0.00783	0.00030	0.01059	0.235	397.98
1740	55.76	0.48	30	1725	0.00861	0.00033	0.01165	0.258	445.48
1770	57.02	0.58	30	1755	0.01017	0.00038	0.01377	0.305	535.55
1800	56.15	0.60	30	1785	0.01060	0.00040	0.01434	0.318	567.45
1830	57.26	0.50	30	1815	0.00873	0.00033	0.01182	0.262	475.46
1860	55.98	0.48	30	1845	0.00857	0.00032	0.01161	0.257	474.60
1890	56.44	0.47	30	1875	0.00833	0.00031	0.01127	0.250	468.42
1920	56.82	0.48	30	1905	0.00845	0.00032	0.01144	0.253	482.83
1950	55.59	0.52	30	1935	0.00935	0.00035	0.01266	0.281	543.01
1980	55.84	0.41	30	1965	0.00734	0.00028	0.00994	0.220	432.83
2010	57.29	0.51	30	1995	0.00890	0.00034	0.01205	0.267	532.79
2040	54.57	0.50	30	2025	0.00907	0.00034	0.01228	0.272	551.06
2100	114.38	0.84	60	2070	0.00734	0.00028	0.01988	0.441	912.12
2160	110.25	0.89	60	2130	0.00807	0.00030	0.02186	0.484	1031.67

Run#2002 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
2220	119.03	1.10	60	2190	0.00924	0.00035	0.02502	0.554	1214.32
2280	114.38	0.92	60	2250	0.00804	0.00030	0.02178	0.483	1085.85
2340	115.75	0.91	60	2310	0.00786	0.00030	0.02129	0.472	1089.64
2460	224.88	1.71	120	2400	0.00760	0.00029	0.04117	0.912	2189.97
2580	224.22	1.72	120	2520	0.00767	0.00029	0.04154	0.921	2319.77
2700	231.19	1.49	120	2640	0.00642	0.00024	0.03478	0.771	2034.90
2820	226.20	1.57	120	2760	0.00694	0.00026	0.03758	0.833	2298.78
2940	225.95	1.26	120	2880	0.00558	0.00021	0.03020	0.669	1927.22
3060	228.62	1.26	120	3000	0.00551	0.00021	0.02984	0.661	1984.12
3180	229.26	1.20	120	3120	0.00523	0.00020	0.02834	0.628	1959.70
3300	227.25	1.10	120	3240	0.00484	0.00018	0.02621	0.581	1881.98
3420	228.55	1.15	120	3360	0.00503	0.00019	0.02725	0.604	2028.79
3540	235.37	1.07	120	3480	0.00455	0.00017	0.02462	0.546	1898.42
3660	229.47	0.86	120	3600	0.00375	0.00014	0.02029	0.450	1619.04
3780	224.04	0.84	120	3720	0.00375	0.00014	0.02030	0.450	1673.70
3900	226.95	0.76	120	3840	0.00335	0.00013	0.01813	0.402	1543.11
4020	234.13	0.76	120	3960	0.00325	0.00012	0.01758	0.390	1542.53
4140	125.93	0.42	120	4080	0.00330	0.00012	0.01784	0.395	1613.47

ΣE(t)Δti = 1.0000

So =	1.888 g/s
Bed weight =	4117.0 g
τ =	2180.1 sec

τ_{obs}=	2180	ΣCitiΔti =	48515.3
		ΣCiΔti =	22.25

Table D.18 Data Run#2003

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	174.30	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	174.30	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	174.30	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	174.30	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	174.30	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	171.8	0.06	10	45	0.00035	0.00012	0.00123	0.003	0.16
70	179.45	0.29	10	60	0.00162	0.00057	0.00568	0.016	0.97
80	174.98	0.76	10	75	0.00434	0.00153	0.01527	0.043	3.26
90	173.05	1.54	10	85	0.00887	0.00312	0.0311	0.089	7.54
100	175.57	1.90	10	95	0.01082	0.00380	0.03804	0.108	10.28
11	178.26	2.10	10	105	0.0117	0.00413	0.0413	0.11	12.34
120	175.00	2.36	10	11	0.01349	0.00474	0.04740	0.135	15.5
130	171.0	2.47	10	125	0.01444	0.00508	0.05075	0.144	18.05
140	176.35	2.70	10	135	0.0153	0.00538	0.05382	0.153	20.67
150	177.39	2.85	10	145	0.01604	0.00564	0.05637	0.160	23.26
160	170.48	2.87	10	155	0.0168	0.00591	0.05907	0.168	26.05
170	173.1	2.49	10	165	0.01435	0.00504	0.05044	0.143	23.68
180	173.79	2.61	10	175	0.01502	0.00528	0.05279	0.150	26.28
190	169.64	2.31	10	185	0.01362	0.00479	0.04786	0.136	25.19
200	170.94	2.39	10	195	0.01398	0.00491	0.04915	0.140	27.26
210	177.20	1.98	10	205	0.0111	0.00393	0.03928	0.11	22.91
220	176.24	2.14	10	215	0.0121	0.00427	0.04268	0.12	26.1
230	173.65	1.84	10	225	0.01060	0.00372	0.03725	0.106	23.84
240	169.62	1.56	10	235	0.00920	0.00323	0.03233	0.092	21.6
250	176.35	1.46	10	245	0.00828	0.00291	0.02910	0.083	20.28
260	167.8	1.30	10	255	0.00775	0.00272	0.02723	0.077	19.75
270	179.39	1.23	10	265	0.00686	0.00241	0.02410	0.069	18.1
280	176.98	0.92	10	275	0.00520	0.00183	0.01827	0.052	14.30
290	174.06	0.92	10	285	0.00526	0.00185	0.01848	0.053	14.98
300	180.4	0.93	10	295	0.00515	0.0018	0.0181	0.052	15.2
310	163.64	0.67	10	305	0.00409	0.00144	0.01439	0.041	12.49
320	174.97	0.70	10	315	0.00400	0.0014	0.01406	0.040	12.60
330	172.69	0.59	10	325	0.00342	0.00120	0.0120	0.034	11.1
340	176.47	0.49	10	335	0.00278	0.00098	0.00976	0.028	9.30
350	174.33	0.40	10	345	0.00229	0.00081	0.00807	0.023	7.92
360	175.89	0.33	10	355	0.00188	0.00066	0.00659	0.019	6.66
370	166.37	0.31	10	365	0.00186	0.00065	0.00655	0.019	6.80
380	176.53	0.30	10	375	0.00170	0.00060	0.00597	0.017	6.37
390	175.94	0.24	10	385	0.00136	0.00048	0.00479	0.014	5.25
400	172.05	0.17	10	395	0.00099	0.00035	0.00347	0.010	3.90
410	173.78	0.14	10	405	0.00081	0.00028	0.00283	0.008	3.26
420	177.87	0.16	10	415	0.00090	0.00032	0.00316	0.009	3.73
430	172.99	0.18	10	425	0.00104	0.00037	0.00366	0.010	4.42
440	173.32	0.08	10	435	0.00046	0.00016	0.00162	0.005	2.01
450	173.63	0.12	10	445	0.00069	0.00024	0.00243	0.007	3.08
460	175.09	0.08	10	455	0.00046	0.00016	0.0016	0.005	2.08
470	174.99	0.1	10	465	0.00063	0.00022	0.00221	0.006	2.92
480	171.3	0.04	10	475	0.00023	0.00008	0.00082	0.002	1.1
490	176.0	0.07	10	485	0.00040	0.00014	0.00140	0.004	1.93
500	177.42	0.03	10	495	0.00017	0.00006	0.00059	0.002	0.84
510	173.1	0.04	10	505	0.00023	0.00008	0.00081	0.002	1.1
520	173.5	0.03	10	515	0.00017	0.00006	0.00061	0.002	0.89
530	172.53	0.03	10	525	0.00014	0.00005	0.00051	0.001	0.76
540	176.56	0.04	10	535	0.00023	0.00008	0.00080	0.002	1.2
550	171.8	0.03	10	545	0.00017	0.00006	0.00061	0.002	0.95
560	177.38	0.02	10	555	0.0001	0.00004	0.00040	0.001	0.63
570	174.40	0.03	10	565	0.00017	0.00006	0.00060	0.002	0.97
580	180.64	0.01	10	575	0.00006	0.00002	0.00019	0.001	0.32
590	171.9	0.03	10	585	0.00017	0.00006	0.00061	0.002	1.02
600	172.1	0.02	10	595	0.00012	0.00004	0.00041	0.001	0.69
610	178.79	0.01	10	605	0.00006	0.00002	0.00020	0.001	0.34
620	176.44	0.01	10	615	0.00006	0.00002	0.00020	0.001	0.35
630	174.54	0.01	10	625	0.00006	0.00002	0.00020	0.001	0.36
						ΣE(t)Δti =	0.99934		

So =	17.430 g/s
Bed weight =	3403.0 g
τ =	195.2 sec

τ_{obs}=	195	ΣCitiΔti =	555.1
		ΣCiΔti =	2.84

Table D.19 Data Run#2004

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	148.20	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
20	148.20	0.00	20	10	0.00000	0.00000	0.00000	0.000	0.00
40	148.20	0.00	20	30	0.00000	0.00000	0.00000	0.000	0.00
60	148.20	0.00	20	50	0.00000	0.00000	0.00000	0.000	0.00
80	148.20	0.00	20	70	0.00000	0.00000	0.00000	0.000	0.00
100	147.91	0.00	20	90	0.00000	0.00000	0.00000	0.000	0.00
120	145.13	0.01	20	110	0.00007	0.00001	0.00021	0.001	0.15
140	144.76	0.12	20	130	0.00083	0.00012	0.00248	0.017	2.16
160	153.60	0.41	20	150	0.00267	0.00040	0.00798	0.053	8.01
180	152.42	0.68	20	170	0.00446	0.00067	0.01334	0.089	15.17
200	151.90	0.90	20	190	0.00589	0.00088	0.01761	0.118	22.39
220	152.72	1.41	20	210	0.00923	0.00138	0.02760	0.185	38.78
240	148.36	1.43	20	230	0.00964	0.00144	0.02881	0.193	44.34
260	152.25	1.81	20	250	0.01189	0.00178	0.03554	0.238	59.44
280	148.72	1.78	20	270	0.01197	0.00179	0.03578	0.239	64.63
300	152.84	2.21	20	290	0.01446	0.00216	0.04323	0.289	83.87
320	149.05	2.42	20	310	0.01624	0.00243	0.04854	0.325	100.66
340	156.70	2.41	20	330	0.01538	0.00230	0.04598	0.308	101.51
360	141.80	2.23	20	350	0.01573	0.00235	0.04701	0.315	110.08
380	150.24	2.28	20	370	0.01518	0.00227	0.04537	0.304	112.30
400	150.07	2.20	20	390	0.01466	0.00219	0.04383	0.293	114.35
420	148.72	2.12	20	410	0.01425	0.00213	0.04261	0.285	116.89
440	150.71	2.02	20	430	0.01340	0.00200	0.04007	0.268	115.27
460	151.13	2.12	20	450	0.01403	0.00210	0.04194	0.281	126.25
480	150.66	1.85	20	470	0.01228	0.00184	0.03671	0.246	115.43
500	151.58	1.69	20	490	0.01115	0.00167	0.03333	0.223	109.26
520	152.03	1.73	20	510	0.01138	0.00170	0.03402	0.228	116.07
540	150.11	1.34	20	530	0.00893	0.00133	0.02669	0.179	94.62
560	150.56	1.37	20	550	0.00910	0.00136	0.02720	0.182	100.09
580	142.68	1.17	20	570	0.00820	0.00123	0.02451	0.164	93.48
600	149.59	1.07	20	590	0.00715	0.00107	0.02138	0.143	84.40
620	148.23	1.19	20	610	0.00803	0.00120	0.02400	0.161	97.94
640	148.53	0.95	20	630	0.00640	0.00096	0.01912	0.128	80.59
660	144.20	0.73	20	650	0.00506	0.00076	0.01513	0.101	65.81
680	150.50	0.79	20	670	0.00525	0.00078	0.01569	0.105	70.34
700	146.06	0.73	20	690	0.00500	0.00075	0.01494	0.100	68.97
720	146.39	0.73	20	710	0.00499	0.00075	0.01491	0.100	70.81
740	144.75	0.70	20	730	0.00484	0.00072	0.01446	0.097	70.60
760	147.11	0.51	20	750	0.00347	0.00052	0.01036	0.069	52.00
780	143.88	0.55	20	770	0.00382	0.00057	0.01143	0.076	58.87
800	146.24	0.44	20	790	0.00301	0.00045	0.00899	0.060	47.54
820	155.52	0.38	20	810	0.00244	0.00037	0.00730	0.049	39.58
840	142.55	0.32	20	830	0.00224	0.00034	0.00671	0.045	37.26
860	145.46	0.36	20	850	0.00247	0.00037	0.00740	0.049	42.07
880	148.32	0.35	20	870	0.00236	0.00035	0.00705	0.047	41.06
900	140.36	0.29	20	890	0.00207	0.00031	0.00618	0.041	36.78
920	147.32	0.26	20	910	0.00176	0.00026	0.00528	0.035	32.12
940	141.45	0.21	20	930	0.00148	0.00022	0.00444	0.030	27.61
960	146.61	0.20	20	950	0.00136	0.00020	0.00408	0.027	25.92
980	152.39	0.15	20	970	0.00098	0.00015	0.00294	0.020	19.10
1000	143.42	0.15	20	990	0.00105	0.00016	0.00313	0.021	20.71
1020	136.46	0.08	20	1010	0.00059	0.00009	0.00175	0.012	11.84
1040	149.28	0.11	20	1030	0.00074	0.00011	0.00220	0.015	15.18
1060	142.46	0.12	20	1050	0.00084	0.00013	0.00252	0.017	17.69
1080	152.88	0.09	20	1070	0.00059	0.00009	0.00176	0.012	12.60
1100	147.41	0.12	20	1090	0.00081	0.00012	0.00243	0.016	17.75
1120	147.79	0.18	20	1110	0.00122	0.00018	0.00364	0.024	27.04
1140	144.35	0.08	20	1130	0.00055	0.00008	0.00166	0.011	12.53
1160	224.49	0.04	30	1150	0.00018	0.00003	0.00080	0.005	6.15
1180	221.11	0.06	30	1170	0.00025	0.00004	0.00112	0.007	8.73
1200	224.98	0.07	30	1190	0.00031	0.00005	0.00140	0.009	11.11

Run#2004 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1220	223.65	0.06	30	1210	0.00027	0.00004	0.00120	0.008	9.74
1240	223.55	0.01	30	1230	0.00004	0.00001	0.00020	0.001	1.65
1260	218.75	0.02	30	1250	0.00009	0.00001	0.00041	0.003	3.43
1280	230.20	0.06	30	1270	0.00024	0.00004	0.00107	0.007	9.10
1300	225.66	0.04	30	1290	0.00018	0.00003	0.00079	0.005	6.86
1320	220.86	0.01	30	1310	0.00002	0.00000	0.00010	0.001	0.89
1340	229.92	0.00	30	1330	0.00000	0.00000	0.00000	0.000	0.00
1360	221.55	0.01	30	1350	0.00005	0.00001	0.00020	0.001	1.83
1380	222.17	0.02	30	1370	0.00009	0.00001	0.00040	0.003	3.70
1240	187.77	0.02	25	1294	0.00011	0.00002	0.00040	0.003	3.48
						ΣE(t)Δti =	0.99937		

So =	7.414	g/s
Bed weight =	3478.0	g
τ =	469.1	sec

τ_{obs}=	469	ΣCitiΔti =	3136.6
		ΣCiΔti =	6.69

Table D.20 Data Run#2005

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	162.40	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	162.40	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	162.40	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	162.40	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	162.40	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	162.40	0.00	10	45	0.00000	0.00000	0.00000	0.000	0.00
60	158.06	0.00	10	55	0.00000	0.00000	0.00000	0.000	0.00
70	163.10	0.01	10	65	0.00006	0.00002	0.00020	0.001	0.04
80	162.83	0.06	10	75	0.00037	0.00012	0.00121	0.004	0.28
90	163.79	0.25	10	85	0.00153	0.00050	0.00500	0.015	1.30
100	163.12	0.61	10	95	0.00374	0.00122	0.01224	0.037	3.55
110	159.13	1.12	10	105	0.00704	0.00230	0.02304	0.070	7.39
120	161.75	1.99	10	115	0.01230	0.00403	0.04028	0.123	14.15
130	163.69	2.22	10	125	0.01356	0.00444	0.04441	0.136	16.95
140	163.32	2.75	10	135	0.01684	0.00551	0.05513	0.168	22.73
150	163.59	3.10	10	145	0.01895	0.00620	0.06205	0.189	27.48
160	154.73	3.32	10	155	0.02146	0.00703	0.07025	0.215	33.26
170	165.11	3.16	10	165	0.01914	0.00627	0.06266	0.191	31.58
180	170.53	3.11	10	175	0.01824	0.00597	0.05971	0.182	31.92
190	158.25	3.05	10	185	0.01927	0.00631	0.06311	0.193	35.66
200	164.22	2.94	10	195	0.01787	0.00585	0.05852	0.179	34.85
210	164.16	2.30	10	205	0.01401	0.00459	0.04587	0.140	28.72
220	163.32	2.27	10	215	0.01390	0.00455	0.04551	0.139	29.88
230	163.30	1.87	10	225	0.01145	0.00375	0.03749	0.115	25.77
240	160.47	2.08	10	235	0.01296	0.00424	0.04244	0.130	30.46
250	160.99	1.80	10	245	0.01118	0.00366	0.03661	0.112	27.39
260	162.15	1.56	10	255	0.00962	0.00315	0.03150	0.096	24.53
270	164.78	1.41	10	265	0.00856	0.00280	0.02802	0.086	22.68
280	160.47	1.11	10	275	0.00692	0.00226	0.02265	0.069	19.02
290	163.78	1.08	10	285	0.00659	0.00216	0.02159	0.066	18.79
300	161.31	0.99	10	295	0.00614	0.00201	0.02009	0.061	18.10
310	160.32	1.09	10	305	0.00677	0.00222	0.02216	0.068	20.64
320	163.00	0.81	10	315	0.00497	0.00163	0.01627	0.050	15.65
330	164.42	0.54	10	325	0.00328	0.00108	0.01075	0.033	10.67
340	162.88	0.53	10	335	0.00325	0.00107	0.01065	0.033	10.90
350	161.63	0.45	10	345	0.00278	0.00091	0.00912	0.028	9.61
360	161.97	0.39	10	355	0.00241	0.00079	0.00788	0.024	8.55
370	162.07	0.44	10	365	0.00271	0.00089	0.00889	0.027	9.91
380	165.17	0.25	10	375	0.00151	0.00050	0.00496	0.015	5.68
390	164.51	0.26	10	385	0.00158	0.00052	0.00517	0.016	6.08
400	162.24	0.19	10	395	0.00117	0.00038	0.00383	0.012	4.63
410	165.54	0.19	10	405	0.00112	0.00037	0.00366	0.011	4.53
420	161.89	0.15	10	415	0.00093	0.00030	0.00303	0.009	3.85
430	162.53	0.09	10	425	0.00052	0.00017	0.00171	0.005	2.22
440	162.94	0.11	10	435	0.00068	0.00022	0.00221	0.007	2.94
450	164.83	0.07	10	445	0.00042	0.00014	0.00139	0.004	1.89
460	160.84	0.06	10	455	0.00037	0.00012	0.00122	0.004	1.70
470	161.89	0.05	10	465	0.00031	0.00010	0.00101	0.003	1.44
480	160.12	0.05	10	475	0.00031	0.00010	0.00102	0.003	1.48
490	160.88	0.03	10	485	0.00019	0.00006	0.00061	0.002	0.90
500	161.98	0.03	10	495	0.00019	0.00006	0.00061	0.002	0.92
510	163.02	0.02	10	505	0.00012	0.00004	0.00040	0.001	0.62
520	162.31	0.02	10	515	0.00009	0.00003	0.00030	0.001	0.48
530	163.01	0.03	10	525	0.00015	0.00005	0.00050	0.002	0.81
540	162.36	0.02	10	535	0.00012	0.00004	0.00040	0.001	0.66
550	166.20	0.01	10	545	0.00006	0.00002	0.00020	0.001	0.33
560	160.69	0.01	10	555	0.00006	0.00002	0.00020	0.001	0.35
570	164.90	0.01	10	565	0.00006	0.00002	0.00020	0.001	0.34
580	159.14	0.00	10	575	0.00000	0.00000	0.00000	0.000	0.00
590	166.14	0.00	10	585	0.00000	0.00000	0.00000	0.000	0.00
600	155.30	0.01	10	595	0.00006	0.00002	0.00021	0.001	0.38

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Run#2005 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
610	163.46	0.00	10	605	0.00000	0.00000	0.00000	0.000	0.00
620	163.84	0.00	10	615	0.00000	0.00000	0.00000	0.000	0.00
630	161.17	0.00	10	625	0.00000	0.00000	0.00000	0.000	0.00
640	164.04	0.00	10	635	0.00000	0.00000	0.00000	0.000	0.00
650	161.75	0.00	10	645	0.00000	0.00000	0.00000	0.000	0.00
660	155.46	0.00	10	655	0.00000	0.00000	0.00000	0.000	0.00
670	163.20	0.00	10	665	0.00000	0.00000	0.00000	0.000	0.00
680	162.62	0.00	10	675	0.00000	0.00000	0.00000	0.000	0.00
690	163.48	0.01	10	685	0.00006	0.00002	0.00020	0.001	0.42
						ΣE(t)Δti =	1.00838		

So =	16.240	g/s
Bed weight =	3370.0	g
τ =	207.5	sec

τ_{obs}=	206.2	ΣCitiΔti =	635.0
		ΣCiΔti =	3.08

Table D.21 Data Run#2006

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	147.00	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
20	147.00	0.00	20	10	0.00000	0.00000	0.00000	0.000	0.00
40	147.00	0.00	20	30	0.00000	0.00000	0.00000	0.000	0.00
60	147.00	0.00	20	50	0.00000	0.00000	0.00000	0.000	0.00
80	147.00	0.00	20	70	0.00000	0.00000	0.00000	0.000	0.00
100	147.00	0.01	20	90	0.00007	0.00001	0.00020	0.001	0.12
120	147.00	0.00	20	110	0.00000	0.00000	0.00000	0.000	0.00
140	147.00	0.07	20	130	0.00048	0.00007	0.00143	0.010	1.24
160	145.88	0.28	20	150	0.00192	0.00029	0.00577	0.038	5.76
180	147.28	0.49	20	170	0.00333	0.00050	0.01000	0.067	11.31
200	142.49	0.81	20	190	0.00568	0.00085	0.01709	0.114	21.60
220	142.83	1.13	20	210	0.00791	0.00119	0.02379	0.158	33.23
240	139.89	1.44	20	230	0.01029	0.00155	0.03095	0.206	47.35
260	137.65	1.50	20	250	0.01090	0.00164	0.03277	0.218	54.49
280	140.01	1.76	20	270	0.01257	0.00189	0.03780	0.251	67.88
300	142.36	1.94	20	290	0.01363	0.00205	0.04098	0.273	79.04
320	144.58	2.19	20	310	0.01515	0.00228	0.04555	0.303	93.91
340	141.96	2.04	20	330	0.01437	0.00216	0.04321	0.287	94.84
360	153.66	2.11	20	350	0.01373	0.00206	0.04129	0.275	96.12
380	157.83	2.32	20	370	0.01470	0.00221	0.04420	0.294	108.78
400	147.13	2.23	20	390	0.01516	0.00228	0.04558	0.303	118.22
420	151.04	2.23	20	410	0.01476	0.00222	0.04440	0.295	121.07
440	144.04	2.18	20	430	0.01513	0.00228	0.04551	0.303	130.16
460	148.52	2.05	20	450	0.01380	0.00208	0.04151	0.276	124.23
480	146.32	1.67	20	470	0.01141	0.00172	0.03432	0.228	107.29
500	151.54	1.76	20	490	0.01161	0.00175	0.03492	0.232	113.82
520	151.11	1.63	20	510	0.01079	0.00162	0.03244	0.216	110.03
540	146.88	1.75	20	530	0.01191	0.00179	0.03583	0.238	126.29
560	149.40	1.45	20	550	0.00971	0.00146	0.02918	0.194	106.76
580	151.16	1.36	20	570	0.00900	0.00135	0.02705	0.180	102.57
600	151.15	1.26	20	590	0.00834	0.00125	0.02507	0.167	98.37
620	151.70	1.13	20	610	0.00745	0.00112	0.02240	0.149	90.88
640	147.67	1.04	20	630	0.00704	0.00106	0.02118	0.141	88.74
660	152.28	0.82	20	650	0.00538	0.00081	0.01619	0.108	70.00
680	146.48	0.75	20	670	0.00512	0.00077	0.01540	0.102	68.61
700	146.39	0.65	20	690	0.00444	0.00067	0.01335	0.089	61.27
720	150.84	0.68	20	710	0.00451	0.00068	0.01356	0.090	64.01
740	150.54	0.69	20	730	0.00458	0.00069	0.01378	0.092	66.92
760	146.42	0.55	20	750	0.00376	0.00056	0.01130	0.075	56.34
780	153.02	0.50	20	770	0.00327	0.00049	0.00983	0.065	50.32
800	150.66	0.55	20	790	0.00365	0.00055	0.01098	0.073	57.68
820	142.99	0.47	20	810	0.00329	0.00049	0.00988	0.066	53.25
840	149.94	0.23	20	830	0.00153	0.00023	0.00461	0.031	25.46
860	148.34	0.34	20	850	0.00229	0.00034	0.00689	0.046	38.96
880	158.11	0.25	20	870	0.00158	0.00024	0.00475	0.032	27.51
900	138.24	0.20	20	890	0.00145	0.00022	0.00435	0.029	25.75
920	150.00	0.30	20	910	0.00200	0.00030	0.00601	0.040	36.40
940	147.52	0.26	20	930	0.00176	0.00026	0.00530	0.035	32.78
960	150.96	0.21	20	950	0.00139	0.00021	0.00418	0.028	26.43
980	153.75	0.13	20	970	0.00085	0.00013	0.00254	0.017	16.40
1000	147.10	0.15	20	990	0.00102	0.00015	0.00307	0.020	20.19
1020	149.60	0.12	20	1010	0.00080	0.00012	0.00241	0.016	16.20
1050	222.74	0.19	30	1035	0.00085	0.00013	0.00385	0.026	26.49

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Run#2006 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
1080	223.43	0.16	30	1065	0.00072	0.00011	0.00323	0.021	22.88
1110	209.39	0.09	30	1095	0.00043	0.00006	0.00194	0.013	14.12
1140	221.26	0.08	30	1125	0.00036	0.00005	0.00163	0.011	12.20
1170	219.77	0.07	30	1155	0.00032	0.00005	0.00144	0.010	11.04
1200	220.18	0.05	30	1185	0.00023	0.00003	0.00102	0.007	8.07
1230	222.47	0.07	30	1215	0.00031	0.00005	0.00142	0.009	11.47
1260	222.29	0.06	30	1245	0.00027	0.00004	0.00122	0.008	10.08
1290	218.43	0.04	30	1275	0.00018	0.00003	0.00083	0.005	7.00
1320	219.43	0.01	30	1305	0.00005	0.00001	0.00021	0.001	1.78
1350	212.70	0.02	30	1335	0.00009	0.00001	0.00042	0.003	3.77
1380	206.53	0.02	30	1365	0.00010	0.00001	0.00044	0.003	3.97
1404.68	181.93	0.03	25	1392	0.00016	0.00002	0.00061	0.004	5.67

ΣE(t)Δti = **0.99107**

So =	7.369	g/s
Bed weight =	3474.0	g
τ =	471.45	sec

τ_{obs}=	471.4	ΣCitiΔti =	3107.1
		ΣCiΔti =	6.59

Table D.22 Data Run#2007

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	170.90	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
10	170.90	0.00	10	5	0.00000	0.00000	0.00000	0.000	0.00
20	170.90	0.00	10	15	0.00000	0.00000	0.00000	0.000	0.00
30	170.90	0.00	10	25	0.00000	0.00000	0.00000	0.000	0.00
40	170.90	0.00	10	35	0.00000	0.00000	0.00000	0.000	0.00
50	170.90	0.00	10	45	0.00000	0.00000	0.00000	0.000	0.00
60	166.70	0.00	10	55	0.00000	0.00000	0.00000	0.000	0.00
80	343.89	8.06	20	70	0.02344	0.00804	0.16074	0.469	32.81
100	345.63	6.95	20	90	0.02011	0.00690	0.13790	0.402	36.19
110	174.22	2.74	10	105	0.01573	0.00539	0.05393	0.157	16.51
120	172.67	2.26	10	115	0.01309	0.00449	0.04488	0.131	15.05
130	168.95	2.09	10	125	0.01237	0.00424	0.04242	0.124	15.46
140	171.15	1.97	10	135	0.01151	0.00395	0.03947	0.115	15.54
150	168.40	1.97	10	145	0.01010	0.00346	0.03462	0.101	14.64
160	172.76	1.70	10	155	0.00891	0.00306	0.03057	0.089	13.82
170	172.42	1.54	10	165	0.00882	0.00302	0.03023	0.088	14.55
180	171.09	1.52	10	175	0.00810	0.00278	0.02776	0.081	14.17
190	172.87	1.39	10	185	0.00758	0.00260	0.02599	0.076	14.02
200	168.60	1.31	10	195	0.00712	0.00244	0.02441	0.071	13.88
210	168.24	1.20	10	205	0.00684	0.00234	0.02344	0.068	14.01
220	171.58	1.15	10	215	0.00688	0.00236	0.02358	0.069	14.79
230	174.68	1.18	10	225	0.00492	0.00169	0.01688	0.049	11.08
240	170.99	0.86	10	235	0.00526	0.00180	0.01805	0.053	12.37
250	170.43	0.90	10	245	0.00434	0.00149	0.01489	0.043	10.64
260	169.46	0.74	10	255	0.00378	0.00130	0.01295	0.038	9.63
270	169.45	0.64	10	265	0.00354	0.00121	0.01214	0.035	9.38
280	170.98	0.60	10	275	0.00386	0.00132	0.01324	0.039	10.62
290	168.84	0.66	10	285	0.00361	0.00124	0.01239	0.036	10.30
300	172.44	0.61	10	295	0.00336	0.00115	0.01153	0.034	9.92
310	169.62	0.58	10	305	0.00318	0.00109	0.01092	0.032	9.71
320	171.18	0.54	10	315	0.00292	0.00100	0.01002	0.029	9.20
330	172.03	0.50	10	325	0.00221	0.00076	0.00757	0.022	7.18
340	171.23	0.38	10	335	0.00228	0.00078	0.00781	0.023	7.63
350	172.60	0.39	10	345	0.00197	0.00068	0.00675	0.020	6.80
360	174.00	0.34	10	355	0.00132	0.00045	0.00453	0.013	4.69
370	169.03	0.23	10	365	0.00175	0.00060	0.00598	0.017	6.37
380	172.42	0.30	10	375	0.00180	0.00062	0.00617	0.018	6.74
390	165.89	0.31	10	385	0.00181	0.00062	0.00620	0.018	6.96
400	173.65	0.30	10	395	0.00104	0.00036	0.00355	0.010	4.09
410	171.12	0.18	10	405	0.00169	0.00058	0.00581	0.017	6.86
420	171.34	0.29	10	415	0.00152	0.00052	0.00520	0.015	6.30
430	169.41	0.26	10	425	0.00118	0.00040	0.00405	0.012	5.02
440	174.58	0.20	10	435	0.00115	0.00039	0.00393	0.011	4.98
450	170.27	0.20	10	445	0.00150	0.00051	0.00514	0.015	6.66
460	168.82	0.26	10	455	0.00124	0.00043	0.00427	0.012	5.66
470	171.17	0.21	10	465	0.00099	0.00034	0.00341	0.010	4.62
480	168.65	0.17	10	475	0.00053	0.00018	0.00183	0.005	2.53
490	170.22	0.09	10	485	0.00094	0.00032	0.00322	0.009	4.56
500	169.71	0.16	10	495	0.00106	0.00036	0.00364	0.011	5.25
510	169.90	0.18	10	505	0.00059	0.00020	0.00202	0.006	2.97
520	165.85	0.10	10	515	0.00054	0.00019	0.00186	0.005	2.79
530	175.32	0.09	10	525	0.00063	0.00022	0.00215	0.006	3.29
540	172.00	0.11	10	535	0.00047	0.00016	0.00159	0.005	2.49

Run#2007 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
550	0.08	17.05	10	545	0.00070	0.00024	0.00241	0.007	3.84
560	0.12	17.07	10	555	0.00070	0.00024	0.00241	0.007	3.90
570	0.12	17.24	10	565	0.00052	0.00018	0.00179	0.005	2.95
580	0.09	17.23	10	575	0.00029	0.00010	0.00099	0.003	1.67
590	0.05	16.93	10	585	0.00024	0.00008	0.00081	0.002	1.38
600	0.04	17.24	10	595	0.00070	0.00024	0.00239	0.007	4.14
610	0.12	17.07	10	605	0.00018	0.00006	0.00060	0.002	1.06
620	0.03	16.83	10	615	0.00018	0.00006	0.00061	0.002	1.10
630	0.03	17.07	10	625	0.00023	0.00008	0.00080	0.002	1.46
640	0.04	17.16	10	635	0.00035	0.00012	0.00120	0.003	2.22
650	0.06	16.92	10	645	0.00050	0.00017	0.00172	0.005	3.24
660	0.09	17.14	10	655	0.00023	0.00008	0.00080	0.002	1.53
664	0.04	17.09	4	662.1	0.00056	0.00019	0.00080	0.002	1.55

ΣE(t)Δti = **0.94697**

So =	17.1	g/s
Bed weight =	3074.0	g
τ =	180	sec

τ_{obs}=	179.9	ΣCitiΔti =	496.5
		ΣCiΔti =	2.76

Table D.23 Data Run#2008

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	70.90	0.00	20	0	0.00000	0.00000	0.00000	0.000	0.00
6	70.90	0.00	20	6	0.00000	0.00000	0.00000	0.000	0.00
26	70.90	0.00	20	16	0.00000	0.00000	0.00000	0.000	0.00
46	70.90	0.00	20	36	0.00000	0.00000	0.00000	0.000	0.00
66	70.90	0.00	20	56	0.00000	0.00000	0.00000	0.000	0.00
86	70.90	0.00	20	76	0.00000	0.00000	0.00000	0.000	0.00
106	70.90	0.00	20	96	0.00000	0.00000	0.00000	0.000	0.00
126	70.90	0.00	20	11	0.00000	0.00000	0.00000	0.000	0.00
146	70.90	0.00	20	136	0.00000	0.00000	0.00000	0.000	0.00
166	70.90	0.00	20	156	0.00000	0.00000	0.00000	0.000	0.00
186	70.90	0.00	20	176	0.00000	0.00000	0.00000	0.000	0.00
206	70.90	0.00	20	196	0.00000	0.00000	0.00000	0.000	0.00
226	70.90	0.00	20	216	0.00000	0.00000	0.00000	0.000	0.00
246	70.90	0.00	20	236	0.00000	0.00000	0.00000	0.000	0.00
266	70.90	0.00	20	256	0.00000	0.00000	0.00000	0.000	0.00
286	70.90	0.00	20	276	0.00000	0.00000	0.00000	0.000	0.00
306	36.48	0.01	5	286	0.00027	0.00004	0.00019	0.001	0.39
316	73.19	1.1	10	31	0.01599	0.00227	0.02267	0.160	49.72
326	70.86	5.24	10	321	0.07395	0.01049	0.10487	0.739	237.38
336	69.86	7.48	10	331	0.10707	0.0151	0.1518	1.07	354.41
346	72.44	7.23	10	341	0.09981	0.0141	0.1415	0.998	340.34
356	70.89	5.02	10	351	0.07081	0.01004	0.10043	0.708	248.56
366	72.55	4.08	10	361	0.05624	0.00798	0.07976	0.562	203.02
376	72.13	2.73	10	371	0.03778	0.00536	0.05358	0.378	140.1
386	70.08	2.47	10	381	0.03525	0.00500	0.04999	0.352	134.29
396	72.08	1.93	10	391	0.02678	0.00380	0.03797	0.268	104.69
406	70.07	1.57	10	401	0.02241	0.00318	0.03178	0.224	89.85
416	70.51	1.1	10	41	0.0161	0.00229	0.02293	0.162	66.45
426	69.62	1.1	10	421	0.01580	0.00224	0.02241	0.158	66.52
436	71.25	0.98	10	431	0.01375	0.00195	0.0195	0.138	59.28
446	71.25	0.80	10	441	0.0112	0.00159	0.01592	0.11	49.52
456	71.1	0.72	10	451	0.0101	0.00143	0.01435	0.10	45.62
466	69.82	0.60	10	461	0.00859	0.00122	0.0121	0.086	39.62
476	70.35	0.48	10	471	0.00682	0.00097	0.00968	0.068	32.14
486	70.35	0.57	10	481	0.00810	0.0011	0.0114	0.081	38.97
496	70.17	0.44	10	491	0.00627	0.00089	0.00889	0.063	30.79
506	70.48	0.33	10	501	0.00468	0.00066	0.00664	0.047	23.46
516	71.1	0.36	10	51	0.00506	0.00072	0.00718	0.051	25.87
526	70.66	0.32	10	521	0.00453	0.00064	0.00642	0.045	23.59
536	71.50	0.28	10	531	0.00392	0.00056	0.00555	0.039	20.79
546	72.04	0.17	10	541	0.00236	0.00033	0.00335	0.024	12.77
556	72.27	0.21	10	551	0.00291	0.00041	0.00412	0.029	16.0
566	69.60	0.17	10	561	0.00244	0.00035	0.00346	0.024	13.70
576	70.95	0.15	10	571	0.0021	0.00030	0.00300	0.021	12.07
586	69.69	0.16	10	581	0.00230	0.00033	0.00326	0.023	13.34
596	73.83	0.13	10	591	0.00176	0.00025	0.00250	0.018	10.4
606	68.14	0.10	10	601	0.00147	0.00021	0.00208	0.015	8.82
626	140.1	0.29	20	616	0.00207	0.00029	0.00587	0.041	25.49
646	143.40	0.19	20	636	0.00132	0.00019	0.00376	0.026	16.85
666	142.34	0.19	20	656	0.00133	0.00019	0.00379	0.027	17.5
686	141.2	0.13	20	676	0.00092	0.00013	0.00261	0.018	12.45
706	140.92	0.15	20	696	0.00106	0.00015	0.00302	0.021	14.82
726	141.7	0.15	20	716	0.00106	0.00015	0.00300	0.021	15.1
756	213.3	0.1	30	741	0.00052	0.00007	0.00219	0.015	11.4
786	211.1	0.08	30	771	0.00038	0.00005	0.0016	0.01	8.76
816	213.59	0.05	30	801	0.00023	0.00003	0.00100	0.007	5.63
846	211.2	0.06	30	831	0.00028	0.00004	0.0012	0.009	7.08
876	211.5	0.03	30	861	0.00014	0.00002	0.00060	0.004	3.66
906	209.75	0.06	30	891	0.00029	0.00004	0.00122	0.009	7.65
936	211.7	0.05	30	921	0.00024	0.00003	0.00100	0.007	6.53
956	139.92	0.02	20	945.9	0.00014	0.00002	0.00040	0.003	2.67

ΣE(t)Δti = 0.99083

So =	7.09 g/s
Bed weight =	2763.0 g
τ =	389.80 sec

τ_{obs}=	381.9	ΣCitiΔti =	2668.2
		ΣCiΔti =	6.99

Table D.24 Data Run#2009

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
0	70.30	0.00	10	0	0.00000	0.00000	0.00000	0.000	0.00
4	70.30	0.00	10	2	0.00000	0.00000	0.00000	0.000	0.00
14	70.30	0.00	10	9	0.00000	0.00000	0.00000	0.000	0.00
24	70.30	0.00	10	19	0.00000	0.00000	0.00000	0.000	0.00
34	70.30	0.00	10	29	0.00000	0.00000	0.00000	0.000	0.00
44	70.30	0.00	10	39	0.00000	0.00000	0.00000	0.000	0.00
54	70.30	0.00	10	49	0.00000	0.00000	0.00000	0.000	0.00
64	70.30	0.00	10	59	0.00000	0.00000	0.00000	0.000	0.00
74	70.30	0.00	10	69	0.00000	0.00000	0.00000	0.000	0.00
84	70.30	0.00	10	79	0.00000	0.00000	0.00000	0.000	0.00
94	70.30	0.00	10	89	0.00000	0.00000	0.00000	0.000	0.00
104	70.30	0.00	10	99	0.00000	0.00000	0.00000	0.000	0.00
11	70.30	0.00	10	109	0.00000	0.00000	0.00000	0.000	0.00
124	70.30	0.00	10	11	0.00000	0.00000	0.00000	0.000	0.00
134	70.30	0.00	10	129	0.00000	0.00000	0.00000	0.000	0.00
144	70.30	0.00	10	139	0.00000	0.00000	0.00000	0.000	0.00
154	70.30	0.00	10	149	0.00000	0.00000	0.00000	0.000	0.00
164	70.30	0.00	10	159	0.00000	0.00000	0.00000	0.000	0.00
174	70.30	0.00	10	169	0.00000	0.00000	0.00000	0.000	0.00
184	70.30	0.00	10	179	0.00000	0.00000	0.00000	0.000	0.00
194	70.30	0.00	10	189	0.00000	0.00000	0.00000	0.000	0.00
204	70.30	0.00	10	199	0.00000	0.00000	0.00000	0.000	0.00
214	70.30	0.00	10	209	0.00000	0.00000	0.00000	0.000	0.00
224	70.30	0.00	10	219	0.00000	0.00000	0.00000	0.000	0.00
234	70.30	0.00	10	229	0.00000	0.00000	0.00000	0.000	0.00
244	70.30	0.00	10	239	0.00000	0.00000	0.00000	0.000	0.00
254	74.40	0.00	10	249	0.00000	0.00000	0.00000	0.000	0.00
264	76.12	0.00	10	259	0.00000	0.00000	0.00000	0.000	0.00
274	73.18	0.03	10	269	0.00041	0.00012	0.00124	0.001	1.1
284	75.46	0.71	10	279	0.00941	0.00285	0.02852	0.029	26.25
294	72.44	0.67	10	289	0.00925	0.00280	0.02803	0.028	26.73
304	68.62	0.46	10	299	0.00670	0.00203	0.02032	0.020	20.04
314	71.39	0.60	10	309	0.00840	0.00255	0.02547	0.025	25.97
324	70.1	0.59	10	319	0.00842	0.00255	0.02551	0.026	26.85
334	72.37	0.44	10	329	0.00608	0.00184	0.01843	0.018	20.00
344	70.43	0.58	10	339	0.00824	0.00250	0.02496	0.025	27.92
354	73.79	0.50	10	349	0.00678	0.00205	0.02054	0.021	23.65
364	72.48	0.53	10	359	0.00731	0.00222	0.02216	0.022	26.25
374	71.59	0.43	10	369	0.00601	0.00182	0.0182	0.018	22.16
384	70.91	0.49	10	379	0.00691	0.00209	0.02094	0.021	26.19
394	68.42	0.59	10	389	0.00862	0.00261	0.02614	0.026	33.54
404	68.00	0.42	10	399	0.00618	0.00187	0.01872	0.019	24.64
414	73.90	0.44	10	409	0.00595	0.00180	0.01805	0.018	24.35
424	68.45	0.47	10	419	0.00687	0.00208	0.02081	0.021	28.77
434	75.42	0.39	10	429	0.00517	0.00157	0.01567	0.016	22.18
444	70.18	0.49	10	439	0.00698	0.00212	0.0211	0.021	30.65
454	69.63	0.38	10	449	0.00546	0.00165	0.01654	0.017	24.50
464	71.23	0.46	10	459	0.00646	0.00196	0.01957	0.020	29.64
474	71.1	0.43	10	469	0.00604	0.00183	0.01832	0.018	28.34
484	71.95	0.46	10	479	0.00639	0.00194	0.01938	0.019	30.62
494	72.78	0.37	10	489	0.00508	0.00154	0.0154	0.015	24.86
504	65.44	0.43	10	499	0.00657	0.00199	0.01992	0.020	32.79
514	71.3	0.50	10	509	0.00701	0.00213	0.02125	0.021	35.69
524	72.32	0.44	10	519	0.00608	0.00184	0.01844	0.018	31.58
534	69.56	0.39	10	529	0.00561	0.00170	0.01699	0.017	29.66
544	73.45	0.34	10	539	0.00463	0.00140	0.01403	0.014	24.95
554	69.39	0.28	10	549	0.00404	0.00122	0.01223	0.012	22.15
564	72.90	0.35	10	559	0.00480	0.00146	0.01455	0.015	26.84
574	72.29	0.46	10	569	0.00636	0.00193	0.01929	0.019	36.21
584	70.56	0.34	10	579	0.00482	0.00146	0.0146	0.015	27.90
594	71.32	0.33	10	589	0.00463	0.00140	0.01402	0.014	27.25
604	73.45	0.28	10	599	0.00381	0.0011	0.0115	0.012	22.83
614	70.67	0.24	10	609	0.00340	0.00103	0.01029	0.010	20.68
624	68.90	0.30	10	619	0.00435	0.00132	0.01320	0.013	26.95
634	67.80	0.23	10	629	0.00339	0.00103	0.01028	0.010	21.34
644	69.97	0.26	10	639	0.00372	0.0011	0.0112	0.01	23.74
654	65.45	0.23	10	649	0.00351	0.00107	0.01065	0.01	22.81
664	74.18	0.29	10	659	0.00391	0.0011	0.0118	0.012	25.76

Run#2009 (Cont..)

Time (sec)	Total	Tracer	Δt	ti	C(t)	E(t)	Δt*E(t)	Ci *Δ ti	Ci * ti *Δ ti
674	69.95	0.23	10	669	0.00329	0.00100	0.00997	0.033	22.00
684	70.06	0.22	10	679	0.00314	0.00095	0.00952	0.031	21.32
694	71.32	0.25	10	689	0.00351	0.00106	0.01062	0.035	24.15
704	70.47	0.17	10	699	0.00241	0.00073	0.00731	0.024	16.86
714	68.36	0.19	10	709	0.00278	0.00084	0.00842	0.028	19.71
724	72.38	0.20	10	719	0.00276	0.00084	0.00838	0.028	19.87
734	74.85	0.16	10	729	0.00214	0.00065	0.00648	0.021	15.58
744	70.17	0.16	10	739	0.00228	0.00069	0.00691	0.023	16.85
754	70.70	0.14	10	749	0.00198	0.00060	0.00600	0.020	14.83
764	71.64	0.20	10	759	0.00279	0.00085	0.00846	0.028	21.19
784	71.47	0.22	20	774	0.00308	0.00093	0.01866	0.062	47.65
804	138.91	0.28	20	794	0.00202	0.00061	0.01222	0.040	32.01
824	140.85	0.30	20	814	0.00213	0.00065	0.01291	0.043	34.68
844	140.53	0.32	20	834	0.00228	0.00069	0.01380	0.046	37.98
864	145.76	0.22	20	854	0.00151	0.00046	0.00915	0.030	25.78
884	141.37	0.29	20	874	0.00205	0.00062	0.01244	0.041	35.86
904	141.17	0.15	20	894	0.00106	0.00032	0.00644	0.021	19.00
924	141.98	0.29	20	914	0.00204	0.00062	0.01238	0.041	37.34
944	140.30	0.22	20	934	0.00157	0.00048	0.00951	0.031	29.29
964	140.02	0.20	20	954	0.00143	0.00043	0.00866	0.029	27.25
984	143.00	0.19	20	974	0.00133	0.00040	0.00805	0.027	25.88
1004	145.08	0.21	20	994	0.00145	0.00044	0.00877	0.029	28.78
1024	141.26	0.18	20	1014	0.00127	0.00039	0.00772	0.025	25.84
1044	139.06	0.13	20	1034	0.00093	0.00028	0.00567	0.019	19.33
1064	146.55	0.11	20	1054	0.00075	0.00023	0.00455	0.015	15.82
1084	135.28	0.11	20	1074	0.00081	0.00025	0.00493	0.016	17.47
1104	137.31	0.11	20	1094	0.00080	0.00024	0.00486	0.016	17.53
1124	140.64	0.10	20	1114	0.00071	0.00022	0.00431	0.014	15.84
1144	137.60	0.15	20	1134	0.00109	0.00033	0.00661	0.022	24.72
1164	140.88	0.07	20	1154	0.00050	0.00015	0.00301	0.010	11.47
1184	142.99	0.11	20	1174	0.00077	0.00023	0.00466	0.015	18.06
1204	142.30	0.05	20	1194	0.00035	0.00011	0.00213	0.007	8.39
1224	139.34	0.07	20	1214	0.00050	0.00015	0.00305	0.010	12.20
1244	140.76	0.05	20	1234	0.00036	0.00011	0.00215	0.007	8.77
1264	137.65	0.03	20	1254	0.00022	0.00007	0.00132	0.004	5.47
1284	142.31	0.08	20	1274	0.00056	0.00017	0.00341	0.011	14.32
1304	138.15	0.06	20	1294	0.00043	0.00013	0.00263	0.009	11.24
1334	142.07	0.05	30	1319	0.00035	0.00011	0.00320	0.011	13.93
1364	214.81	0.07	30	1349	0.00033	0.00010	0.00296	0.010	13.19
1394	212.73	0.07	30	1379	0.00033	0.00010	0.00299	0.010	13.61
1424	217.46	0.06	30	1409	0.00028	0.00008	0.00251	0.008	11.66
1454	211.65	0.09	30	1439	0.00043	0.00013	0.00387	0.013	18.36
1484	213.39	0.03	30	1469	0.00014	0.00004	0.00128	0.004	6.20
1514	209.91	0.04	30	1499	0.00019	0.00006	0.00173	0.006	8.57
1544	205.56	0.02	30	1529	0.00010	0.00003	0.00088	0.003	4.46
1574	210.24	0.01	30	1559	0.00005	0.00001	0.00043	0.001	2.22
1604	213.50	0.03	30	1589	0.00014	0.00004	0.00128	0.004	6.70
1634	214.65	0.04	30	1619	0.00019	0.00006	0.00169	0.006	9.05
1664	214.31	0.03	30	1649	0.00014	0.00004	0.00127	0.004	6.93
1660.78	188.29	0.02	27	1653	0.00011	0.00003	0.00086	0.003	4.70

ΣE(t)Δti = 1.0000

So =	**7.029** g/s
Bed weight = 2962	g
τ =	**421.4** sec

τ_{obs}= **414.2**	**ΣCitiΔti =**	**1379.77**
	ΣCiΔti =	**3.331**

APPENDIX E

IDENTICAL STAGES TEST

The three-stage column was built using three stages as close to identical as possible. The following diagram (Figure E.1) shows the particular geometry of the designed vessels. Table E.1 shows the experimental measurements for each vessel, and Table E.2 the experimental data used/obtained in a particular set of operating-test conditions.

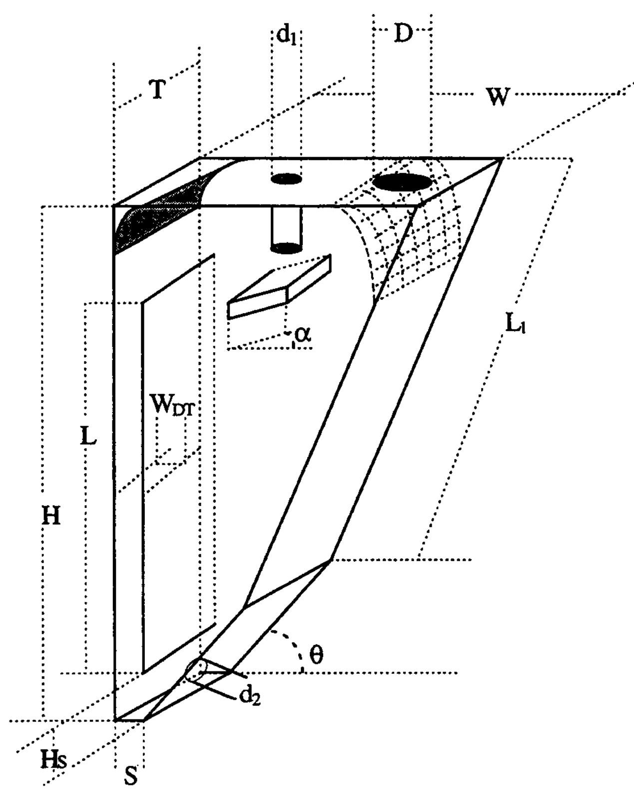

Figure E.1 Diagram of the designed vessels.

	VESSEL 1	VESSEL 2	VESSEL 3
H	33.0	33.0	33.0
W	18.0	18.0	18.0
T	4.0	4.0	4.0
L	22.7	22.7	22.4
L_1	30.0	30.1	30.0
H_S	1.6	1.7	1.6
S	0.32	0.32	0.32
D	3.0	3.0	3.0
d_1	1.6	1.6	1.6
d_2	1.6	1.6	1.6
W_{DT}	1.9	1.9	1.9
α (°)	25	24	23
θ (°)	44	44	42

Table E.1 Construction data. Experimental measurements in cm.

	RUN #98	RUN #99	RUN #100
Bed weight (g)	1215.5	1225	1210
S_o **(g/s)**	12.03	11.88	11.95
τ (s)	101.0	103.1	101.25
τ_{obs} (s)	100.2	102.7	100.6
τ_p (s)	28.4	28.38	27.64
τ_M (s)	71.8	74.3	73.0
GFR (lit/sec)	3.7	3.7	3.7
Tracer weight (g)	50.0	50.0	50.0

Table E.2 Operating data used/obtained in testing the vessels.

Figure E.2 shows the concentration curves from these experiments, while Figure E.3 shows the corresponding E(t) curves. There is no reason to suspect that the stages would behave differently when used separately.

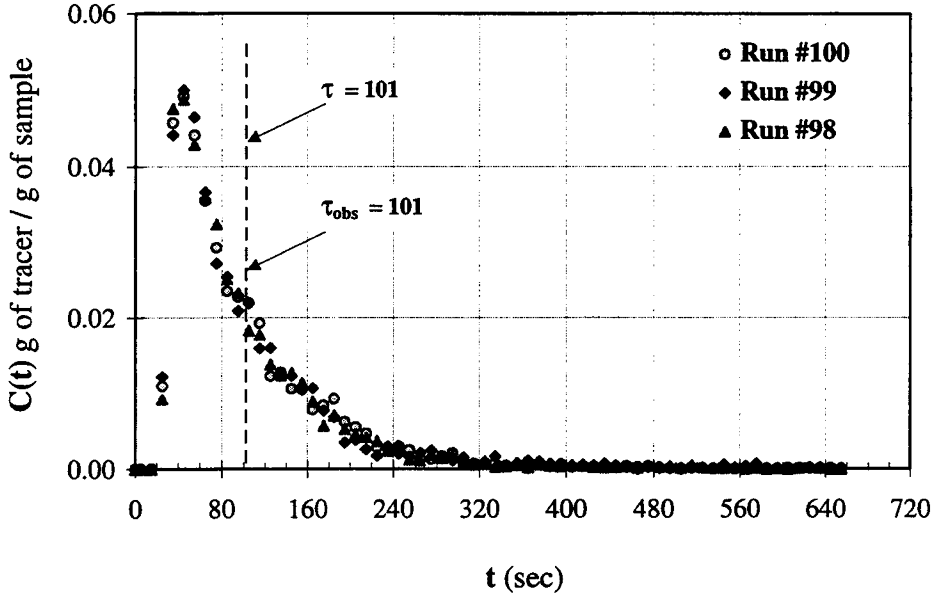

Figure E.2 C(t) curves of experiments to test identical stage behavior.

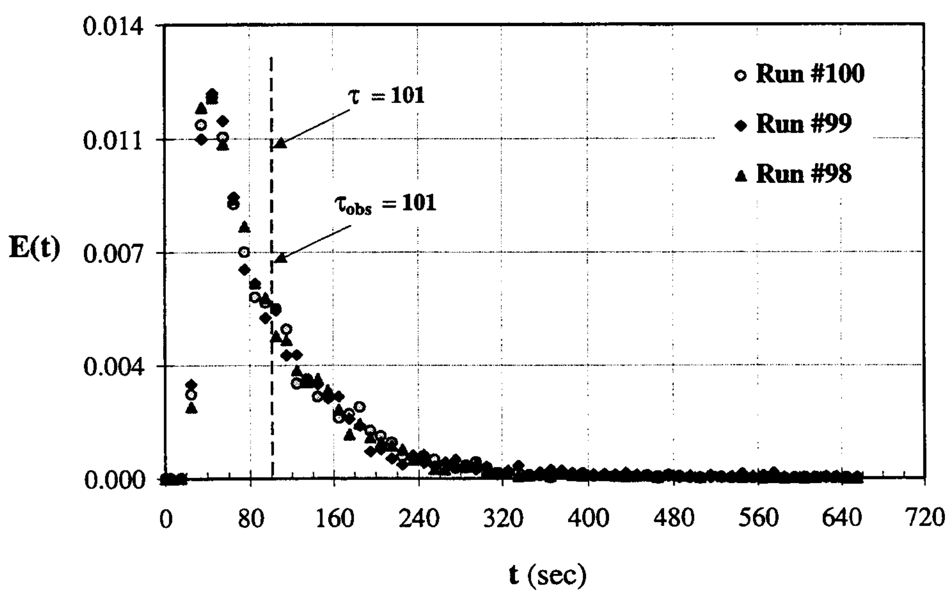

Figure E.3 E(t) curves of experiments to test identical stage behavior.