XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

ADJUSTED METHODOLOGY FOR DETERMINING RESIDENCE TIME BY IMAGE ANALYSIS ON A VIBRO-FLUIDIZED DRYER

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CSBE101173 – Presented at Section VI: Postharvest Technology and Process Engineering conference

ABSTRACT Fluidized bed dryers are used extensively for the drying of wet particulate and granular materials that can be fluidized with or without mechanical assistance. Furthermore, agitation contributes to achieving the fluid like behaviour of solids where rapid, easy transport and intimate fluid contacting are often the most important fluidization properties for industrial operations. Therefore, dryers that permit solid movement are frequently used. In this research work, we pretended to evaluate a new treatment procedure on image analysis methodology for determining residence time distribution on a continuous vibro-fluidized dryer. Knowing what is happening within the dryer, i.e., a complete velocity distribution map for the solid; makes it possible to predict the behaviour of this solid inside the dryer. In many cases, it is not necessary to have substantial knowledge about the flow, simply how long the individual particles stay in the dryer. The intention of this work was to determine the residence time of granular material using image analysis without any manual procedure. The material used was black beans, whereas tracers were black beans painted with white spray ink. The digital images were fitted in a specific computational program. The residence time values obtained by evaluated methodology were compared with ideal threshold image analysis and manual separation procedure values. The residence time distribution curves were determined for different vibration amplitudes. Residence time values obtained by adjusted method present lower mean relative deviation modulus than simple image analysis.

Keywords: granular material, black bean, fluidization, tracer.

INTRODUCTION Vibro-fluidized drying consists of a warm air flow passage through the material in the drying bed, which is also submitted to a mechanical agitation. It is used for materials that demand short residence time, high drying rates and low drying temperatures (Brod, 2003).

Accomplished studies suggested some necessary adjustments for operational optimization of the dryer, as analyses of the solids behavior in dryer bed, effects of the vibration in the drying rate and pressure drop. Those parameters are of vital importance in the drying system design, providing the appropriate drying rate and higher efficiency of the dryer.

The residence time distribution (RTD) refers to the behavior of the solids in the drying bed, taking into account the routes traveled by solids inside of dryer. For evaluation of that parameter, it is necessary to observe how much time individual particles take to pass through drying bed. The method used for that determination is the stimulus-response method.

In this research work, it was intended to determine the residence time distribution in the vibro-fluidized dryer, using an image analysis methodology which was not based on handling of studied material. It means that there was not manual procedure, even separation of marked and non-marked material. The results obtained by this method were compared to results obtained by conventional method and an image analysis method with manual separation. Conventional method refers to manual separation of marked and non-marked mass of solids.

Vibro-fluidization Fluidization is the operation by which a solid particles bed exhibits a fluidlike state as result of a fluid flow passing through it. That fluid can be a liquid or a gas and the fluidized bed can present different behaviors depending on type of fluid and properties of particulate material (Kunii and Levenspiel, 1991).

Heat, mass and momentum transfers are phenomena usually associated to fluidization. Due to the fast and vigorous mixture of the bed, heat and mass transfers between fluid and solid happen easily, corresponding to high transfer coefficients. This fluidlike behavior of solids with its rapid, easy transport and its intimate fluid contacting is often the most important property recommending fluidization for industrial operations (Kunii and Levenspiel, 1991).

Residence time distribution - RTD According to Keey (1992), the particles must be retained in the dryer for sufficient time to allow the moisture to be driven off at the rate determined by the process conditions. It is also necessary that the moisture content and temperature of final product are inside of a small variation range. It means that the residence time distribution (DTR) of the solid particles in the bed should be as uniform as possible.

The vibro-fluidized dryer aerodynamics can be characterized by a short/medium residence time and by a residence time of particulate material dispersed in the bed. It is important, because these parameters influence on moisture content and temperature of the final product (Han et al., 1991). Knowing what is happening within the dryer, i.e., a complete velocity distribution map for the solid; makes it possible to predict the behavior of this solid inside the dryer. Though logical in principle, the accompanying complexities make it impractical to use this knowledge (Levenspiel, 1972).

In many cases, it is not necessary to have substantial knowledge about the flow, simply how long the individual particles stay in the dryer, or more precisely, the distribution of residence times of the solid. This information can be determined easily and directly by a widely used method of inquiry: the stimulus-response experiment. To obtain information on solids movement and mixing, the solid tracers are fed into a fluidized bed and detected either in situ, as in the case of isotope tracers, or by sampling and analysis. It is assumed that the tracers behave like the solids in the flow. Tracer particles of the same size, density, and shape as the bed material should be used wherever possible (Yang, 2003).

Solids taking different routes through the dryer may require different lengths of time to pass through the bed. The distribution of these times for the solids leaving the dryer is called the exit age distribution E, or the residence time distribution (Kunii and Levenspiel, 1991).

$$E(t) = \frac{C(t)}{Q} \qquad (1)$$

Besides, it is convenient to represent RTD in such a way that the area under the curve is unitary (Equation 2). This procedure is called normalization of the distribution.

$$\int_0^\infty E dt = 1 \qquad (2)$$

The F curve is the cumulative fraction of the solids that has passed through after residing in the dryer up to a given time t (Levenspiel, 1972, Keey, 1972). So, F curve varies from 0 to1 (Equation 3):

$$\mathrm{F}(\mathrm{t}) = \int_0^\infty \mathrm{E}(\mathrm{t})\mathrm{dt} = \sum_{\mathrm{n}} \left(\frac{\mathrm{E}(\mathrm{t})_{\mathrm{n}+1} + \mathrm{E}(\mathrm{t})_{\mathrm{n}}}{2} \right) \cdot \left(\mathrm{t}_{\mathrm{n}+1} - \mathrm{t}_{\mathrm{n}} \right) \qquad (3)$$

Finally, the mean residence time is defined as (Keey, 1972):

$$\bar{t} = \sum_n t_n \cdot E(t_n) \cdot \Delta t \qquad (4)$$

Brod (2003) and Brod et al. (2004) applied a methodology which consists of the analysis of digital images of the material in the discharge of continuous dryer. This material contained the material to be dried and a tracer of another color. This image processing is made starting from histograms of the pixels in each image (corresponding to a certain period of time) and the construction of curve of residence time distribution.

MATERIAL AND METHODS

Vibro-fluidized dryer The vibro-fluidized dryer used in this research work is constituted of a vibrated bed with three separated compartments that allow the admission of air in different drying conditions. The air system is composed of an inflated blower (to supply air), an exhaustion blower (to balance the pressure in the dryer) and a cyclone (a dust-collector). The VFD body is suspended on four spiral springs that absorb the vibration. Four adjusting screws control the inclination of the layer and two exciters (1100W each) vibrate the dryer. Four eccentric half-plates on the exciters allow the adjustment of vibration amplitude. Brod et al. (2004) reported that the vibro-fluidized dryer used in this present research work presented a high particle dispersion number, characterizing a disperse plug flow regime.

Material The material used to determine the residence time was black beans purchased in a food commercial store. A part of the grains was painted with white spray ink. The porosity ε of black beans was calculated by the relation between true and apparent densities. Apparent density (ρ_{ap}) was determined by filling a graduated beaker with a weighted portion of black beans. The residual volume was full filled with distillated water. True density ρ_t is the ratio between the immersed mass and the free void sample volume.

Residence time distribution - RTD In order to do the survey of residence time distribution in the vibro-fluidized dryer, it was used the stimulus-response method. The stimulus consisted of a pulse of previous weighted mass of marked material (white beans), called tracer. The response was the measurement of fraction of white beans in relation to the rest of black beans, in given periods of time. This method presents some difficulties related to separation of marked and non-marked material. Tracer and non-marked were considered similar concerning to their drainage characteristics in the bed.

Brod (2003) used the indirect method of separation of the materials, in which the digital pictures were analyzed by the difference of colors of marked and non-marked materials. In this way, it was possible to determine the proportion of tracer in relation to black beans. This method was used because the manual separation, especially for small particle size materials, becomes impracticable. The material used by Brod (2003) was triturated eggshell, and eggshell painted with black spray ink as tracer.

Oliveira et al. (2008) determined the residence time distribution of black beans in a vibro-fluidized dryer. The authors used an image analysis method and compared it to the conventional method, i. e., the manual separation method of product and tracer masses.

In the present research work, an adjusted image analysis method was accomplished and, then, compared to manual separation of tracer and black beans as well as to the separation by images analysis.

Five experimental runs were executed in different vibration amplitudes. The vibration amplitudes were the same as used by Oliveira et al. (2008). The number of the experimental run corresponds to the preset amplitude: 1 (maximum), 2, 3, 4 and 5 (minimum).

The residence time distribution was measured by injecting an impulse of tracer particles into the feed stream after steady-state operation with regular non-marked particles was attained. After a small amount of tracer granules had been instantaneously injected into the feed stream, samples were taken from the outlet of the dryer at fixed time intervals.

Each sample was weighed and homogenized and then distributed in a tray of plastic. A digital picture was taken with a fixed distance which was enough for the whole top view of the material distributed in the tray appeared at the image. It was used a digital camera SONY, model DSC-P32, which presents resolution of 2048 x 1536 pixels (3 megapixels). The pictures of the respective samples were transmitted to computer for subsequent images analysis. Later, the white beans (tracer) were manually separated and weighed separately. The same procedure was accomplished for all experimental runs.

Considering both tracer and total masses ($m_{tr}(t)$ and m_{tot} respectively) of the samples, the fractions of tracer in each one of them could be calculated. All the tracer masses were added to determinate the tracer total mass that was collected in the whole experimental run. Then, for each sample, the concentration C (t) of tracer was calculated by the following equation:

$$C(t) = \frac{m_{tr}(t)}{m_{tot}} \qquad (5)$$

Then, the area below the curve of concentration curve versus time curve (Q curve) was determined by numeric integration:

$$Q(t) = \int_0^\infty C(t)dt = \sum_n \left(\frac{C(t)_{n+1} + C(t)_n}{2} \right) \cdot (t_{n+1} - t_n) \qquad (6)$$

F curve and mean residence time distribution were calculated by Equations 3 and 4, previously mentioned.

Image analysis The images obtained at laboratory were colored images of 24 bits. These images were then converted for images of 8 bits, in gray scale, using GIMP software version 2.4. It was necessary, because the software used for analysis of these images (IDRISI version 32) works with this resolution. Using IDRISI software, the images of 8 bits in gray scale were converted from .jpeg format to Raster file format (.rst). This kind of format is typically used by the program. For each image, its respective histogram was generated. It graphically represents the distribution of gray shades in the image and shows the amount of pixels for each one of gray tones ranging from 0 (black) to 255 (white).

Figure 1 shows an example of a grayscale image and its respective histogram. The histograms were generated by IDRISI software, with the brightness values varying from 0 to 255 in the horizontal axis. The histogram scale shows brightness values until 235, because there were not pixel shade values above this brightness level. The vertical axis represents the total number of pixels with each brightness level.

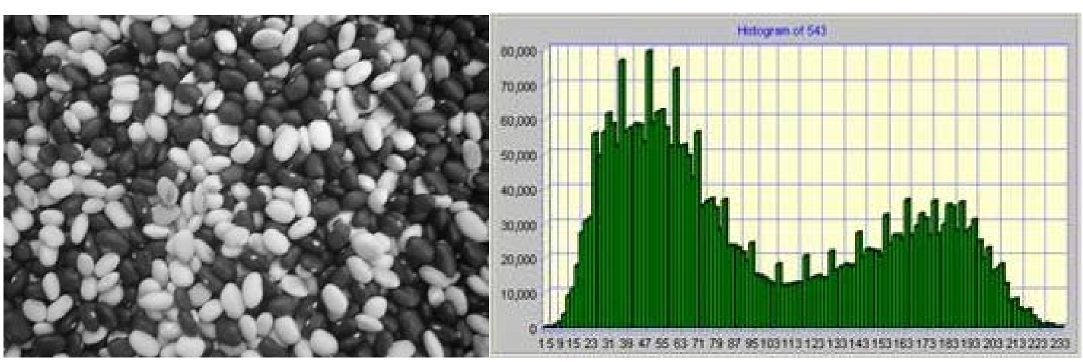

Figure 1. Grayscale sample image and respective histogram.

For image analysis used by Oliveira et al. (2008), an ideal threshold was calculated for each sample based on concentration obtained by tracer mass concentration, i.e., a brightness level whose tracer pixel concentration was equaled to the proportion of tracer in each sample. In the experimental runs, each sample presented a different ideal threshold. Then, all samples images of the same experimental run were treated with a mean threshold calculated by the average all ideal thresholds. It allows the comparison between manual separation method and image analysis method. This method needs at least one experimental run and, consequently, the manual handling (separation) of studied product in order to determine the mean threshold. Then, this mean threshold value can be applied in other experimental runs for the same product. This fact is considered a disadvantage of the method, because of the difficulty in handling particle/granular products.

The adjusted method uses a threshold obtained by a standard image analysis which consists in a histogram of image of some of the material (only the marked or only the marked material). By the image histogram, a threshold which differentiates product and tracer is determined and it can be applied to same product without handling it.

The adjusted method was compared to method presented by Oliveira et al. (2008).

After definition of threshold (by manual separation or standard image), in each sample, using IDRISI software, a reclassification process of samples images was accomplished. Reclassification process consisted in separating pixels above and below the mean threshold of the respective experimental run. With all divided in two classes (tracer and non-marked), it was possible to find the amount of pixels regarding the tracer in each sample.

Using tracer pixels concentration, the same procedure was done for tracer mass concentration. So, based on tracer concentrations and Equations 1, 3 and 4, curves E and F and mean residence time values could be calculated for each experimental run.

In that way, it is possible to compare the mean residence times obtained by applied methods of separation. This comparison was done by mean relative deviation modulus values (MRD). These values represent in percentage the difference between residence time results obtained by different methods.

RESULTS AND DISCUSSION

Material physical properties Some physical properties of black beans were determined (Table 1). These properties allow the experimental material characterization.

Table 1. Physical properties of black beans.

Physical property	Experimental data
Average diameter d	0.0069 m
Apparent density ρ_{ap}	795.9 $kg.m^{-3}$
True density ρ_t	1277.5 $kg.m^{-3}$
Porosity ε	0.377
Sphericity ϕ	0.701

Adjusted image analysis method In the adjusted image analysis method, the threshold was obtained by a histogram of black beans image. Figure 2 shows this standard image and its respective histogram.

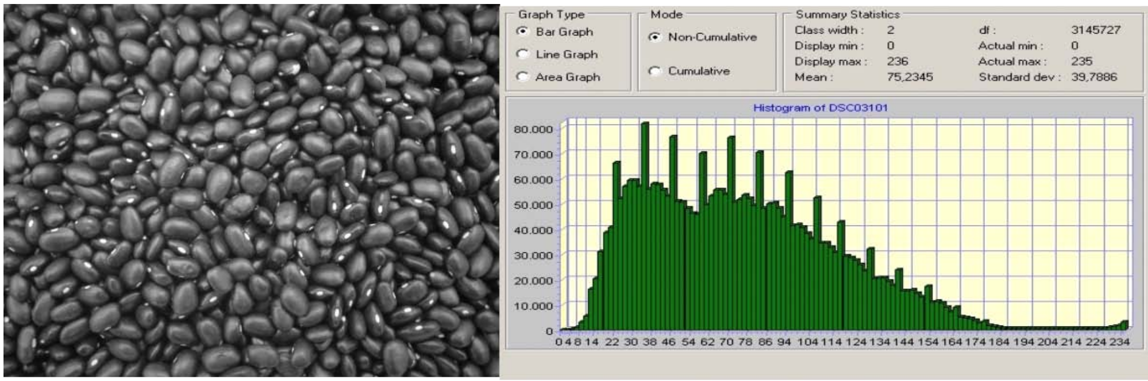

Figure 2. Standard black beans image and its respective histogram.

It can be observed the decrease of pixels amount at right side of histogram until about 190 at the gray scale. In this way, it was considered the threshold value as 190. It means that pixels above this value were considered tracer and pixels below this value were considered black beans.

In these experimental runs analyses, the tracer concentration C (t) was obtained by histogram of the reclassified images. Tracer concentration was the relation between amounts of pixels corresponding to tracer and raw material. After tracer concentration determination, all curves E(t) and F(t) were obtained based on mass fractions and Equations (1) and (3). Curves E and F for all experimental runs are shown on Figures 3 to 7:

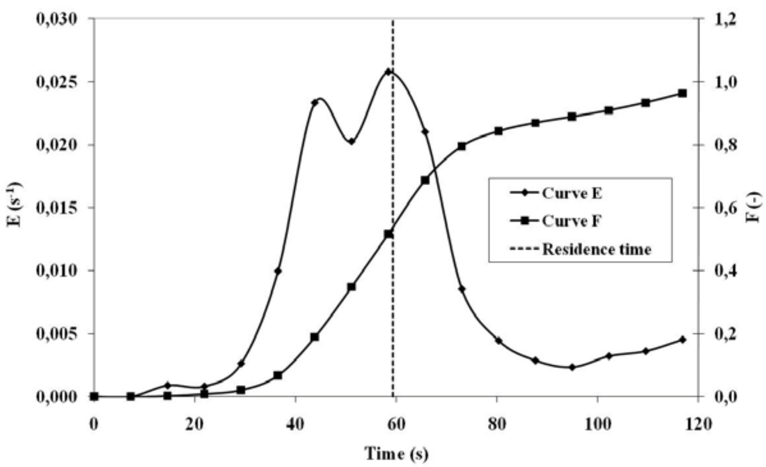

Figure 3. RTD curves and residence time for black beans obtained by image analysis – amplitude 1.

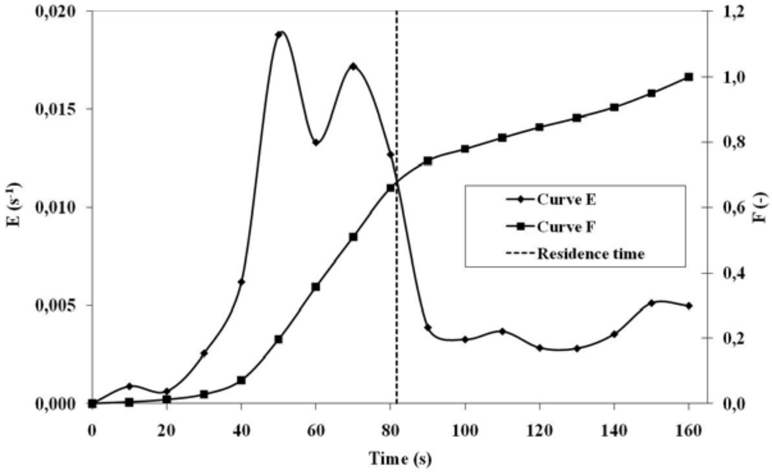

Figure 4. RTD curves and residence time for black beans obtained by image analysis – amplitude 2.

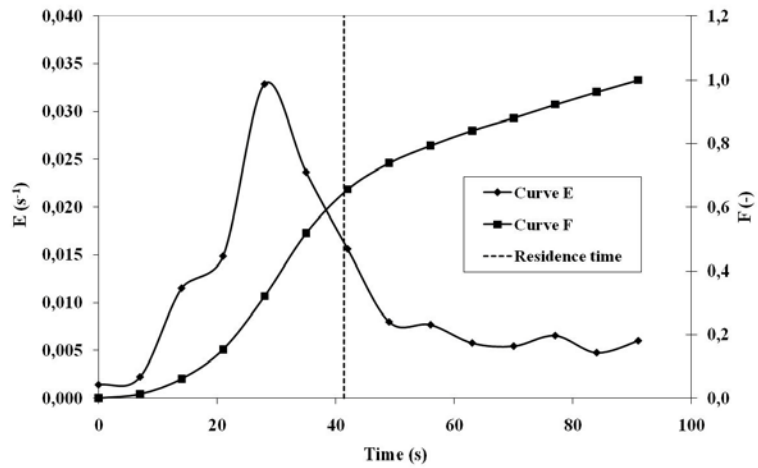

Figure 5. RTD curves and residence time for black beans obtained by image analysis – amplitude 3.

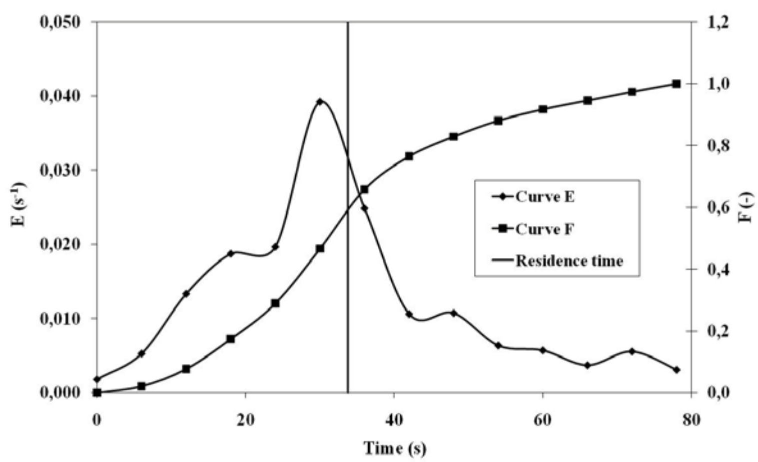

Figure 6. RTD curves and residence time for black beans obtained by image analysis – amplitude 4.

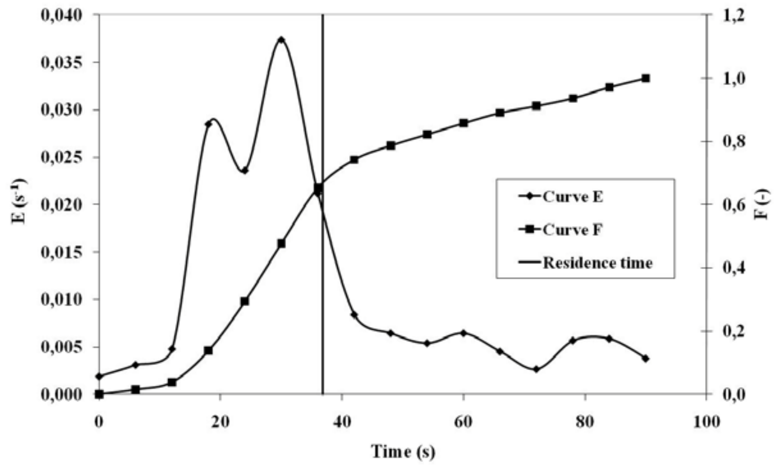

Figure 7. RTD curves and residence time for black beans obtained by image analysis – amplitude 5.

Table 2 shows the mean residence time values obtained by the different method of analysis.

Table 2. Mean residence time and respective M.R.D. values for different methods of analysis (manual separation, image analysis and adjusted image analysis.

	Mean residence time (s)				
Amplitude	Manual Separation	Image analysis	M.R.D. (%)	Adjusted image analysis	M.R.D. (%)
1	28.33	35.77	26.26	36.82	29.95
2	26.75	34.69	29.68	33.76	26.19
3	31.91	42.88	34.38	41.44	29.87
4	57.65	60.67	5.24	59.31	2.88
5	73.73	79.64	8.02	81.59	10.66
		Mean	20.72	Mean	19.91

Comparing the three methods of residence time determination, we can notice that the MRD from both image analysis methods are about 20%. However, the adjusted method presented a lower mean relative deviation modulus. It is not a substantial reduction, but it is close to image method.

CONCLUSION Concerning to residence time distribution determination and applied evaluation methodology, we can conclude that this adjusted image analysis technique is viable in practice. However, it is even necessary a fine adjustment in the treatment of digital images. The adjusted analysis presented lower mean relative deviation. In spite of the reduction was not substantial, this method allowed the residence time determination using only digital images, without any handling or manual procedure.

Acknowledgements. The authors acknowledge the support of The State of São Paulo Research Foundation (FAPESP), The National Council for Scientific and Technological Development (CNPq) and University of Campinas (UNICAMP).

REFERENCES

Brod, F.P.R. 2003. Avaliação de um secador vibro-fluidizado (Evaluation of a vibro-fluidized dryer), PhD Thesis, February 2003, School of Agricultural Engineering, UNICAMP, Brazil.

Brod, F. P. R., K. J Park and R. G. de Almeida 2004. Image analysis to obtain the vibration amplitude and the residence time distribution of a vibro-fluidized dryer. Journal of Food and Bioproducts Processing. 82(c2): 157-163.

Han, W., B. Mai, T. Gu 1991. Residence time distribution and drying characteristics of a continuous vibro-fluidized bed. Drying Technology. 9(1): 159-181.

Keey, R. B. 1972. Drying: principles and practice, Pergamon Press, Oxford.

Keey, R. B. 1992. Drying of loose and particulate materials, Hemisphere Publishing Corporation, New York.

Kunii, D., O. Levenspiel 1991. Fluidization engineering, Butterworth - Heinemann, Washington.

Levenspiel, O. 1972. Chemical reaction engineering, John Wiley & Sons, New Jersey.

Oliveira, R. A. de, K. J. Park, B. S. Oliveira. 2008. Residence time by image analysis on a vibro-fluidized dryer. International Drying Symposium – IDS' 2008, Hyderabad, India. Proceedings… 2008. 778-785.

Yagi S, D. Kunii 1961. Fluidized-solids reactors with continuous solids feed - I: Residence time of particles in fluidized beds. Chemical Engineering Science. 16: 364–371.

Yang, W. C. 2003. Handbook of fluidization and fluid-particle systems, Marcel Dekker, New York.