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Plotting Residence Time Distribution Diagram for a Two-Dimensional Airlift Reactor Using Imagej Software

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***Abstract*—**In this paper, the residence time distribution (RTD) diagram has been plotted for a two-dimensional airlift reactor. For this purpose, after injecting the tracer, the reactor has been photographed during specified time intervals. The images have been analyzed by the imageJ software and the residence time distribution diagram for two zones of the reactor (the riser and the downcomer) has been obtained. The Bodenstein number for the downcomer and the riser was obtained 12.5 and 4 respectively. This method could be used to find out the hydrodynamic of some reactors for more efficient mixing. Some of the advantages of this method than prior methods of the RTD measurement are the more accuracy of it, minimization delay time in measurement and the low cast of it.

***Keywords*—** residence time distribution, imageJ, airlift reactor

I. Introduction

As it has been known, the behavior of real reactors is often very different from the ideal reactors. The residence time distribution (RTD) of a reactor is one of the most important hydrodynamic characteristic of each reactor. Knowledge of the liquid RTD is significant for a number of reasons, being an aid in reactor design to reach a desired flow pattern, and allowing for a correct kinetic modeling of the system [1,2]. There is an extensive range of experimental techniques that available to measure the liquid element's RTD in reactors. The simplest and most direct way of finding the RTD is using a physical or nonreactive tracer. The properties of the tracer (such as density, viscosity, sometimes interfacial tension and miscibility) must as close as possible to those of the medium [3,4]]. Some of the important experimental techniques to find RTD for liquid phase are using:

- Chemically different tracers [5,6,7]
- Refractometry [3]
- radioactive tracers [8,9]
- thermal tracing [10]
- dye tracers [3,6]

The last method is direct, inexpensive, and excellent for deriving a primary qualitative idea of the paths taken by the liquid. It also helps obtain data very quickly on the effect of changes in specific operating conditions, or in the geometry of a specific internal component.

In this paper, the residence time distribution diagram of a two dimensional airlift reactor has been plotted using imageJ software. ImageJ is a public domain Java image processing and analysis program. In RGB stake images the gray value of each pixel is between 0-255 that zero is awarded to the black color and 255 to the white color and it can be inverted. The profile of each image displays a two-dimensional graph. The X-axis represents the length of the image, and the Y-axis represents the average gray values of pixels along a vertical line within the image. Figure 1 illustrates an example of this profile.

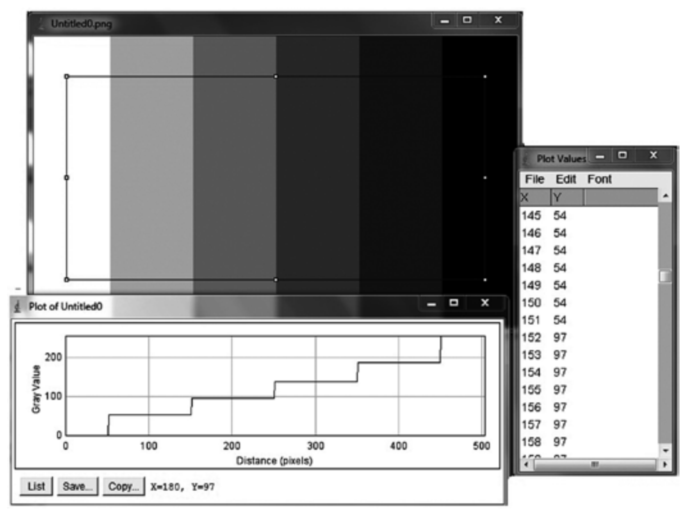

Fig.1.The graph is depicted for the selected area of the image by imageJ software

II. Experimental

A. Experimental strategy

The RTD of the liquid phase was plotted for a two-dimensional airlift reactor. The reactor size is 3×10×50cm. A glassy wall with a width of 4cm has divided the reactor into two parts. In one side of the wall, there are four needles as air bubble distributors. The height of the internal wall is 40cm Figure 2 illustrates the reactor. Blue ink has been injected into the reactor as the tracer. Figure 2 illustrates the reactor. Blue

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ink has been injected into the reactor as the tracer. Before injecting the tracer and after that, the reactor has been photographed in specific time intervals (1 sec) up to the color of the tracer in the reactor reaches to the uniform state. During photographing, the camera has been fixed, without any motion. Figure 3 illustrates the photos.

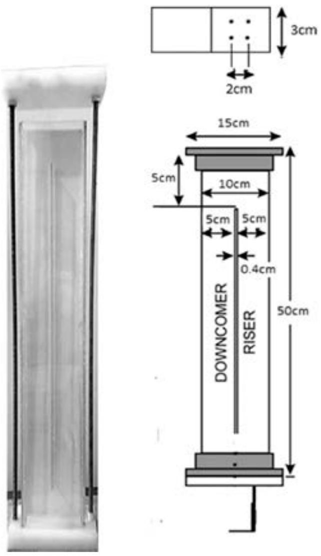

Fig.2. The experiment reactor

B. Using imageJ to find concentration versus time curve

RTD diagram has been plotted for two zones of the reactor, the riser and the downcomer. For this purpose the desired parts of all the photos have been cut in the same size, by stacks option of the imageJ (figure 4), then the value versus distance diagram has been plotted for each image. In the figure 5 this diagram has been plotted for six photos of the downcomer zone.

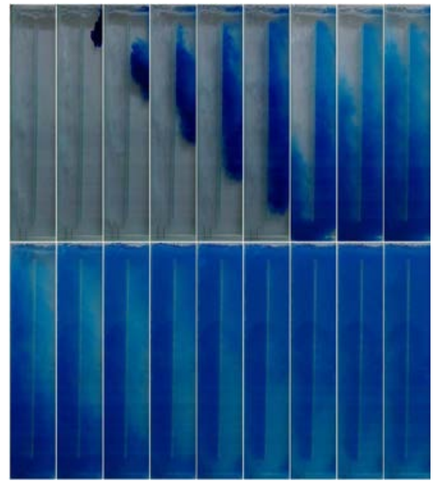

Fig.3. The reactor at t=0 (before injecting the tracer) up to t=18sec (steady state condition)

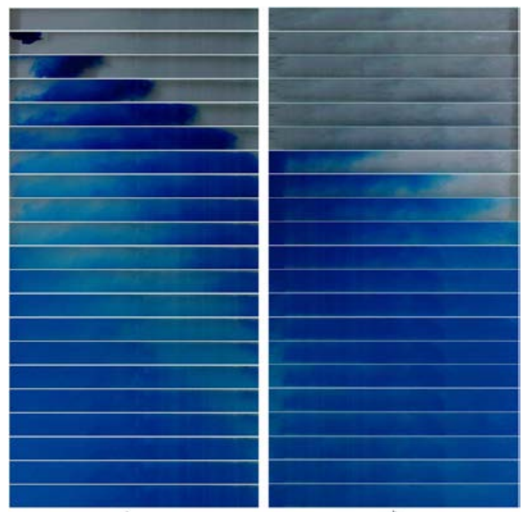

Fig.4. a) The downcomer zone of the reactor at t=0sec (before injecting the tracer) up to t=20sec (steady state condition), b) The riser zone of the reactor at t=0sec (before injecting the tracer) up to t=20sec

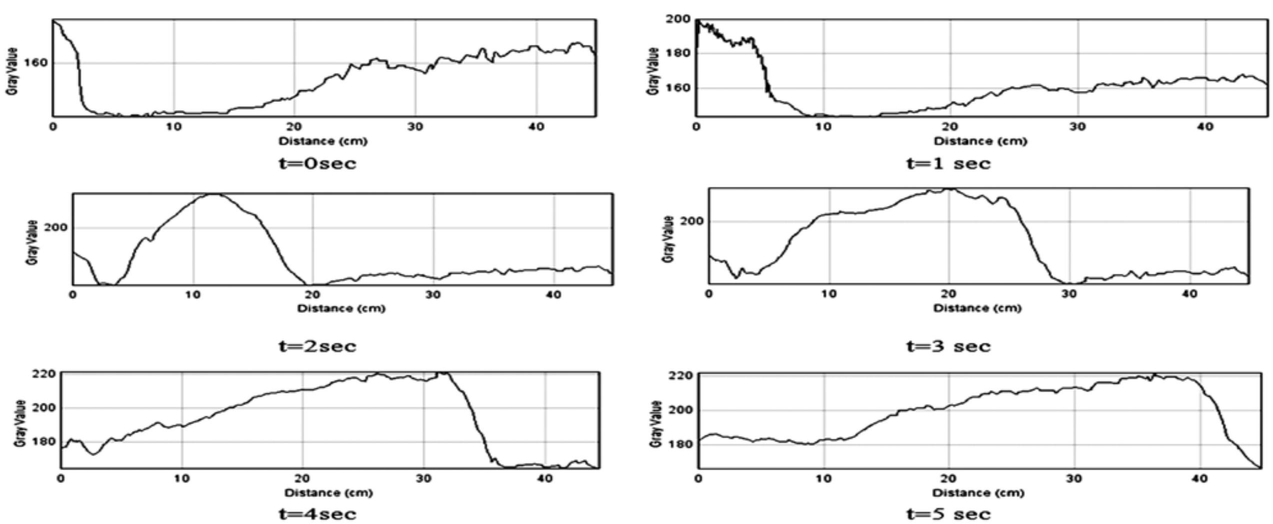

Fig.5. The gray value versus distance (length of the downcomer) profile for the downcomer zone, for the first six photos before (t=0 sec) and after injection the tracer obtained by the imageJ software

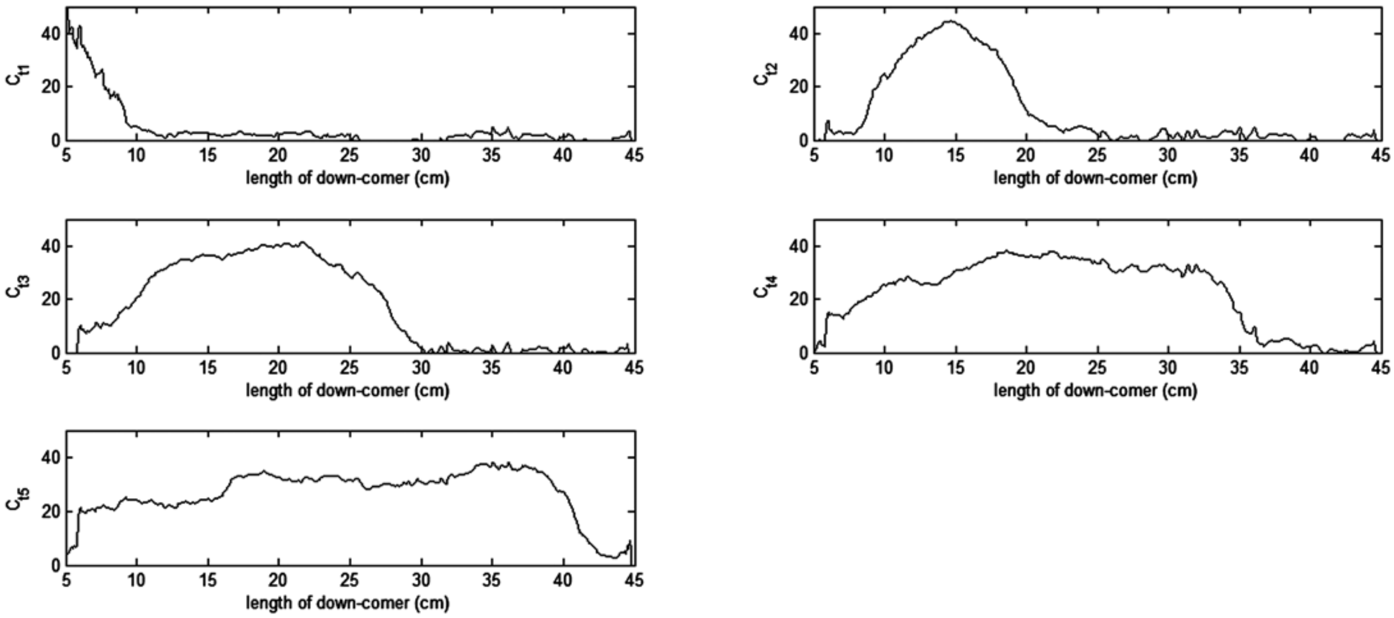

Fig.6. Real gray value of the tracer versus the length of the downcomer after injection the tracer

The first diagram in the figure 5 is related to the downcomer zone before injecting the tracer, so the gray value in each point of this diagram has been considered the base gray value and has been subtracted from the gray value of each corresponding point of the other images.

$$t=t_i \qquad C_{ti} = C_i - C_0 \qquad (1)$$

C_i: The gray value of each point at $t=t_i$
C_0: The gray value of each point at t=0 sec (before injecting the tracer)
C_{ti}: The real gray value of the tracer of each point at $t=t_i$
The new gray value of the tracer, C_{ti}, has been plotted versus the length of the reactor's downcomer again (figure 6). All of the diagrams of each image have been plotted in one scale. Figure 7 illustrates the diagrams of the five photos, after injecting the tracer, for downcomer zone.

To find the concentration versus time curve from this data for each zone of the reactor, a vertical line has been drawn in the desired length of the downcomer. Intersection of this line with each curve indicates the gray value of the tracer in this length at each moment (figure 7).

C. Measurement of residence time distribution

The curve *C(t)* allowed us to find the residence time function. For this purpose the *C(t)* curve has been plotted for the first circulation of the liquid with tracer in the whole of the reactor, starting with liquid entrance in the downcomer, without liquid recirculation. The circulation time of the liquid is 10 seconds, so the *C(t)* curve has been plotted for the first 10 seconds after injecting the tracer.

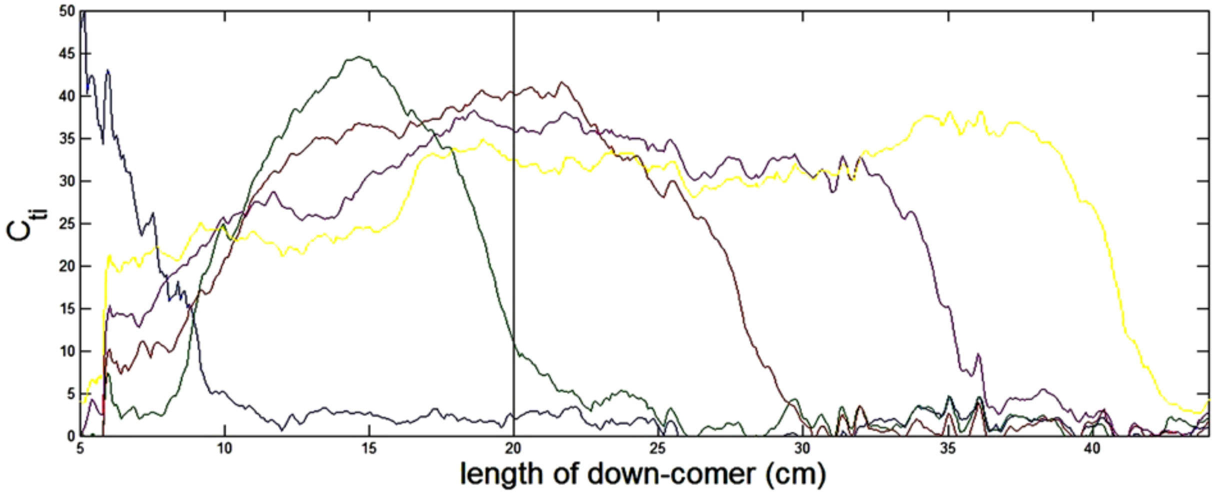

Fig.7. Gray value of the tracer at each second versus length of the downcomer for the first five seconds after injection the tracer, (blue: t=1sec, green: t=2sec, red: t=3sec, violet: t=4sec, and yellow: t=5sec after injection the tracer), Intersection of the vertical black line with all the curves at the 20cm length of the downcomer zone, indicates the gray value of the tracer at each moment.

To obtain the *E(t)* curve from the *C(t)* curve, we just divided *C(t)* by the integral:

$$\int_0^\infty C(t)dt \qquad (2)$$

which is just the area under the C curve. This area can be found using the graphical integration.

$$E(t_i) = \frac{C(t_i)}{\sum_{i=1}^{n} C(t_i)\Delta t_i} \qquad (3)$$

E(t) is the most often used of the distribution functions which are related to reactor analysis. Figure 8 illustrates the RTD diagram for the 20cm length of the downcomer zone.

III. Results and Discussion

In the figure 9 the RTD diagram is plotted for different Lengths of the downcomer. In the downcomer section, where the flow is monophasic, the E function illustrates the deviation from plug flow with dispersion. By circulation of water in the reactor, axial dispersion has occurred and the spread of distribution has increased during the downcomer length.

The axial dispersion number Bo has been estimated for the downcomer and the riser zones by using the axial dispersion model (Eq. (4)) [1]:

$$\frac{\partial C}{\partial \theta} = \frac{1}{Bo}\frac{\partial^2 C}{\partial x^2} - \frac{\partial C}{\partial x} \qquad (4)$$

where Bo is the Bodenstein number and θ has been obtained from Eq.(5):

$$\theta = \frac{t}{\bar{t}} \qquad (5)$$

and

$$\bar{t} = \int_0^\infty tE(t)dt \qquad (6)$$

The solution of the Eq.4 for an initial Dirac pulse in the airlift reactors considering the first circulation is given by [1,11-13]:

$$C = \left(\frac{Bo}{4\pi\tau}\right)^{0.5} \exp\left[\frac{(x-\theta)^2 Bo}{4\theta}\right] \qquad (7)$$

For a single circulation in the reactor the Bodenstein number has been determined by using Eq.8:

$$\frac{\sigma^2}{\bar{t}^2} = \frac{2}{Bo} + \frac{8}{Bo^2} \qquad (8)$$

where σ is the spread of distribution and it was obtained from the following relationship:

$$\sigma^2 = \int_0^\infty (t-\bar{t})^2 E(t)dt \qquad (9)$$

Fitting the model to the experimental response for an initial Dirac function, the Bodenstein number for the downcomer and the riser has been obtained 12.5 and 4 respectively.

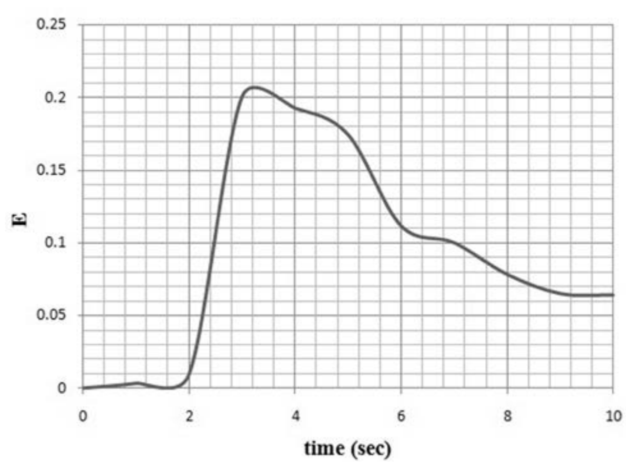

Fig.8. RTD diagram for the 20cm length of the downcomer zone

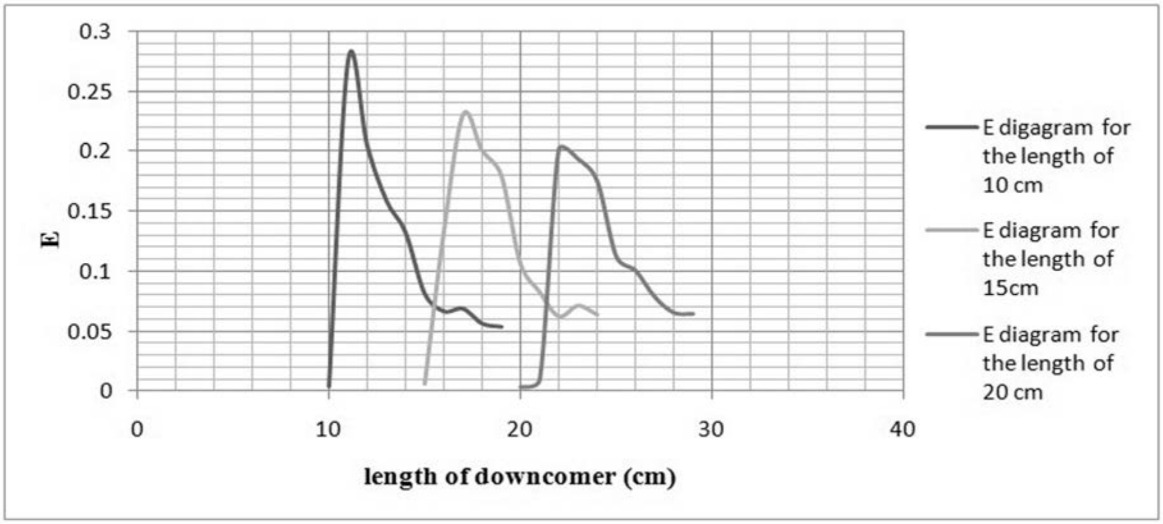

Fig.9. The RTD diagram for different lengths of the downcomer zone (the third graph of this figure is the same graph in the fig. 8)

In the riser section, which contains a disperse flowing gas-liquid mixture, the deviation from ideal flow is more evident than the downcomer zone because the presence of the gaseous phase generates intensive shear rates which promote axial dispersion. So we can conclude that it has a somewhat better mixing performance than the downcomer zone. In the figure 10 the RTD diagram has been plotted for the riser zone of the reactor. The RTD diagram after 10 seconds (circulation time) not reach to zero because the diagram has been plotted for the first circulation of the liquid in the reactor and the tracer's concentration not reach to zero.

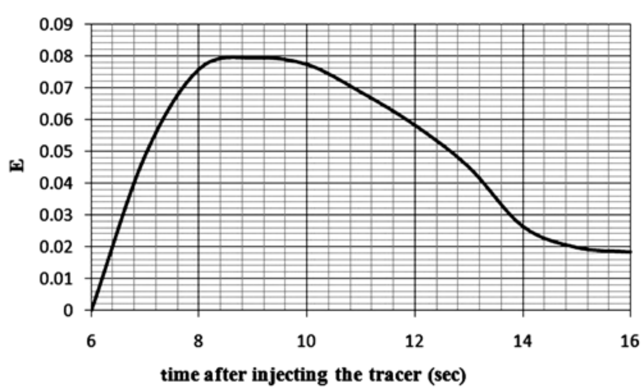

Fig.10. The RTD diagram for the 15cm length of the riser zone of the reactor

IV. CONCLUSION

Data on the RTD functions in the two-dimensional airlift reactor give information on the time spent by various fluid elements in the reactor and has been obtained using a new method to detect the pulse response. The reactor has been photographed during specified time intervals. The images have been analyzed by the imageJ software and the residence time of distribution diagrams for two zones of the reactor (the riser and the downcomer) have been obtained. The advantages of this method than prior methods of evaluating concentration distribution, which used some probes for recognition concentration of the tracer in each zone, are the more accuracy of it, minimization delay time in measurement and the low cast of it.

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