SOLID-PHASE DWELL TIMES IN THE CENTRAL AND PERIPHERAL PARTS OF A GAS–SOLID JET

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Dwell-time measurements are reported for the core and periphery of a fluidized bed.

An over-fluidized bed is used in heat treatment of powders; the particles are heated in an oscillatory fashion. The heat transfer between phases at the core of the bed is accompanied by entrainment in the gas jet, and particles at the core are heated to a temperature above the mean temperature of the bed. These particles then give up their excess heat to cold particles entering the bed at the periphery. Therefore, it is necessary to know the times $\Delta\tau$ spent by the solid in each of the zones separately in heat-transfer calculations.

Some information is available [1-3] on dwell times for the periphery, which is derived from visual observations on particles; this evidence is rather qualitative because the speeds of particles at the wall differ from the mean speed within the main body of particles even in a given section of the periphery. Nevertheless, the results do indicate the general order of $\Delta\tau_p$ and the relevant factors. Nothing appears to have been published on the determination of $\Delta\tau_c$, which is evidently due to the difficulty of direct measurement. Some evidence has been given on $\Delta\tau_c$ [4-6], which was derived from measurements on individual particles in the core by means of piezoelectric transducers [4, 5]; radioactive particles have also been used [6]. However, the parameters were varied over a comparatively narrow range, particularly those that affect $\Delta\tau_c$, and not all features of the phenomena were identified.

A method has been described [7] for determining the complete cycle time in a bed by means of a particle bearing a permanent magnet. When this particle passes through the plane of a coil in the upper part of the core, the resulting emf is recorded on an oscilloscope. The circulation time is determined from the intervals between the pulses. In these experiments, all the particles performed only complete circulation loops. On the other hand, the individual cycle times varied widely, which indicates that the process is stochastic.

A deficiency of the method of [7] is that generation of a reliable signal requires either that the particle move with a high speed or that the magnet be strong, which increases the size of the particle. Also, the coil is large, which may influence the structure of the bed. This naturally restricts the scope for using this method, in particular, for separate determination of $\Delta\tau_c$ and $\Delta\tau_p$.

Here we describe a method of determining these times and present results for various apparatus dimensions and working parameters.

The system was a combination of cylinder and cone of diameter 210 mm, in which the cone angle could be varied (β = 60 and 90° and d_0 = 30, 50 and 70 mm); the materials were narrow fractions of aluminosilicate catalysts (δ = 2.5 and 3.5 mm, ρ_s = 1200 kg/m^3), an explosive (δ = 7.3 mm and ρ_s = 1400 kg/m^3), and glass spheres (δ = 2.7 mm and ρ_s = 2600 kg/m^3); air was the fluidization medium.

The values of $\Delta\tau_c$ and $\Delta\tau_p$ were determined by detecting tagged particles passing through certain parts of the core, which contained coils connected in an ac bridge (Fig. 1). The tagged particles were made from a mixture containing ferrite powder and an appropriate filler, and they did not differ in size and density from the main material. A tagged particle passing through the coil alters the inductance, so a signal is produced in the bridge diagonal, which is amplified and detected for recording. There were two coils in the core, one at a height H_0 and the other at a distance h = 30 mm from the plane of the inlet. Coils of internal diameter 60 mm were used. It has been found that all the particles moving in the core then pass through the plane of the coil.

The time spent in the core was deduced from the difference in time between the pulses in the lower trace (passage through the lower coil) and the next following pulse in the upper trace (passage through the upper

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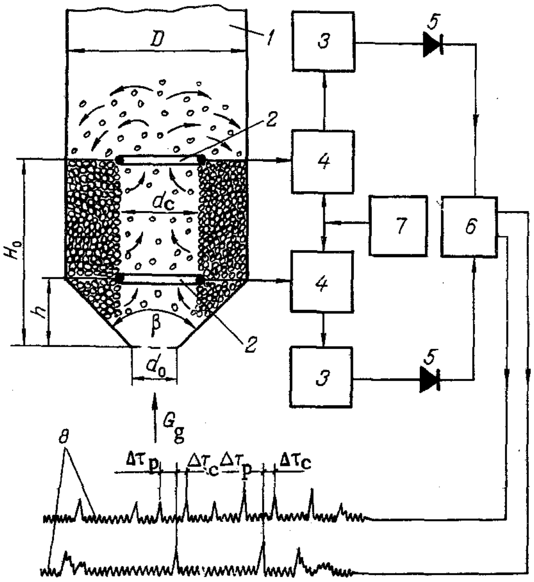

Fig. 1. The apparatus: 1) fluidized bed; 2) coil; 3) ac amplifier; 4) ac bridge; 5) detector; 6) loop oscilloscope; 7) audio oscillator; 8) oscillogram.

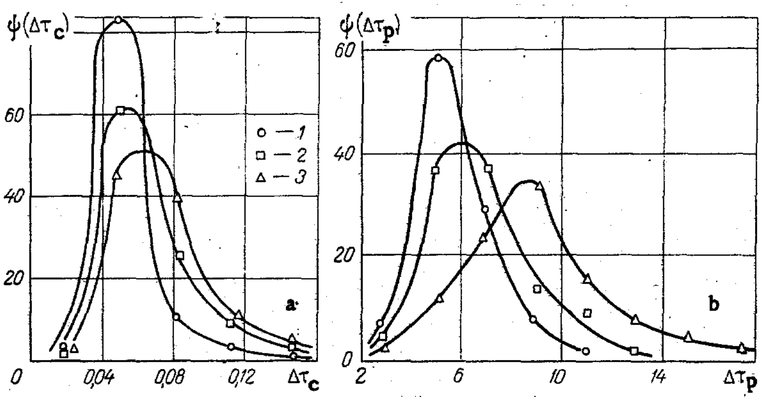

Fig. 2. Histograms for dwell times in core (a) and at periphery (b): 1) $G_g = 236$ kg/h; 2) 188; 3) 157. $\psi(\Delta\tau_p)$, %; $\Delta\tau_p$, sec.

coil), while the time spent in the periphery was the time between a pulse in the lower trace and the closest preceding pulse in the upper one.

It was found that the frequency of passage through the upper coil was greater than that for the lower one, which indicates that the particles enter the core throughout the height.

The time spent in the core was less than that at the periphery by about 2 orders of magnitude; it is therefore desirable to determine $\Delta\tau_c$ and $\Delta\tau_p$ separately and for different recording speeds. Also, several (3-5) tagged particles were present in determining $\Delta\tau_c$. The core contains only a small fraction of the total number of particles, and the time spent in the core is only a fraction of a second, so it is unlikely that two or more tagged particles will be present in the core together. There was always only one tagged particle in the bed when $\Delta\tau_p$ was determined.

The mean dwell times for each of the zones were derived from 150-300 individual measurements, the exact value being dependent on the working conditions; this ensured that the mean dwell time, which is defined as $\Sigma\Delta\tau/m$, where m is the number of measurements, would differ from the population mean by not more than ±10% with a probability of 0.95.

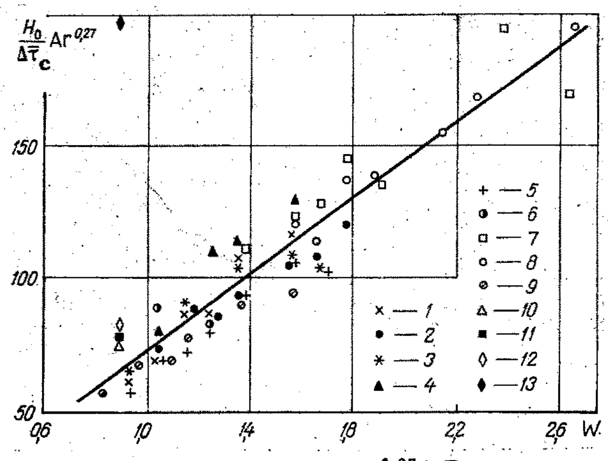

Fig. 3. W dependence of $H_0 Ar^{0.27}/\Delta\bar{\tau}_c$: 1-5, 7-9) β = 90°; 6) 60°; 1-3, 5-9) d_0 = 50 mm; 4) 30; 1-4, 6) δ = 3.55 mm; ρ_s = 1200 kg/m^3; 5) 2.7 and 2600; 7, 8) 7.3 and 1400; 9) 2.5 and 1200; 1, 7, 9; 3-5, 8; 6; 2) H_0 respectively 120, 180, 215 and 240 mm; 10-13) D = 94 mm; d_0 = 15 mm; β = 45° [5]; 10) δ = 4 mm, ρ_s = 1400 kg/m^3, H_0 = 100 mm; 11) 3-5 mm, 1040 and 115 mm; 12) 3.6, 1420 and 100; 13) 1.5-2, 1040-1200 and 250. W, m/sec.

This method provided the statistical characteristics of the dwell times (mean, dispersion D, and coefficient of variation $\sqrt{D}/\Delta\bar{\tau}$) for particles performing complete circuits.

Figure 2 shows histograms for the time spent in the core (Fig. 2a) and at the periphery (Fig. 2b) for one particular series. The histograms for other conditions were similar. The distributions are skewed and are nearly log-normal in form. The dispersion at the periphery decreases as the air flow rate increases. For example, D = 12.5 sec^2 for W = 0.93 m/sec, whereas the value is 2.84 sec^2 for W = 1.47 m/sec. The coefficient of variation also decreases from 0.36 to 0.30. There was no obvious correlation between D and W for the core. The core showed more clearly a relationship between D, H_0, and Ar. The histograms show that $\Delta\tau_c$ and $\Delta\tau_p$ vary fairly widely under given conditions. The main reason is that the particles follow random paths in the core and at the periphery. Also, the bed does not have a stable structure, since pulsations occur. On the other hand, the mean time spent in the core is fairly closely related to the major parameters, and the following relationship (Fig. 3) applies:

$$\frac{\Delta\bar{\tau}_c W}{H_0} = 0.014\,Ar^{0.27}, \quad (1)$$

which is correct for $0.68\cdot10^6 \le Ar \le 19.6\cdot10^6$ and $120 \le H_0 \le 240$ mm; no effects on $\Delta\bar{\tau}_c$ from the cone angle and inlet-held diameter were detected.

These results show direct proportionality between $\Delta\bar{\tau}_c$ and H_0, which indicates that the mean speed of the solid within the core is virtually independent of the initial depth of the bed, so it is possible to assume that the particles in the core move uniformly with a mean speed $\bar{U}_c = H_0/\Delta\bar{\tau}_c$ for the purpose of calculations on heat and mass transfer. Other results [5] are in qualitative agreement with ours as regards the effects of the flow rate and the characteristics of the solid phase on the mean speed and core dwell time. The value of $\Delta\bar{\tau}_c$ given in that paper as derived from the longitudinal velocity distributions for particles of silica gel (δ = 4 mm) and polystyrene (δ = 3-5 mm) differ from those given by (1) by 15-20%. More marked discrepancies occur for small particles of polystyrene and starch (Fig. 3).

There is a clear correlation between the mean dwell time and the reciprocal of the gas flow speed (Fig. 4) for the periphery of the bed:

$$\Delta\bar{\tau}_p = AW^{-1}. \quad (2)$$

This agrees with other results [1-3].

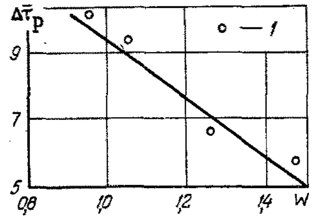

Fig. 4. W dependence of $\Delta\bar{\tau}_p$: 1) observed points (d_0 = 50 mm, β = 90°, H_0 = 165 mm, δ = 3.55 mm, ρ_s = 1200 kg/m³). W, m/sec; $\Delta\tau$, sec.

The coefficient of proportionality A is dependent not only on Ar but also on the geometry of the apparatus, the mass of the bed, and the reduced height H_0/δ; A = 8.67 for the conditions of Fig. 4.

NOTATION

- d_0 is the diameter of inlet;
- D is the variance;
- G_g is the mass flow rate of gas;
- U is the particle velocity;
- h is the distance from inlet;
- H_0 is the height of bed;
- W is the gas velocity calculated for cylindrical cross section;
- β is the vertex angle of cone;
- $\Delta\tau$ is the particle dwell time;
- $\Delta\bar{\tau}$ is the mean particle dwell time;
- δ is the particle diameter;
- ρ_s is the particle density;
- Ar is the Archimedes number;
- p is the periphery;
- c is the core.

LITERATURE CITED

1. S. V. Kalinnikov, V. S. Afremtsev, A. F. Dolidovich, and O. D. Makarova, in: Heat and Mass Transfer in Two-Phase Systems during Phase Transitions and Chemical Reactions [in Russian], Nauka i Tekhnika, Minsk (1976).
2. H. A. Becker, Chem. Eng. Sci., 13, 4 (1961).
3. A. D. Gol'tsiker, "Structure and hydrodynamics of fluidized beds," Author's Abstract of Candidate's Dissertation, LTI im. Lensoveta, Leningrad (1967).
4. A. E. Gorshtein and I. P. Mukhlenov, Zh. Prikl. Khim., 40, 11 (1964).
5. V. D. Mikhailik and N. V. Antonishin, Vestsi Akad. Nauk B. SSR, Ser. Fiz.-Tekhn. Nauk, No. 1 (1967).
6. D. Van Velzen, H. J. Flamm, H. Langenkamp, and A. Casile, Can. J. Chem. Eng., 52, 2 (1974).
7. Uzi Mann and E. J. Crosby, Can. J. Chem. Eng., 53, 10 (1975).