An in situ turbidimetric sensor for measuring solid concentration profiles in a stirred tank

P. Sessiecq, Frédéric Gruy, Michel Cournil

AN IN SITU TURBIDIMETRIC SENSOR FOR MEASURING SOLID CONCENTRATION PROFILES IN A STIRRED TANK.

SESSIECQ P., GRUY F. and COURNIL M.

Département SPIN, Ecole des mines de Saint-Etienne
158 cours Fauriel - 42023 SAINT-ETIENNE CEDEX (France)

Abstract

Local solid concentration profiles were investigated in a contoured bottom cylindrical reactor, mechanically stirred by a 45 pitched blade turbine and equipped with baffles. The solid-liquid system was formed by water and spherical glass beads or alumina powder. The effect of stirring rate and physical properties of solid were examined and compared with profiles given by the litterature.

Introduction

In many industrial units such as polymerisation reactors and fermentors, in dissolution and crystallization processes, in many catalytic operations... the knowledge of the condition for complete suspension often does not suffice for the design of these heterogeneous reactors, it is necessary to have information on the distribution of solid particles within the agitated liquid. There have been few reported studies in which the distribution of particles in the agitated liquid has been investigated systematically. This is the aim of the present work. In order to obtain information on the solid distribution, one requires measurements of the solid concentration at different locations in the vessel. To do it, the simplest method consists in sampling suspension aliquotes followed by off line concentration measurements. Nevertheless particle inertia can cause significant error when the particle and fluid velocity vectors are different (Typically in the case of non isokinetic sampling and/or large density difference between solid and fluid). Moreover, the shape of the sampling tubes has a strong influence (Barresi et al. 1987, Nasr-El-Dim et al. 1989, Smith 1990...). Despite this serious inconvenience, sample withdrawal continues to be used as a method of determining local solid concentration in mixed tanks (Barresi et al.1994).
The possibility of in situ measurements is of highest interest for studying solid concentration profiles. In situ sensors have been developped only recently. Several authors employed a conductivity probe (Nasr-El-Din et al. 1987, MacTaggart et al. 1993...) observing that non conducting particles suspended in a conducting liquid reduce the global conductance of the systems. But any electrolyte addition and temperature fluctuation will drastically alter the fluid conductivity and complicate the solid concentration measurements. In this study, a turdidimetric sensor has been used to characterize in situ the solid concentration profile. This method permits us to measure the solid concentration and also gives us information on particle distribution.

Experimental section

Turbidimetry

The optical properties of a medium are characterized by a refractive index. When there are discrete variations in this index due to partcles in suspension, part of the radiation will be scattered in all directions. The turbidity of a suspension of particles represents a measurement of the attenuation of of the transmitted light beam intensity by light scattering. For a suspension of particles, the extinction phenomenon is described by :

$$\tau = \frac{1}{L} \ln\left(\frac{I_0}{I}\right)$$

where τ is defined as the turbidity, I_0 is the intensity of the incident beam, I the intensity of the transmitted beam after an optical path of length L.
Turbidity is related to the PSD by the Mie theory (Van dd Hulst 1957, Kerker 1969). For a polydisperse suspension of N particles per unit volume, the turbidity at wavelength λ is given by :

$$\tau(\lambda) = \frac{N\pi}{4} \int_0^\infty d_p^{\,2} f(d_p) Q(d_p) dd_p$$

where $f(d_p)$ is the population density of the particle diameter d_p and $Q(d_p)$ the Mie scattering coefficient. Their determination requires the knowledge of the refraction indices of the different media (Kerker 1969).

Materials and reactor

The experiments were carried out in a cylindrical vessel with a diameter T equal to 0.15 m. The vessel was equipped with four baffles, T/10 in width, and the liquid depth H, in the vessel was equal to the diameter (H/T=1).The base of the tank was contoured. Agitation was ensured by a 45 pitched blade turbine impeller D=T/3 with four blades pumping downwards. Local solid concentration in the stirred tank was measured using a turbidity probe mounted at different axial positions along the vessel wall (r/R=0.6) midway between two baffles from near the bottom of the tank (z/H=0.1) to near the top free liquid surface (z/H=0.93). The experimental set-up is shown in figure 1. A polychromatic light beam is passed to the sensor by optical fibres. After this light has crossed the sensor window, where it is scattered by the particles in suspension, the transmitted light is led again via optical fibres to a photodiode array spectrophotometer which delivers the turdidity spectrum of the suspension. The pratical and theoretical details of this method have been described in Crawley (1994) and Crawley and al (1995).
The working fluid employed was water and the particles used where glass beads (ρ=2600 kg/m^3) with mean particle size of 240 µm and spherical alumina particles (ρ=3980 kg/m^3) of narrow size distribution ($\bar{d}_p$=44µm).

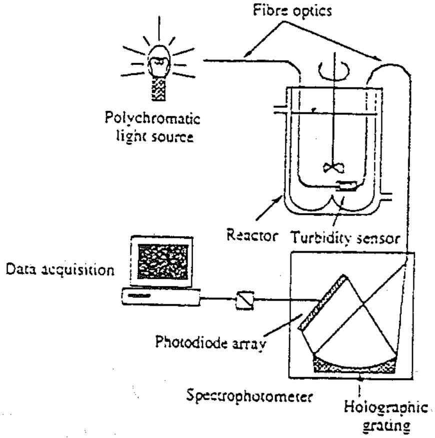


Figure1 : Experimental set-up

Results and perspective

Figures 2 and 4 show the variation of the local solid concentration with the axial distance for the 236 µm glass bead and alumina powder at a normalised radial position r/R of 0.6 for different stirring rates. In general, the geometry of a contoured vessel is considered to be particularly favourable to ensure both a good agitation and a good homogeneity of the suspension (Nienow 1985), figures 2 and 4 show that the experimental axial profile is flat only at high rotational speed and for small particles. Local solid concentration is low near the liquid surface and increases toward the bottom of the tank. Both profiles have a maximum solid concentration above the impeller plane. This particularity has been already found by conductivity method (Nasr-El-Din 1996) and by sampling method (figure 3). Our aim now is to validate a sedimentation-dispersion model for solid distribution in mixed tanks, using the solid concentration profiles found in this study.

Literature cited

Barresi, A., Baldi, G., 1987, Chem.Eng.Sci.., 42, 2949-2956

Crawley, G.M., 1994, Ph D Thesis, INP Grenoble, France (1996)

Crawley, G.M., Di Benedetto, D. and Cournil, M., 1996, Powder Technology, accepted

Kerker, M., 1969 "The scattering of light and the other electromagnetic radiation", Acad. Press, New York (1969)

MacTaggart, R.S, Nasr-El-Din, H.A., Masliyah J.H., 1993, Sep.Technol, 3, 151-160

Nasr-El-Din, H.A., Afacon, A., Masliyah, J.H., 1989, Chem.Eng.Commun., 82, 203

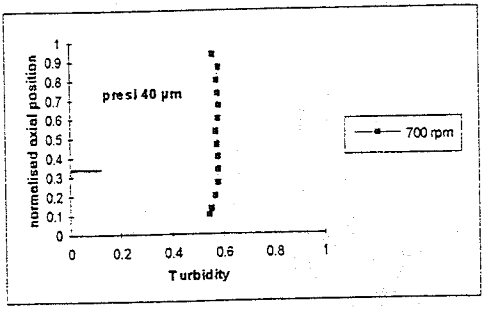
Nasr-El-Din, H.A., Shook, C.A., Colwell, J.M., 1987, Int.J.Multiphase Flow, 13, 661-670

Nasr-El-Din, H.A., MacTaggart, R.S., Masliyah, J.H., 1996, Chem.Eng.Sci., 8, 1209-1220

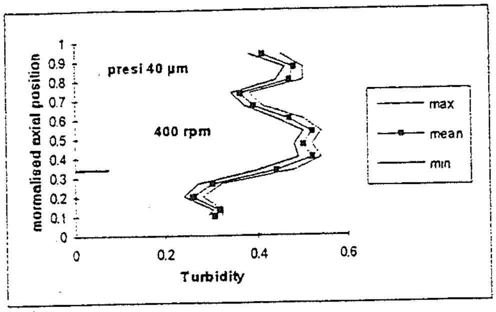
Nienow, A.W., 1985, The suspension of solid particles in, Mixing inthe process industries, edited by N. Harnby, M.F. Edwards and A.W. Nienow, Butterworths, London

Smith, J.M., 1990, Trans.I.Chem.E., 68, 3-6

Van de Hulst, H.C., 1957, "Light scattering by small particles", Wiley, New York



(2a)



(2b)

Figure 2 : Solid concentration profiles for alumina powder in fonction of stirring rate (2a) 700 rpm, (2b) 400 rpm

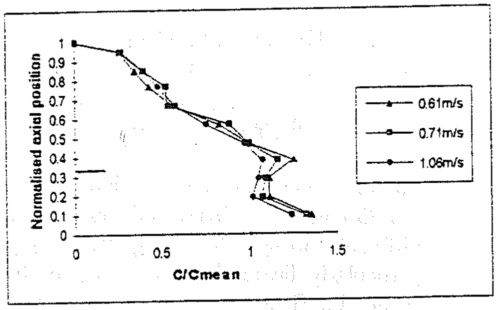
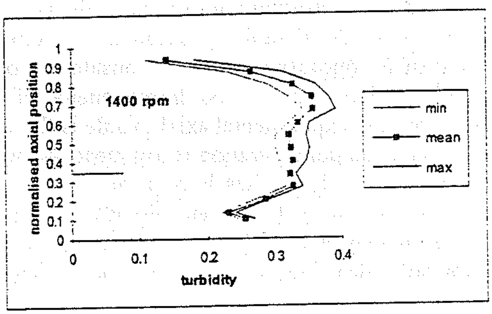
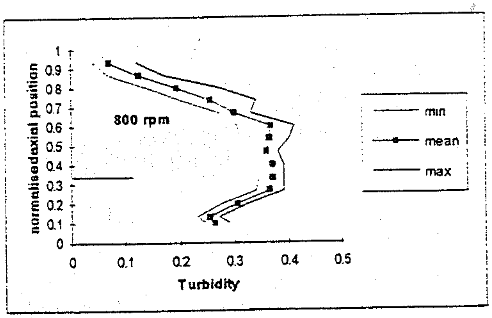


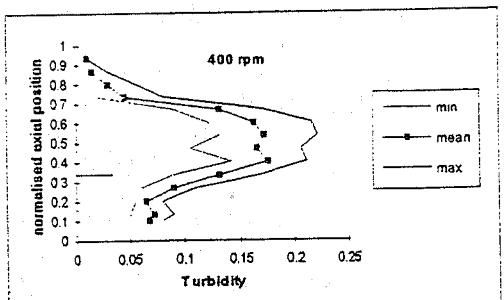
Figure 3 : Influence of the withdrawal velocity on the axial concentration profiles. Experiments of Barresi 1987 in the same experimental conditions for glass beads [208-250µm], 400 rpm.



(4a)



(4b)



(4c)

Figure 4 : Solid concentration profiles for glass beads in function of stirring rate (4a) 1400 rpm, (4b) 800 rpm, (4c) 400 rpm