Military Technical College
Kobry Elkobbah,
Cairo, Egypt

8th International Conference
on Aerospace Sciences &
Aviation Technology

EXPERIMENTAL INVESTIGATION OF THE CEMENT- AIR CYCLONE EFFICIENCY

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ABSTRACT

The following work is an experimental investigation of the cement – air cyclone efficiency. A Test cyclone is designed to measure the collection efficiency of cement powder at different flow speeds. The cement powder is sifted into patches of closer particle size. The cyclone efficiency is measured for each particle size at different flow speeds. Measured data is used to compute the sticking probability of the cement powder and of the cement particles of different sizes at different flow speeds. Obtained values can be used for the design of new large size industrial cyclones.

KEY WORDS

Cyclone, Environments, Cement, Particle, Efficiency, Sticking Probability.

INRODUCTION

Looking for clean environment; man has to invent suitable methods and roles to reduce pollution level. Wastes of the industrial plants pollutes the air we breath, the water we drink and the food we eat. Among the most environments polluting industries; cement industry is considered the worst. Besides the pollution caused during mining and transporting of the lime stone; chimneys eject toxic gases and suspended fine cement particles. The wind carries these particles to far distances. Particles of smaller sizes remain suspended for longer time, consequently they fall at far distances, while particles of bigger sizes fall at nearer distances, **Soo [1]**. The higher the wind speed and its turbulent level the longer the transport distance of the particles, **Chen and Soo [2]** and **Noel et. Al [3]**. Experimental work showed that the higher the relative humidity the shorter the transport distance, **stern [4]**. Unfortunately, the weather of Egypt is windy, with high turbulent level in spring and dry most of the year. This weather aggravates the pollution problem in Egypt. Experimental studies demonstrated that there is both downward and upward deposition of particles, **Noll and Fang [5]**. This falling dusts Jeopardizes the human, animal and plant life in wide areas surrounding factories producing cement.

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In recent years, improved definition of the human health effects of particulate air pollution has focused attention on the inhalable particles in the atmosphere. Evidence has been gathered which shows that airborne particles with aerodynamic diameters $\leq$ 15μm are deposited on the airway walls and gas exchange surfaces of the human respiratory system during mouth breathing. For nose breathing, the critical aerodynamic value is reduced to 10μm, **US. Environmental Protection Agency [6].** The aerodynamic diameter of particle is not a direct measure of the physical size. Rather, it is the equivalent diameter of a spherical particle of unit density that settles at the same rate as the particle of interest. The settling velocity is based on Stokes' law.

To reduce the dust air pollution cement chimneys should be equipped with some sort of particle collector. Among the most widely used collectors of particulate matter from a gaseous suspension are the cyclone separators. These cyclone separators collect the solid particles in a reservoir and eject cleaned gases to the ambient atmosphere. The collected solid particles can be considered as a useful product. The added value of it might compensate the cost of the air filter. Cyclones might be used also for monitoring the particulate pollution in the ambient atmosphere, **Smith [7]** and **John and Reischl [8].**

In the effort of studying the cyclone efficiency, the **author,[9],** investigated the parameters defining the cyclone efficiency using copper and glass particles. Nowadays; the design procedure of the air cyclone became a routine work if the properties of the ejected solid – gas mixture are well defined. All parameters defining the cyclone efficiency are available except the sticking probability of the solid particles with the cyclone wall. Values of this parameter might be available for some specific cases, like, copper, aluminum and glass beads. But for some economic reasons, it is not available for cement dust.

The following work aims at the experimental determination of the Egyptian Portland cement particles sticking probability with the cyclone walls. This value is an essential parameter for the design of an efficient cyclone. Obtained data are plotted in diagrams so that it can be used to design large size industrial cyclone separators, which are urgently needed for the cement industrial plants.

THEORETICAL

When the exhaust of cement chimney, which is a solid-gas suspension, is introduced into a cyclone, figure 1, the flow rotates around the core. This rotating flow is subjected to the gravity force in the vertical direction [downward] and to the centrifugal force in the horizontal direction [outward]. To improve the cyclone efficiency an electric field might be applied to the vertical and/or horizontal directions. Due to the centrifugal force and the horizontal electric field force; the solid particles are separated from the gas. The distribution density of the particle phase and its deposition is strongly influenced by the finite particle diffusivity, D, and the electric field forces, together with the cyclone height, L, and the sticking probability, σ, of the particles at the walls or with the deposited layer of particles. Due to the vertical fields including gravity and electrical fields; the particle phase goes down to be collected in the reservoir, while the gaseous phase goes up through the core to be ejected to the atmosphere.

The efficiency of the particle collection, η, for a cyclone with a steep cone of small angle, φ is expressed as, **Soo [1]:**

$$\eta = 1 - \exp\left\{-\sigma\left[\frac{2\pi C^2 L}{FQR_o^2} + 8\pi\frac{\rho_p}{\varepsilon_o}\left(\frac{q}{m}\right)^2\frac{LR_o^2}{FQ} + 2\pi E\left(\frac{q}{m}\right)\frac{R_o L}{FQ}\right]\right\} \qquad [1]$$

where σ, C, F, Q, R_O, ρ_p, ε_o, $[q/m]$ and E are sticking probability of the cement particles with the cyclone walls, maximum vorticity in the cyclone, inverse relaxation time for the momentum transfer from the fluid to the particle, volumetric flow rate of the solid-gas phase to the cyclone, radius of the cyclone at the entrance section, material density of the solid particles, permitivity of free space [8.854×10^{-12} Farad/m], ratio of the charge acquired by the particle to its mass, and electric field strength respectively.

The maximum vorticity is

$$C = VR_o \qquad [2]$$

The inverse of the relaxation time means that the particle takes a time interval of [1/*F*] for the velocity difference between the particle and the fluid to be reduced to [1/*e*] of its initial value. In general, the value of F, in Stokes' regime, for a particle with radius, *r*, and of a material density, ρ_p, in a flow having a dynamic viscosity, μ, is expressed as:

$$F = 4.5\frac{\mu}{r^2\rho_p} \qquad [3]$$

The first term in the efficiency equation is just the empirical cyclone number of **Ritma and Vever [10],** which is $C^2L/18FQR_o^2$. This term stands for the centrifugal force effect, while the second and the third terms stand for the electric field contribution to the efficiency of the cyclone.

Substituting by Eq.2 and Eq.3 into Eq.1; shows the following two cases:

- In absence of the electric fields; the efficiency of the cyclone does not depend on the cyclone diameter.
- In presence of electric fields; the efficiency increases by the increase of the cyclone diameter.

In absence of the electric field, Eq.1 can be used to express the particle sticking probability on the cyclone walls as:

$$\sigma = -\frac{FQR_o^2}{2\pi LC^2}\ln(1-\eta) \qquad [4]$$

The sticking probability of the solid particles with the cyclone walls is influenced by the force of adhesion of particles on a clean surface or with a layer of deposited particle. The adhesive forces are either electrical or liquid viscosity and surface tension in origin, **Corn [11].** The electrical forces include those due to contact potential difference, dipole effect, space charges, and electronic structure. In general, the sticking probability depends on the velocity of the flow and the mutual interaction between the material of the cyclone walls and the material and size of the collected particles, the **author [12]. Loeffer** and **Muhr [13],** measured the sticking probability of some materials, and plotted the obtained data in charts. These charts show that the sticking probability decreases rapidly by the increase of the flow speed. Then, it keeps almost constant at flow speeds higher than about 0.7 m/s for most of the investigated materials. Also, the charts show that the sticking probability of the smaller size particles is higher than that of the bigger size particles. In the following work the sticking probability of the cement particles will be experimentally determined for different flow speeds.

EXPERIMENTAL

The British standard 12:1978 lays down the minimum specific surface as 225 m^2/kg for the ordinary Portland cement. This means that its expected average diameter is about 15 μm. This is a global value. But in reality; the cement particles have a wide range of particle size variety and very fine cement dust with diameters down to 1 μm are to be expected during cement production. Plate 1 taken by the microscope, shows the wide variety of the cement particle size distribution. It shows also that, these particles are not exactly spheres but rather it has a wide variety of shapes.

In this study, the cement particles are considered as spheres with an average diameter of 15μm. The sticking probability of the particles to the wall of the cyclone will be related to this value. The density of the solid particles is determined by measuring the apparent density of the cement powder. Then a value of 0.63 is taken as the packing coefficient to calculate the solid particle density. The density of the cement particles is found to be 2482 kg/m^3

To study the effect of the particle size on the collection efficiency of the cyclone, the cement powder is sifted into patches of closer particle size distribution and the cyclone efficiency is measured for each patch

Test Facility

The test facility, shown in figure 2, is designed to measure the collection efficiency of a cyclone with a diameter of 25 cm, internal core diameter of 7.5 cm, height of 50 cm and cone angle of 30°. A rectangular feeding duct with a width of 5.25 cm and a height of 1.6 cm, is used to feed controlled amount of solid-air flow to the cyclone. The airflow is fed to the duct from a pressurized air source through a rotameter, which measures the volumetric rate of the airflow. Consequently, the flow speed can be determined. The solid particles are fed to the duct by an auger, driven by a dc. servo motor and a system of reduction gears. The solid particles are pneumatically conveyed through the feeding duct. To suspend the solid particles at low flow speeds, below the particle saltation speed, an electric field is applied to the duct by connecting its upper and lower plates to a high DC voltage difference of 12 kV, **the author [14]**. The side walls of the duct are made of insulating glass strips. The cyclone itself is kept free of any electric field. The relative humidity of the airflow is controlled to be in the level of 40% to avoid the effect of its variation on the measured data. For each run; two kg of the solid particles is fed to the cyclone and the collected particles are weighed. The collection efficiency of the run is the mass ratio of the collected to the fed particles.

Cement–Air Cyclone Collection Efficiency

An amount of 2 kg of cement powder is fed to the cyclone in a low rate so that particle-air suspension can be considered as diluted flow. The collected cement powder is weighted and the collection efficiency is calculated. The test is repeated for different airflow speeds, namely (0.25, 0.5, 0.75, 1.0, 2.0, 3.0) m/s. In each test the same amount of cement powder is fed. But, in each test the rate of powder feed is controlled so that the volumetric rate ratio of solid to airflow is kept constant. So, fixed dilution condition is maintained. Measured efficiency versus the flow speed is presented in Table 1, and plotted in figure 3. Obtained data show that the higher the airflow rate, the higher the cyclone efficiency.

Table 1 Cyclone Efficiency of the Cement Powder

Flow speed (m/s)	0.25	0.5	0.75	1.0	2.0	3.0
Efficiency	0.2835	0.3655	0.4585	0.5170	0.7365	0.8650

Effect of the Particle Size on the Collection Efficiency

To study the effect of the particle size on the collection efficiency of the cyclone, the cement powered is sifted into patches of closer particle sizes using an array of electric shacking sievers. Results of the cement particles sieving are presented in Table 2.

Table 2 Particle Size Distribution

Particle size (μm)	<15	15:30	30:37	37:45	>45
Mass percent	41	36	16	6	1

Each patch of close particle sizes, namely (<15, 15-30, 30-37, 37-45) μm, is used to measure the cyclone efficiency at different flow speeds, namely (0.25, 0.5, 0.75, 1.0, 2.0, 3.0) m/s. Measured data are presented in Table 3 and plotted in figure 4. Continuous lines show the trend of the phenomenon. This figure shows that the collection efficiency of the cyclone increases due to the increase of the particle size and flow speed.

Table 3 Cyclone Efficient for Different Particle Size and Flow Speeds

Flow speed (m/s) / Particle Size	Efficiency					
	0.25	0.5	0.75	1.0	2.0	3.0
< 15 μm	0.2660	0.3325	0.3455	0.3845	0.5545	0.7025
15.30 μm	0.2780	0.3870	0.4705	0.5307	0.7798	0.8965
30.37 μm	0.4232	0.5855	0.6675	0.7330	0.9287	0.9810
37:45 μm	0.5211	0.6775	0.7430	0.7950	0.9580	0.9915

Determination of the Cement Particles Sticking Probability on the Cyclone Walls

Obtained data of the cyclone efficiency of the cement powder and the investigated different particle sizes are used to compute the sticking probability at different flow speeds. The investigated particle sizes are (<15, 15-30, 30-37, 37-45) μm. The corresponding average particle sizes are taken as (10, 22,33, 41) μm respectively. The average particle size of the cement powder is taken as 15 μm. Computed values of the sticking probability of the cement powder and cement particles of different sizes, using data of Tables 2 and 3 and substituting in Eq.4, are presented in Table 4 and plotted in figure 5.

Table 4 Sticking Probability for Cement Powder and Cement Particles of Different Particle Sizes at Different Flow Speeds

Flow speed (m/s) / Particle Size	Particle Sticking Probability					
	0.25	0.460	0.750	1.000	2.000	3.000
<15 μm	0.500	0.300	0.210	0.180	0.150	0.150
15:30 μm	0.100	0.075	0.065	0.058	0.058	0.058
30:37 μm	0.075	0.060	0.050	0.045	0.045	0.045
37:45 μm	0.065	0.050	0.040	0.035	0.035	0.035
Cement powder	0,220	0.150	0.135	0.120	0.110	0.110

Obtained data, plotted in figure 5, show that:

- For the same particle size; the sticking probability decreases until it reaches a constant value at a flow speed (0.75:1.0) m/s. Then it keeps constant.
- At the same flow speed; the particle sticking probability of the smaller particle size is higher then that of the bigger particle size. This tends to improve the collection efficiency of the fine dust.

CONCLUSION

A modern technique using an electric field to suspend particles of cement powder at very low speeds below saltation is implemented. The cyclone efficiency for collecting the air suspended cement dusts is measured for different flow speeds. Test data shows that the collection efficiency is increased by the increase of the flow speed, hence the vorticity inside the cyclone. Measurements of the cyclone efficiency for cement particles of different particle size at different flow speed show that the efficiency increases by the increase of the particle size and flow speed

The sticking probability of the cement powder and cement particles of different size patches is measured at different flow speeds. Obtained data, plotted in figure 5, show that:

- For the same particle size; the sticking probability decrease until it reaches a constant value at a flow speed (0.75:1.0) m/s. Then it keeps constant.
- At the same flow speed; the particle sticking probability of the smaller particle size is higher then that of the bigger particle size. This tends to improve the collection efficiency of the fine dust.

Obtained data are plotted in graphs, which can be used to design new large size industrial cyclones.

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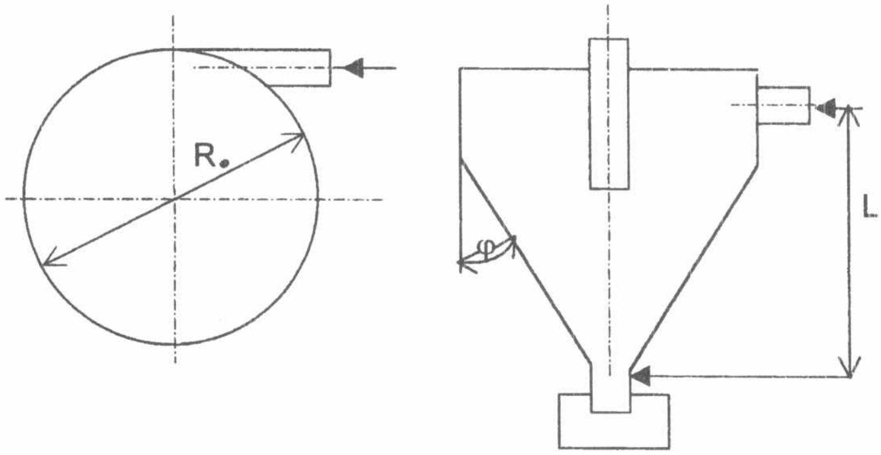

Fig.1. Cyclone Collector

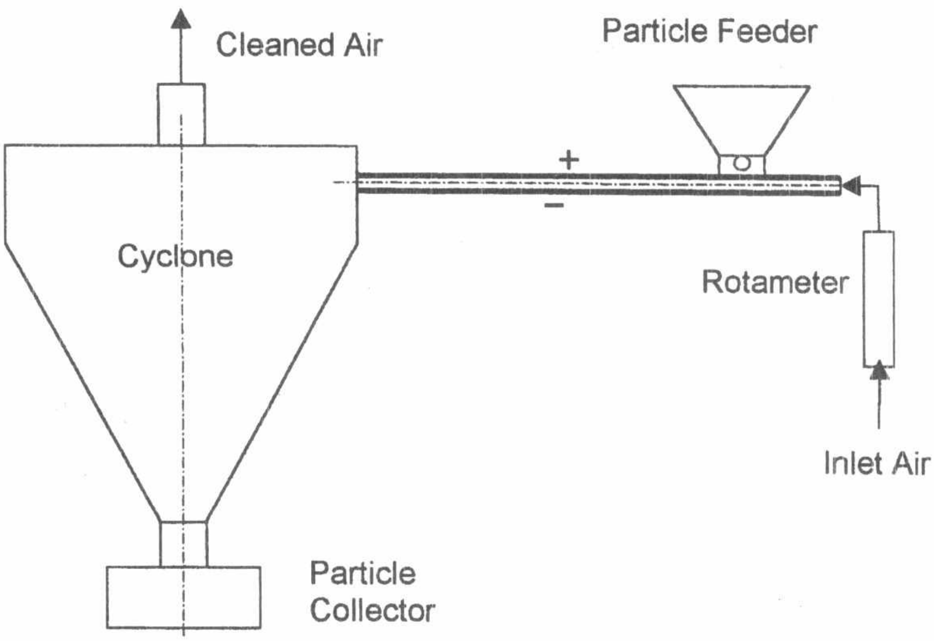

Fig.2. Test Rig

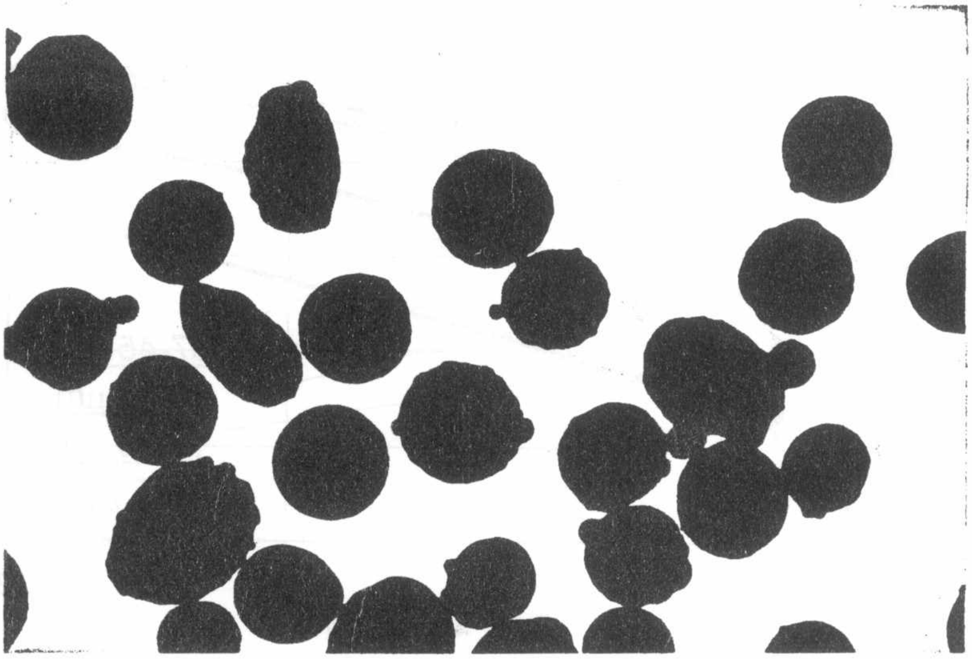

Plate 1 Cement Particles

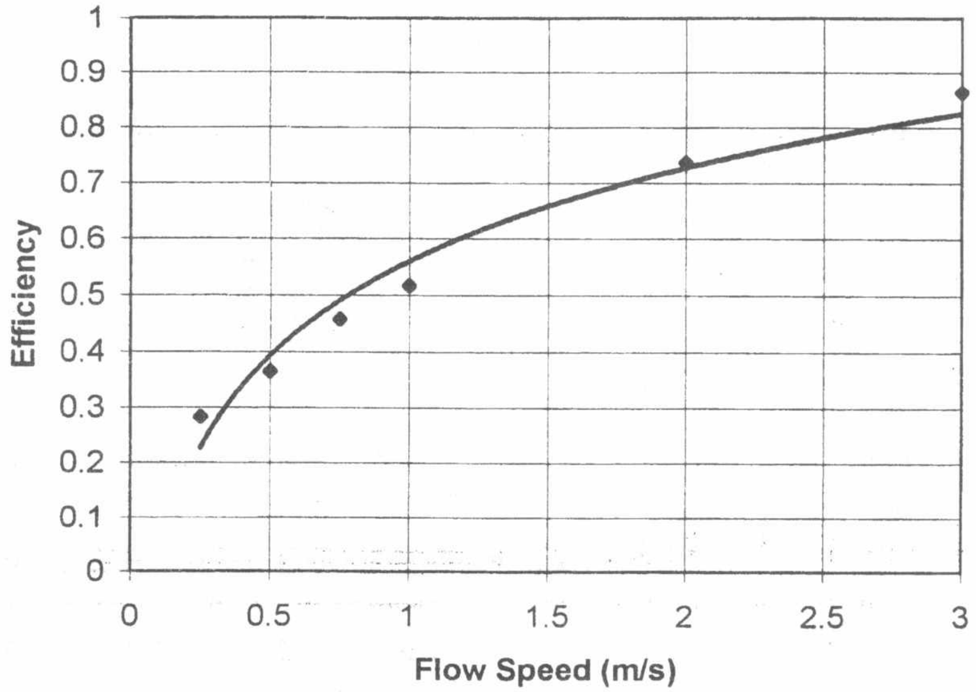

Fig.3 Cyclone Efficiency of Collecting Cement Powder

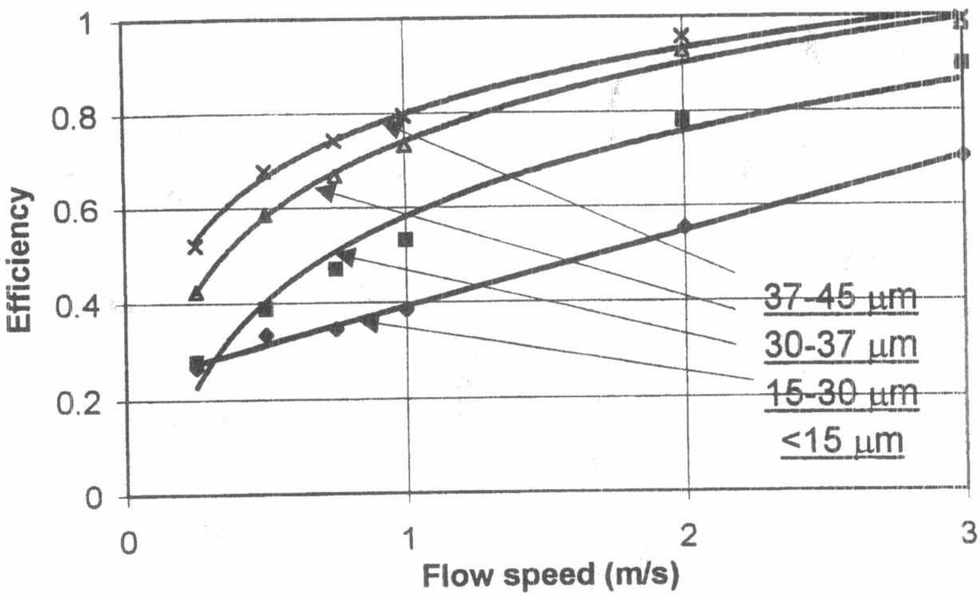

Fig.4 Cyclone Effeciency of Collecting Cement with Different Particle Size

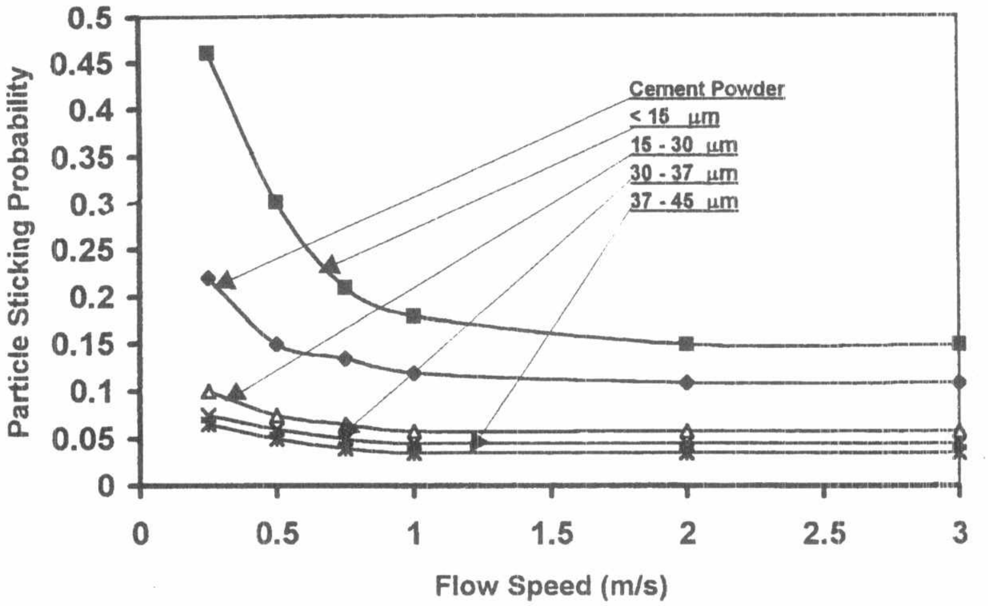

Fig.5 Sticking Probability Versus Flow Speed