Coagulation of S/L dispersions under microgravity conditions : status report 1.11.1986

COAGULATION OF S/L DISPERSIONS UNDER MICROGRAVITY CONDITIONS: Status Report 1.11.1986.

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ABSTRACT

Microgravity experiments are necessary for investigating shear induced coagulation at low shear rates. Such experiments are essential are essential for understanding the role of inertia in shear induced collisions.

An apparatus for investigating these phenomena under microgravity conditions is described!

Keywords: coagulation by shear,
shear induced coagulation,
microgravity.

Objective and background of the investigation.

The project "Coagulation of S/L dispersions under microgravity conditions" forms part of an investigation with the objective to test the theory of orthokinetic coagulation, especially concerning the influences of inertia and deviations from spherical shape of the coagulating particles.

Coagulation of dispersed particles is an essential part of some technological processes such as preparation of plastics by emulsion polymerization, preparation of drinking water, etc. In other cases, such as fermentation, coagulation should be avoided. Essentially, coagulation is caused by the fact, that attraction between volume elements containing equal material, is stronger than attraction between volume elements containing unequal material. Two particles forming a pair must be close enough to make attraction important.
Two particles can be brought into each other's proximity, either by diffusion or by a shear. The former is more important for small particles, the latter for larger ones; the limit between both regions is situated at about 1 µm.

Theoretical conceptions regarding pair formation under the influence of a shear start with von Smoluchowski's theory [1)] postulating rectilinear approach up to a certain distance, the "collision radius" R_{ij}. When the distance between two particles becomes equal to or smaller than R_{ij}, the attraction will become important enough to drive the particles towards each other. One particle is singled out as the "central" particle; the number of particles colliding with it per unit of time is then given by:

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$$J = 2 \int_0^{R_{ij}} 2\pi\,(R_{ij}^2 - z^2)\; n\, \dot{\gamma}\, z\, d z$$

$$= \frac{4}{3} R_{ij}^3\, n\, \dot{\gamma}$$

where n is the number of particles per unit volume; $\dot{\gamma}$ = the shear rate (= the velocity gradient in the case of rectilinear shear). The coagulation rate is given by :

$$-\frac{dn}{dt} = \frac{1}{2} * n * J = \frac{2}{3} n^2 R_{ij}^3\, \dot{\gamma}$$

This formula is based on the idea that each particle may be regarded as "central", but a factor 1/2 is added in order to avoid counting each particle both as a central particle, and as one colliding with it.

The difficulty with this formula is that it is not easy to know anything definitive about R_{ij}. Thus, R_{ij} was usually equated to twice the particle radius b :

$$-\frac{dn}{dt} \sim \frac{16}{3}\, n^2 b^3 \dot{\gamma}.$$

However, the last-mentioned assumption comes down to postulating rectilinear approach up to direct contact between the colliding perticles. For spherical particles, recently some progress has been made in theoretically describing the deviations from rectilinear approach.

a. In the absence of attraction, repulsion and inertia, around any particle a "limiting trajectory" exists which cannot be crossed [2]. Trajectories starting at an infinite distance between two particles remain outside this limiting trajectory, and a collision cannot occur under the idealized conditions of the theory.

b. When attraction is taken into account, the limiting trajectory can be crossed, and the number of collisions to be expected can be calculated [3) 4)]. The quotient of the number of collisions thus calculated, and the number of collisions expected on rectilinear approach up to direct contact is called the "capture efficiency" (α_o). It is shown in fig. 1, in dependence of a parameter log $\bar{\gamma}$ (with $\bar{\gamma}$ = the average shear rate), as "theoretical values" (□).

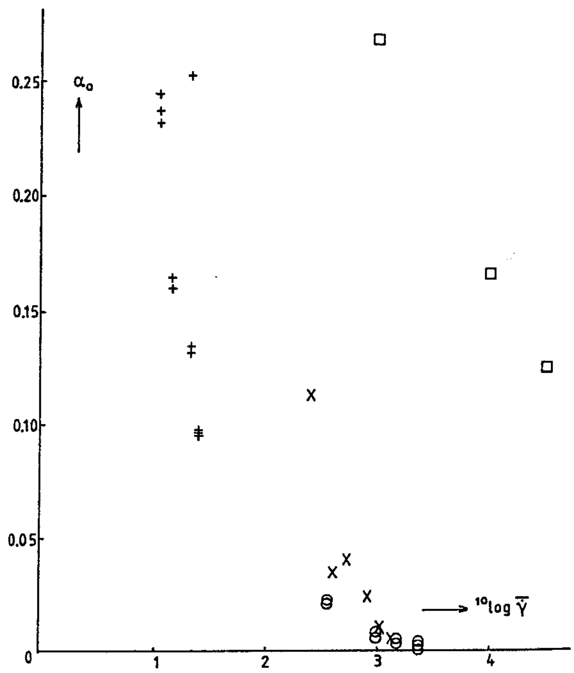

Fig. 1.

Capture efficiency (α_o) for quartz 1,5 µm as a function of average shear rate.

(+) Inner cylinder rotating; laminar flow, sample quartz 1.5 µm I;

(o) inner cylinder rotating; Taylor vortex flow, sample quartz 1.5 µm I;

(x) outer cylinder rotating; laminar flow, sample quartz 1.5 µm II;

(□) theoretical values for spherical particles (A = 4 * 10^{-20} J; b = 0.7 * 10^{-6} m).

c. Repulsion makes this figure more complicated [3]; but since in practice coagulation is usually performed under conditions where repulsion is not important, we will not enter into details in this respect here. More important is the influence of inertia: whenever there is a difference in specific mass between the disperse and the continuous phases, the particles will, on being deflected from their rectilinear path, be hurled onwards in their original direction. This has been approximately taken into account; for spherical particles the influence of inertia is not very pronounced [6].

d. Deviations of the shape of the colliding particles, from a spherical shape, express themselves in a lowering of the attraction [7]. In addition a lower hydrodynamic interaction is expected [8], because sharp edges on the surfaces of the particles may penetrate through the last liquid layer between the approaching particles more easily than the ideally smooth spherical surfaces introduced into the theory.

Three different types of apparatus have been employed to study coagulation under the influence of shear experimentally :

a. An apparatus consisting of two coaxial cylinders, with the outer one stationary and the inner one rotating [7]; coagulation proceeds in the space between the two cylinders. Experiments with this apparatus led to the conclusion that coagulation of quartz particles (hydrodynamic diameter 1 - 5 µm) is distinctly lower than expected from Van de Ven and Mason's calculations (see fig. 1). In this case, the lower attraction between the rather irregularly shaped quartz particles, compared with spherical particles, outweighs the lowering of hydrodynamic interaction.

b. An apparatus consisting of two coaxial cylinders, with the outer one rotating and the inner stationary [9]. This apparatus permits larger shear rates without deviations from laminar flow, than that mentioned sub a.). On the whole, experiments with this apparatus confirm the conclusions reached in the experiments described sub a.)

c. An apparatus consisting of a stirred cylindrical vessel [6] [10]. Here, the experiments indicate that at large stirring rates α_0 values increase with increasing $\dot{\gamma}$, approaching 1 at high stirring speeds. This was interpreted [8] as indicating predomination of the lowering of hydrodynamic interaction, on the lowering of attraction between irregular particles as compared with spherical ones.

In the latter case, solid particles (ZnO, 0.3 - 0.5 µm) were employed with a shape differing from that of the quartz particles mentioned sub a.) and b.). The ZnO particles were cubical rather than irregularly shaped.

However, conclusions from the latter experiments are uncertain because of the interplay of four factors: the role of inertia; the lower attraction; the lower hydrodynamic interaction; and the complicated nature of the flow pattern in a stirred cylindrical vessel, at least at large stirring rates. The present investigation aims at

elucidating this uncertainty, by studying coagulation kinetics in the third type of apparatus mentioned, at low stirring speeds.
Such experiments must be conducted under microgravity conditions, for excluding sedimentation. The third type of apparatus has been chosen for microgravity experiments, because it is much easier to automate than the coaxial cylinder apparatus.

<u>Present state of the investigation</u>

The apparatus envisaged for microgravity research is shown in general view in fig. 2. Eight experimental units are arranged in a circle, a ninth is situated approximately in the center of the circle.

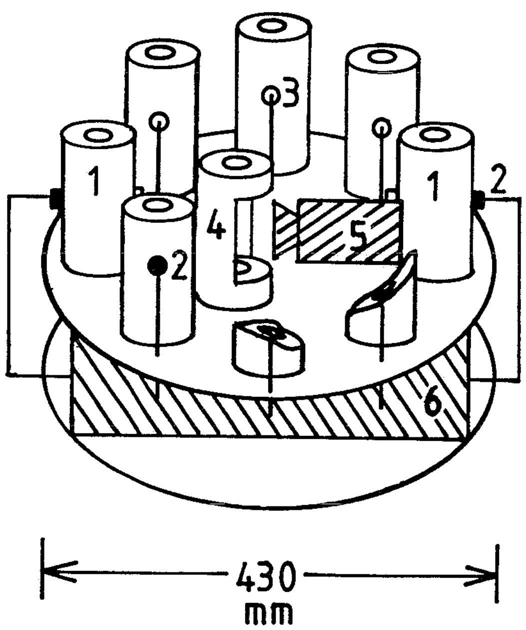

Fig. 2.
General view of apparatus for microgravity research.
1. Experimental units; 2. lasers; 3. light detectors; 4. cell for checking the flow pattern; 5. camera; 6. electronic unit.

This latter experimental unit checks whether the absence of gravity entails differences in the flow pattern in a stirred cylindrical vessel: the flow is visualized by adding anisometric strongly reflecting Al particles (stabilized against coagulation by sodium dodecyl sulfate), and the flow pattern is recorded by a camera.

The other experimental units comprize (fig. 3) a slave magnet (1), a master magnet (2), a laser issuing light of 820 nm wavelength (3), a light detection unit (4), and an ultrasonic vibrator (5).

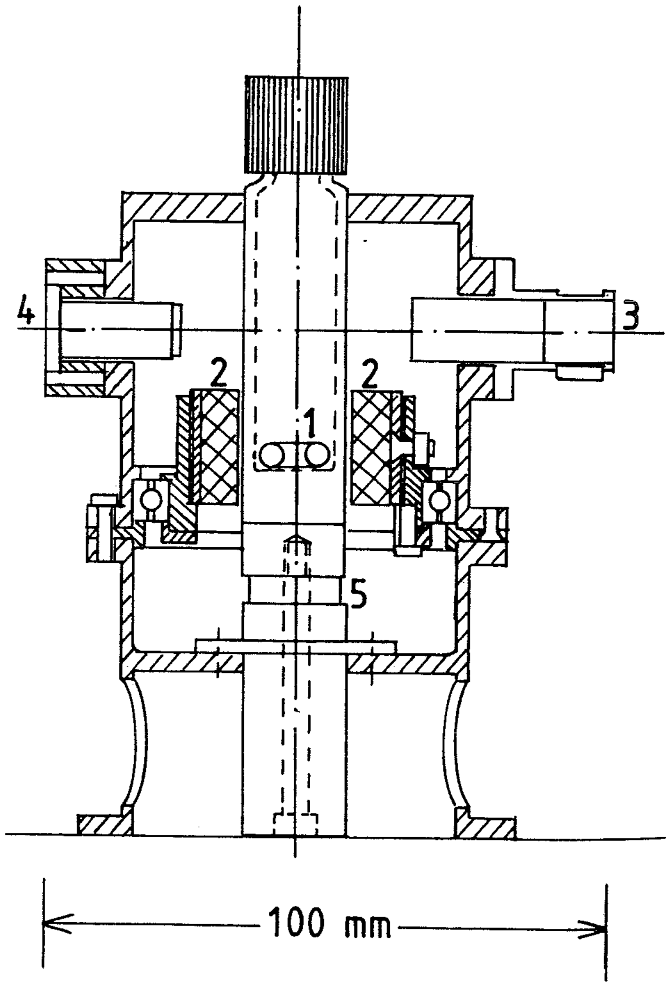

Fig. 3.
Details of experimental unit for studying coagulation kinetics. For significance of numbers see text.

Coagulation rates at various stirring speeds of the slave and master magnets are recorded by following light transmission.

A prototype of an experimental unit has been developed at Eindhoven University. The apparatus itself is being constructued and assembled by ERNO GmbH, Trauen (BRD); some parts of the final apparatus are constructed at Eindhoven University. The last design review was September 23rd, 1986, at Trauen. Assemblage is scheduled to be finished in January 1987. Towards the end of January a test of the module and experiments with it under one g conditions are planned.

Preliminary experiments, with a slightly different apparatus, have been performed in order to ascertain, whether ultrasonic vibration indeed is strong enough to redisperse sediments formed in a centrifuge, at different values of the centrifugal acceleration a. This was tested by measuring light transmission in quartz suspensions before and after centrifuging, and after ultrasonic vibration (see table I).
Up to a = 20 g, sediments could be redispersed by 3 minutes'ultrasonic vibration (or less), but at larger a values sediments were formed which were difficult to redisperse. The objective of these experiments was to evaluate whether short periods of increased gravity acceleration during the launching of the rocket night cause trouble during redispersion.

In addition, we investigated whether repeated cycles of coagulation and redispersion lead to a drift in particle size distribution at the start of the coagulation. This appeared not to be the case.

TABLE I.

Light transmission (560 nm) in quartz suspensions after treatment at different simulated gravity acceleration and after ultrasonic vibration.

Centrifuge treatment for 40 min.

a/g	light transmission (%)				
	Before centrifuging	After centrifuging	Ultrasonic treatment for 1 min	2 min	3 min
3.48	1.8	19.8	2.0	1.8	1.8
	1.8	24.4	1.8	1.8	1.8
7.75	1.8	21.3	2.2	1.9	1.8
	1.8	25.5	1.9	1.8	1.8
19.35	1.8	43.4	2.6	2.0	1.8
	1.8	38.8	2.2	1.9	1.7
31.88	1.8	49.4	3.1	2.4	2.0
	1.8	55.7	2.8	2.0	1.9
46.98	1.8	64.9	3.5	2.3	2.0
	1.8	62.2	3.6	2.5	2.1

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