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The mechanisms of disintegration of compressed particulate systems

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Summary

Disintegration of compacts in the presence of a solvent is followed by measurement of the disintegration force development as a function of time. The process is described by the delamination of the compact and the rate of expansion of the detached layers using a new equation.

Introduction

There has long been controversy over the question of mechanisms involved during the disintegration of a system consisting of viscoelastic particles compressed to form a compact (1). Since these systems may consist of two or more components of varying hydrophilicity, mechanisms such as particle swelling during water penetration, wicking, capillarity and particle-particle repulsion have been considered (2). We have recently shown that a reliable method of following the phenomenon of compact disintegration is by measuring the force developed during water penetration in a compressed particle disc which is in contact with a pressure transducer. We now support the analysis of such data with a new theoretical model according to which, the overall phenomenon of disintegration can be controlled by either a diffusional or an interfacial mechanism.

Theory

When a compact composed of two or more particulate components, one of which is a hydrophilic, uncrosslinked or crosslinked polymer known as the disintegrant, is placed in contact with water, a process of disintegration occurs. Using a transducer in contact with the upper surface of the compact, in an otherwise closed measuring system (3), it is possible to follow the development of a disintegration force, F, as a function of time up to a maximum force, F_∞.

The process of disintegration is analyzed by describing the delamination of the compact due to separation of successive "layers of particles". The rate of such a layer detachment process, $\dot{N}(\tau)$, depends on the relative importance of the swelling of the disintegrant particles. The rate of volume expansion of the

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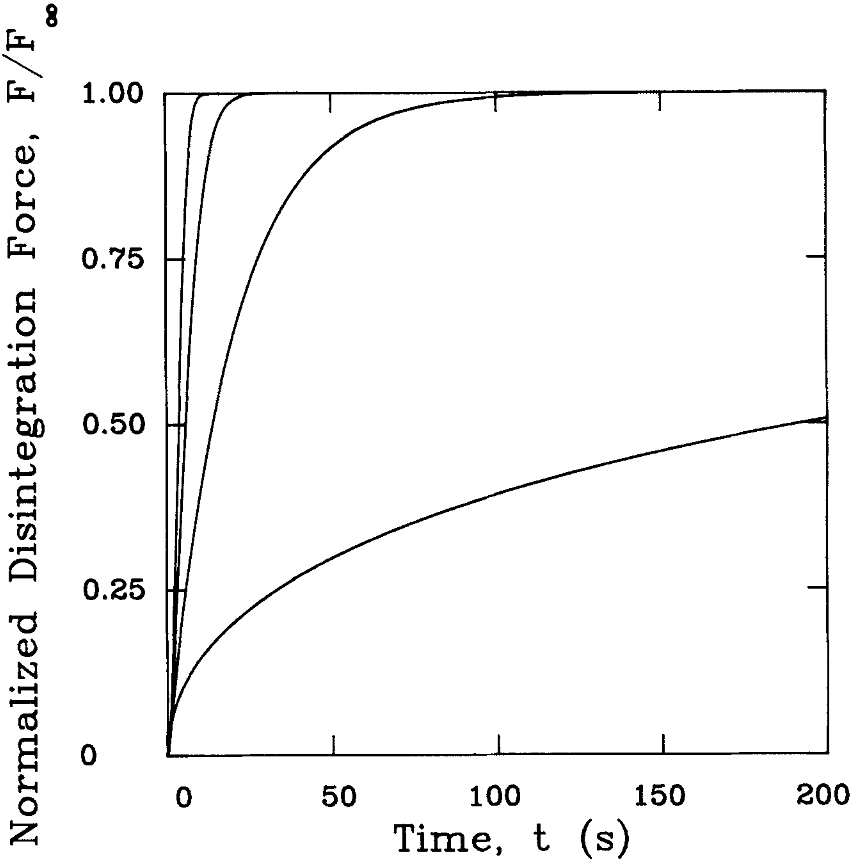

Figure 1: Simulation of diffusion- and interface-controlled disintegration processes for $k = 5 \times 10^{-2}$ s^{-n}. Curves from left to right are for n = 2.0, 1.5, 1.0 and 0.5.

compact, $\dot{v}(\tau)$, is thus coupled with $\dot{N}(\tau)$, and the disintegration process is expressed in terms of these two rates. The final result of the analysis is that the disintegrated fraction of the compact is expressed as the normalized disintegration force, F/F_∞, as

$$F/F_\infty = 1 - \exp(-kt^n) \tag{1}$$

Here k is an expansion rate constant and n is an exponent indicating the controlling mechanism.

For values of n greater than 1, the disintegration process is controlled by the interfacial delamination of particle layers from the compact; then the phenomonon is interface-controlled. For values of n smaller than 1, the disintegration process is controlled by the particle diffusion away from the compact surface; then the phenomenon is diffusion-controlled.

Discussion

Figure 1 presents a simulation of the force development for various physically acceptable values of k and n. At a given expansion rate constant, for a diffusion-controlled disintegration process (for example n = 0.5) the force increases with a relatively low rate, indicating a slowed down process due to particle diffusion, whereas an interfacial mechanism (for example with n = 2) leads to a fast force development, since the delamination is not impeded by diffusional barriers.

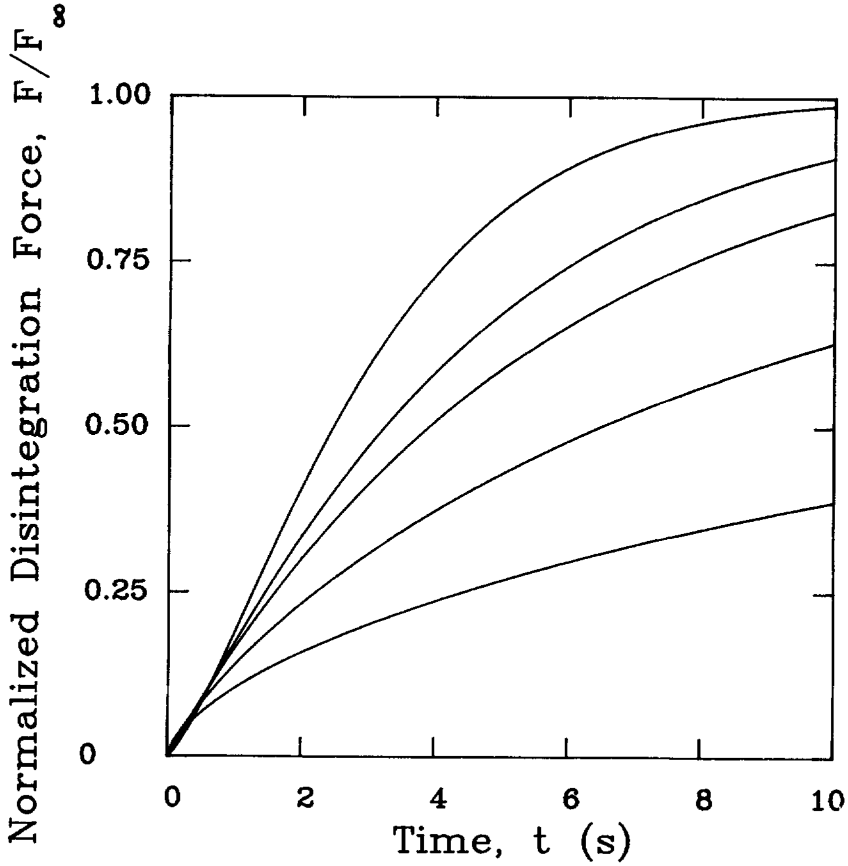

Figure 2: Variation of normalized disintegration force, F/F_∞, with amount of disintegrant (crosslinked PNVP) as a function of time. Curves from top to bottom are for 1, 5, 10, 20 and 40 wt % PNVP.

Table 1

Analysis of Compact Disintegration

Quantity of PNVP (wt %)	Exponent n	Expansion Constant k (s^{-n})
1	1.32	0.21
5	1.10	0.19
10	0.99	0.18
20	0.82	0.15
40	0.65	0.11

Experimental results indicate that large amount of hydrophilic, hydrogen bond-inducing disintegrants lead to a diffusion-controlled disintegration process. Interface-controlled disintegration processes are observed for hydrophobic model substances compressed with small amounts of hydrophilic disintegrants.

As an example, we have recently performed disintegration experiments with compacts in the form of discs consisting of calcium diphosphate dihydrate as a model substance, crosslinked poly(N-vinyl-2-pyrrolidone) (PNVP) as a disintegrant, and 2 wt % talc as lubricant. The amount of PNVP was varied from 1 to 40 wt %, and the compacts were made by compression at 20°C and 50% RH with a force of 25 ± 0.5 kN.

Figure 2 indicates the development of the disintegration force as a function of time. For 1 wt % disintegrant the mechanism is interfacial since the exponent n is 1.32 (see also Table 1). The process becomes diffusion-controlled ($n < 1$) as the amount of disintegrant increases. In addition, the expansion rate constant decreases because of prevailing diffusional barriers.

Thus, the new theoretical model can be used to identify the mechanisms controlling the disintegration process.

Acknowledgements

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