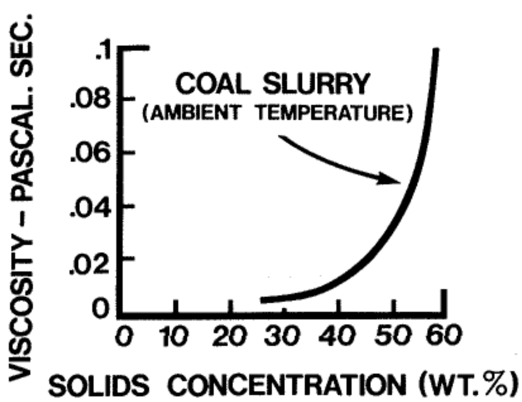

Figure 1. Viscosity of coal slurry as a function of solids concentration at shear rates of 20 s^{-1}.

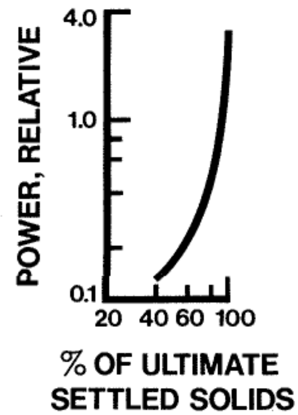

Figure 2. Power consumption for a mixer to provide complete uniformity of solids as a function of the percent approach to ultimate weight percent settled solids.

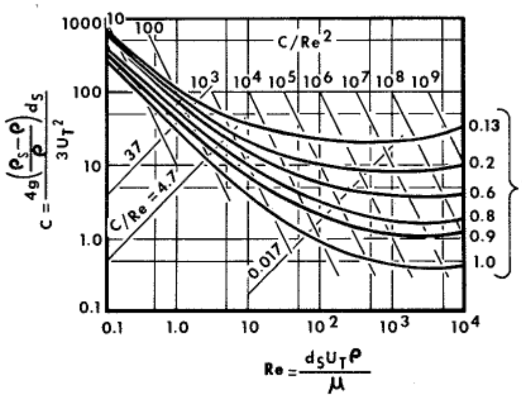

Figure 3. Drag coefficient versus Reynolds number for various particles of different kinds of solid materials.

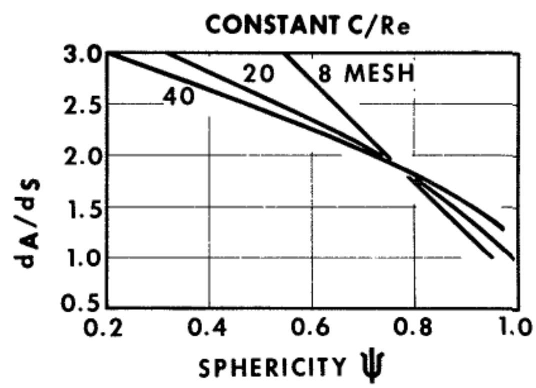

Figure 4. Drag coefficient versus Reynolds No. with parameters of d_s and sphericity, Ψ.

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Mixing of Slurries Near the Ultimate Settled Solids Concentration

Coal and other slurries can be handled at high solids concentration by proper design of the mixing equipment.

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Many solid suspension applications involve solids that are near the wt. % ultimate settled solids. In this area, many factors are involved in the effect of mixing in the process. These include the viscosity of the slurry which the impeller "sees," the viscosity of the slurry which the process "sees," and the degree of non-progressive fillets that are allowed. The "ultimate wt. % settled solids" used here is the percentage by weight which the solids have when they are allowed to settle in a tank until no further supernatant liquid collects above them.

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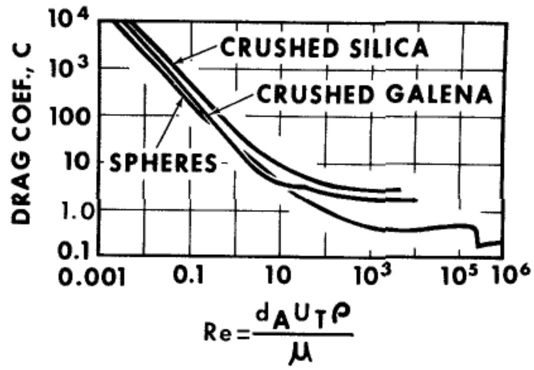


Figure 5. For measuring settling velocities of different size particles, possible combinations of d_a/d_s and sphericity, Ψ, are plotted, the interaction giving the unique combination.

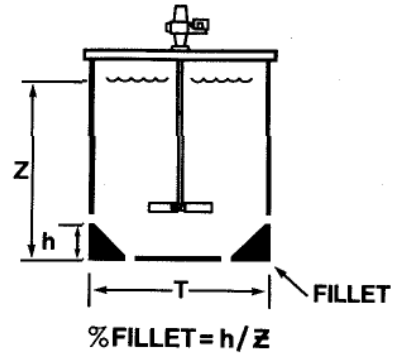


Figure 6. Illustration of the height of fillet and definition of percent solids.

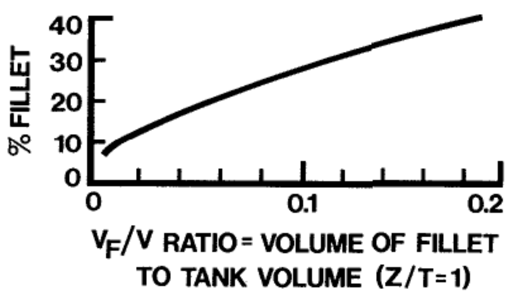


Figure 7. Volume percent of tank occupied by various fillet sizes.

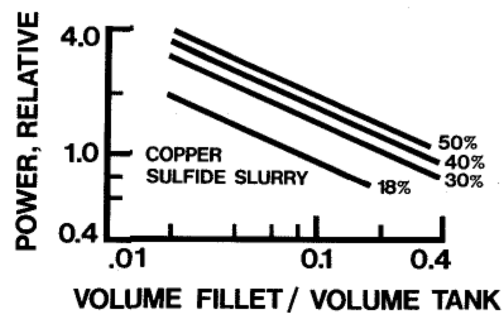


Figure 8. Illustration of the increase in power required to reduce the percent of tank volume occupied by fillets of copper sulfite ore.

Depending upon the density of the solid particles, ultimate wt. % settled solids, can be somewhere between 60 and 90%. The ultimate vol. % settled solids is a more uniform guide, but does vary somewhere between 50 and 70%. Since the curves are so steep for mixer performance as a function of percent of ultimate settled solids, all percentages are based on wt. % solids. In this way we can avoid having to use approximation factors which can be seriously in error.

Measuring settlement velocity

The "percent of ultimate weight percent settled solids" (%UWPSS), is defined as the wt. % solids in the actual slurry relative to the wt. % solids in the ultimate settled slurry. Figure 1 shows how viscosity at a given shear rate increases dramatically as wt. % solids goes up, using a coal slurry for illustration. Figure 2 gives a typical relationship for many slurries tested which shows the dramatic change in power as we approach 100% UWPSS.

The settling velocity of particles in a fluid can be measured by visual timing devices. Results can be expressed in terms of a drag coefficient correlated vs. the Reynolds No. of the particle at its settling velocity. The curves shown on Figure 3 are typical (*1*). In order to correlate these curves into a common set of geometric relationships, two arbitrary parameters have been suggested, giving the results shown in Figure 4.

The two arbitrary diameters are the diameter of the sphere, d_s, having the same volume as the diameter of the particle, d_a, and the sphericity, ψ, which is defined as the area of the sphere relative to the area of the particle. If it is desired to determine these two ratios for a given type of particles produced either in a process or from a grinding circuit, it is necessary to take three or four different particle sizes; measure their settling velocity; calculate for each

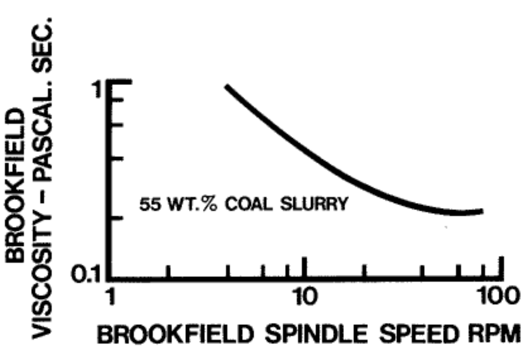
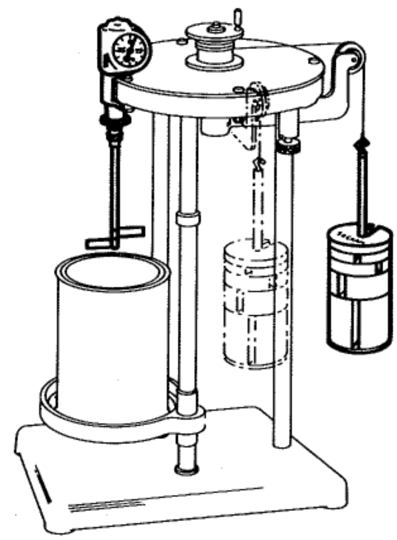


Figure 9. Typical viscosity relationship for coal slurry as a function of Brookfield viscosity spindle speed.

Figure 10. Stormer viscosimeter.



particle size all the possible combinations of the diameter and area ratios; and plotting them as shown in Figure 5. The common intersection point of these curves will be the unique combination of the diameter and area ratio that can be used in the future to convert the particle size to any other combinations of fluids or particles.

In the free settling particle range, which goes from 0% solids up to 30 to 50% solids depending upon the nature of the slurry, the exponent on the effect of settling velocity and the power required, with all other factors equal, varies from 0.8 to 3.0 as an exponent on the settling velocity. This obviously gives range for tremendous latitude in mixer selections, and this is what is observed in practice. My own experimental observations indicate that the exponent of 2.0 is a more common exponent than others suggested (*1,3,4*).

In hindered settling, the question comes up whether it is better to correlate percent solids as a separate function, using the settling velocity for free settling unhindered particles, or whether attempts to measure the hindered settling velocity of the particles in the slurry would be of value in obtaining a more accurate or usable correlation. In my observation, obtaining hindered settling velocities in the slurries does not aid in the correlation, so in this report all settling velocities will be free particles settling essentially by themselves in liquids. In the range of 50 to 100% ultimate wt. % settled solids, the effect of settling velocity can be expressed as an exponent of 0.5 on the free settling velocity for its effect on power requirement.

Figure 6 defines percent fillets, which is the height the fillet rises relative to the diameter of the tank. Figure 7 shows the percent of tank volume occupied with various percent fillets. Fillets on the order of 10% are quite common to allow in large slurry storage tanks, since they give a volume of fillet occupied of some 2–3% and the additional power required to remove the last vestige of the fillet is not economically justified.

Whether the fillet is allowed to build up with the original ore, or whether it is initially filled with metal or concrete, is only a matter of cost. Figure 8 shows a typical curve of the power required to change the percent volume fillet showing that there is a major economic evaluation required.

When the power is about one-third of the power required for 2% volume fillets, the tank is on the verge of incipient sanding in, and usually even if started in a clean condition, within several days will ultimately sand in causing potential damage to impeller, shaft and mixer drive.

Measuring viscosity

Viscosity of a slurry needs to be measured with a device which mixes the slurry as it measures viscosity. The impeller of the mixing device needs to have a mixing capability; it needs to be two or three times bigger in vertical dimensions than the largest particle under consideration. Brookfield viscosimeters do not fulfill that requirement usually, although in very finely divided particles which may approach a homogeneous fluid, Brookfield viscosimeter data can be an aid in interpretation. Figure 9 shows a typical curve of Brookfield viscosity vs. spindle speed illustrating the non-Newtonian nature of this coal slurry.

A more suitable device is the Stormer viscosimeter, Figure 10, which has a paddle impeller and which can provide suspension while measuring the viscosity of the slurry. It also has shear rates which are more typical of what will be found in the mixing tank itself, and there is less danger in extrapolating pseudoplastic properties to mixer tank shear rates. Other devices which can be used include 20–40 L tanks which have been calibrated to measure viscosity at sufficient power levels to provide suspension and uniformity of the slurry. Figure 11 shows the viscosity at a shear rate of 10 s^{-1} of two different grinds of an ore, labeled coarse and fine.

Process-wise, the impeller speed in a pilot plant to obtain off-bottom suspension of the coarse particles in the ore is shown in Figure 12. This shows that the higher viscosity of the fine ore actually helps in the 60 to 80% UWPSS range, but hurts in the 80 to 100% UWPSS range.

The use of viscosity, Figure 13, allows a good correlation of mixer process requirements for both the fine and coarse ores.

In summary

Mixing, suspending and blending slurries in the range of 60 to 100% of UWPSS, the ultimate settled solids require special consideration of the effect of fillet size, mesh size

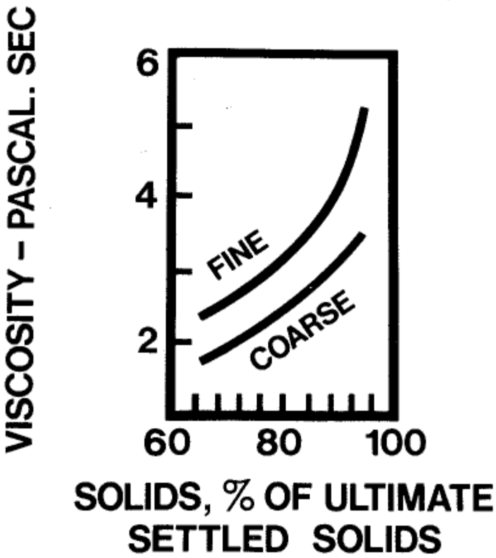


Figure 11. Viscosity measurements, at a shear rate of 20 reciprocal s, of two solid samples as percent ultimate weight percent settled solids.

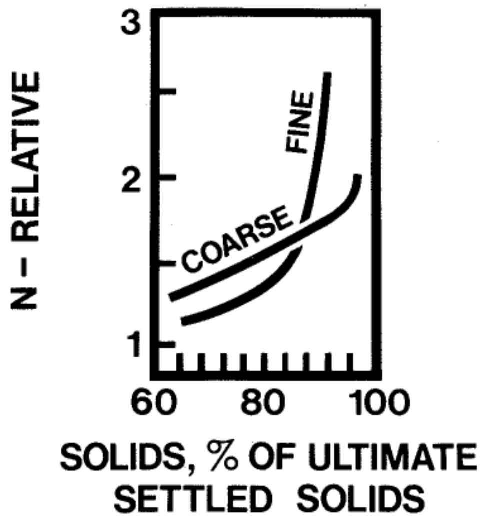


Figure 12. Process impeller speed required to provide the same degree of uniformity with the coarse and fine particles referred to in Figure 11.

and the viscosity of the material. Summaries have been given here of typical relationships which exist in these slurries over a wide range of actual materials.

Materials which exhibit these kinds of properties and are often run in these ranges of wt.% solids include coal, iron concentrate, alumina hydrate, backfill tailing, pyrrhotite concentrate, copper sulfides, and various nickel ores among many others. These typical slurries can be handled by proper design of the mixing equipment. Other factors not included here include the effect of multiple vs. single impellers, Z/T ratios, and D/T ratios for the impeller. #

Nomenclature

D = impeller diameter
d_a = diameter of actual particle
d_s = diameter of sphere of same volume as the particle
N = speed
N_{Re} = Reynolds No., $N D^2 \rho/\mu$
SR = shear rate, seconds^{-1}
T = tank diameter
U_t = terminal settling velocity of solids
UWPSS = ultimate wt. % settled solids
Z = liquid level
μ = viscosity
ψ = sphericity, area of particle per area of sphere of same volume

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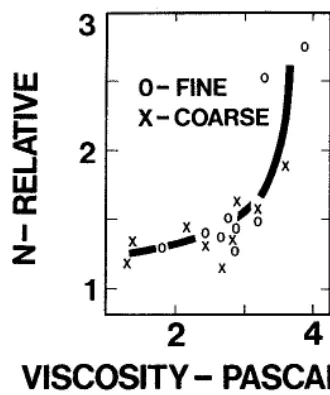

Figure 13. Process speed required for the same degree of uniformity for the two fine and coarse solids shown in Figures 11 and 12, but showing correlation as a function of viscosity.

J. Y. Oldshue is vice president, mixing technology, of Mixing Equipment Co., and a Past President of AIChE. He earned his B.S.Ch.E., M.S.Ch.E., and Ph.D. at the Illinois Institute of Technology. A registered professional engineer in New York, he has authored numerous articles on fluid mixing and given seminars in the U.S. and abroad.