

NMR Relaxation and the Zeta Potential of Particulate Suspensions - Complimentary Measurements?

Introduction

Systems in which one phase is distributed – or “dispersed” – in another are termed dispersions. There are numerous examples of dispersed systems including foams (gas-in-liquid), emulsions (liquid-in-liquid), and aerosols (solid- or liquid-in gas) that have found application in manufactured products. In this short Technical Note we will focus on the most widely formulated type of dispersion – particulate suspensions (solid-in-liquid) – though the terminology is applicable to a variety of systems.

The physical nature of any dispersion depends on the respective roles of the constituent phases, and these can distinguished by the terms *disperse phase* (the internal phase forming the particles) and the *dispersion medium* (the external fluid in which the particles are distributed). Two fundamental parameters control the nature and behavior of every system in which one phase is dispersed in another phase, and these are the *extent of the interface* of the disperse phase and the *interfacial chemistry* of the disperse phase.

The physico-mechanical characteristics that constitute the *interfacial extent* can be summarized as:

- Particle size and distribution
- Particle shape and morphology
- Surface area
- Porosity

The physico-chemical characteristics that constitute the *interfacial chemistry* are more complex and include:

- The chemical nature, or type, of surface group
- The number and distribution of surface groups
- The degree of dissociation or ionization of those groups
- The lyophilic-lyophobic balance inherent in any particle surface

While the reader may well be acquainted with the measurement of one or more characteristics of the former group, unfortunately the *interfacial chemistry* is often a neglected parameter (particularly in pharmaceutical applications), even though in the formulation of suspensions it is as significant as—and sometimes more so than—the *interfacial extent*.

Importantly, while it is technically possible to create particles that are all of the same size, shape, or porosity, it is generally extremely difficult to create a particle with a constant surface charge because of the inherent anisotropic nature of materials – in particular with metal oxides and especially those with a crystalline structure. Of course, it is possible to chemically modify a material *post-creation* to obtain a more uniform surface chemistry and, of course, to add extra components such as surfactants and polyelectrolytes.

“NMR relaxation offers intelligence that Zeta potential cannot, but the combination of both measurements can provide a more complete insight into the particle-liquid interface in dispersions.”

Finally, it needs to be recognized that the two fundamental parameters are not, strictly, independent variables. The extent of the interface can be modified, for example, by particle comminution (grinding) that will not only reduce the particle size but also expose new surfaces and, hence, alter the interfacial chemistry, especially if the external surface prior to comminution has been modified. Alternatively, a change in interfacial chemistry brought about by, say, an adjustment of solution pH may change the particle charge and can also result in particle aggregation which, in turn, increases the particle size and reduces the extent of exposed surface area.

In practical situations, one of the parameters will be more dominant and it is this parameter that must be monitored and controlled initially but, ultimately, both parameters need to be quantified in order to obtain a complete understanding of any disperse system.

The Zeta Potential

The zeta potential (ZP), denoted by the Greek letter zeta (ζ), is a parameter related to the surface charge, a property that all materials possess, or acquire, when suspended in a fluid. ZP is, more precisely, an empirical non-linear relationship with the particle surface *potential* – not directly the surface *charge*. Also, its measured value depends crucially on the constitution of the suspension liquid, such as pH, concentration of any ionic (electrolytic) moieties, temperature and, for non-aqueous systems, dielectric constant.

The sign and magnitude of ZP can affect process control, quality control, and product specification. So, at the simplest level, it can help maintain a more consistent product; at a complex level, it can improve product quality and performance. At the very least its measurement answers two questions. First, is the electrical charge on the material particle positive or negative? This information is often enough to suggest further steps in formulation or processing. Second, the next higher level of inquiry has to do with quality control: does the product have sufficient electrostatic repulsion to maintain its stability?

ZP is a well-established measurement technique that is particularly useful to predict the resistance of an electrocratic (i.e., governed by electrostatics) dispersion to coagulation by electrolytes by determining the “critical ZP” (i.e. the value of ζ below which the suspension is coagulated). It is often used in determining the critical coagulation concentration (CCC) of an electrolyte, which is the minimum concentration required for the onset of coagulation). The CCC is proportional to ζ^4/z^2 (where z is the electrolyte *counterion* valence). Its measurement is also used to determine the *iso-electric point* (IEP) of metal oxides (including ceramics and refractories). The IEP is the pH at which the specific metal oxide material will have no ZP – and hence no surface *potential* – and so such a suspension will be inherently unstable, and all the particles will eventually aggregate.

Although the ZP can be a useful parameter to monitor the adsorption of a nonionic surfactant, or macromolecule, onto a charged particle surface, ZP measurements are useful *primarily* for systems in which particles are electrostatically charged. They are of very limited value in systems in which the particle surface groups are not dissociated or ionized, or for particles that are completely sterically stabilized by, for example, polymers. Moreover, while there are a variety of commercial instruments available for measuring ZP, the vast majority are based on electrophoretic- and phase analysis-light scattering methods that necessitate dilution of samples for measurement and analysis. This can be problematic because, in order to be properly formulated, suspensions or slurries should be analyzed as they are prepared and without dilution (see Mageleka Technical Note #5 at www.mageleka.com).

NMR Relaxation

By contrast, measurements made using nuclear magnetic resonance (NMR) relaxation do not require sample dilution and, further, make no assumptions about particle shape. The relaxation time is a fundamental, *intrinsic* property of both solids and

liquids, and it can be determined directly using an NMR spectrometer such as the Mageleka *MagnoMeter* XRS. The relaxation time, in and of itself, can be used to provide direct information about both the *extent and nature* of any particle-liquid interface, and a detailed discussion of this can be found in the Mageleka White Paper 1 at www.mageleka.com.

What the *MagnoMeter* measures is the extent of molecular motion as protons react when perturbed by a magnetic field. Liquid in contact with a particle surface ("bound" liquid) relaxes much more rapidly than does the rest of the liquid, which is free (i.e., "bulk" liquid). The surface relaxation for solids is typically of the order of microseconds, compared with that for liquids which is much longer (on the order of seconds). The relaxation time of particulate suspensions will, therefore, be intermediate between that for the specific solid and that for the dispersion liquid used. The actual value is a function of exactly how the liquid interacts with the particle surface (i.e., the wettability and resulting interfacial structure). Hence, the relaxation time is directly related to the number and type of surface groups and the surface lyophobic-lyophilic balance, which, in turn, determine the particle surface *charge* in relation to the properties of the bulk fluid used. It is assumed that there is fast exchange between the two liquid states (bound and free) and so, generally, a single average relaxation rate is measured but with slow/intermediate exchange, such as the case with porous materials, multiple values can be observed.

Other methods such as potentiometric and conductimetric titration have been used to determine the concentration of, for example, surface hydroxyl (OH) groups in metal oxides, as well as the *point-of-zero charge* (PZC, which is the pH at which the specific metal oxide material will have no surface *charge*). In general, these techniques are non-routine, time consuming and can have poor sensitivity/selectivity.

The difference between the values of the IEP and the PZC is a measure of the degree of *specific adsorption* of ions (i.e., those ions whose adsorption at a surface

is governed by forces other than simple electrostatics, such as covalent bonding). Further discussion of this subject is beyond the scope of this short Technical Note.

Many dispersed systems rely on inter-particle repulsion mechanisms such as steric forces (from adsorption of polymeric materials), which would not be detected by ZP measurements. In contrast, and advantageously, this will be detected by NMR relaxation. Thus, NMR relaxation measurements offer intelligence that a ZP measurement cannot. But, importantly, the combination of both measurements can provide a more complete understanding of the physico-chemical structure at a particle-liquid interface.

Further, NMR relaxation measurements are fast, straightforward and will work with suspensions at any industrially relevant solids concentration and opacity; the inherently simple measurements technique takes only minutes (see Mageleka Technical Note 2: The Mageleka *MagnoMeter* XRS at www.mageleka.com). Importantly, the *MagnoMeter's* measurement technique is both non-invasive and non-destructive so samples can be stored, if required, for re-analysis at some future time.

In Conclusion

This Technical Note has suggested the need for complementary measurements of zeta potential and NMR relaxation to better characterize a (complex) surface in a solvent (which may also be complex). Understanding and quantifying the nature of the particle-liquid interface is critical to the creation of suspensions with specific behavior and performance characteristics. It endows the formulator with the *fundamental* information necessary to design more effective and stable suspensions.

NMR relaxation and ZP measurements provide different, but complimentary, information about the interfacial chemistry of suspensions. While both are techniques are individually useful, data from a

combination of both techniques will certainly be far more instructive and informative and may be used to synergistically enhance intelligence of dispersion/aggregation processes.

Until recently NMR spectrometry had been limited to universities and large research installations. However,

powerful benchtop instruments, such as the Mageleka MagnoMeter XRS, are now a practical and affordable alternative for routine laboratory analysis.

For more information, to send samples, to arrange a demonstration of the MagnoMeter at your facility, or to talk to one of Mageleka's technical applications specialists, please email roger@mageleka.com