Comparing Goniometer-based & enclosed Light Scattering instruments

At first sight, goniometer based and enclosed light scattering instruments look very different in terms of the bench space they occupy. In this technical article we look to underline some of the key details and differences between these two approaches to Dynamic Light Scattering (DLS) which might not be immediately obvious to someone interested in learning more about the topic.

Optimised Performance vs Speed of Use

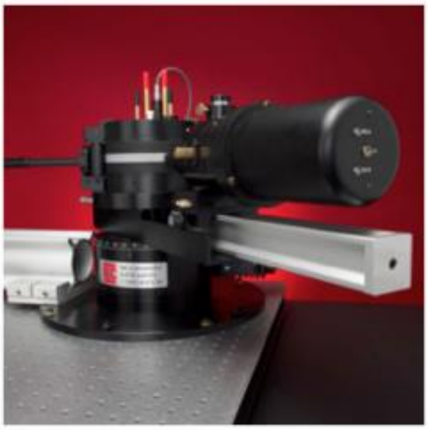

Figure 1: A goniometer based light scattering instrument.

When a decision is to be made about acquiring a new instrument for particle sizing, basically two options are available: a goniometer based or an enclosed light scattering instrument. It is therefore interesting to compare the strengths and weaknesses of the two technological solutions in order to select the instrument best suited for the task. In both cases, Dynamic Light Scattering (DLS), is the fundamental technology used by the two instruments. In modern instruments, both technological approaches should be equipped with a digital correlator capable of transforming photon counts into the correlation function which is the basis for all calculations leading to size data.

In addition, the correlator should provide a wide range of time delays and offer a reasonably high number of delay channels to provide the required resolution. However, correlators used in goniometer based and enclosed light scattering systems do differ markedly. In a goniometer light scattering system, the layout of the correlator and setting the distribution of the available delay channels over the required time range, is user selectable and as such, fine tuneable to specific requirements. Enclosed light scattering instruments usually do not allow reconfiguration of the correlator layout, they may offer two or more presets but rarely allow fine tuning. Now, an endless discussion about "what is better" might start at this point, but this would miss the point. The truth lays in the application. A goniometer based light scattering system is per se defined by its adaptability to provide optimised measurement for a wide range of investigations. Thus, a fine tuneable correlator layout is a must. An enclosed light scattering instrument often is sold on its speed of operation and therefore it comes equipped with few fixed layouts designed to offer a suitable but not optimised set-up for most common investigations. So we have two solutions both based on DLS, one more focused on adaptability to provide optimised performance for almost any application, the second more focused on speed / ease of use.

Looking at non-spherical particles

One of the most common topics of discussion when discussing light scattering, is of geometric angles. Measuring the light scattered by a sample in solution or a particle dispersion at different angles of detection is a common method of investigation. The fundamental principle behind this is that when the hydrodynamic diameter of molecules or particles is larger than about 1/20 of the wavelength of the utilized laser source, then the intensity of the scattered light will be angle dependent. Larger particles will tend to be forward scattered.

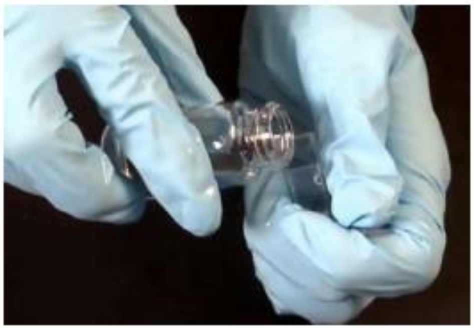

Figure 2: Preparing samples for analysis by light scattering.

The intensity will therefore increase with decreasing angle of observation (please note that at an angle of zero you would be when looking directly into the laser). The Zimm Plot used for molecular solutions in static light scattering takes advantage of this fact and is used to determine the gyration radius Rg of the investigated molecules. For this it is common to measure at a least seven different angles ranging from 15° (or lower) to 155°. A goniometer based light scattering is the perfect platform for this type of application as by nature it allows measurement at any angle from around 8° to 155°. All this is valid for static light scattering measurements but how does it apply to dynamic light scattering? Particle Size determination is actually performed by measurement of Translational Diffusion Coefficient Dt and consequent application of the Einstein equation.

This equation however, is strictly designed for spherical particles and does not take into account different particle shapes leading to errors in the determination of the hydrodynamic diameter of those particles whose shape is far from spherical, for example rod shaped particles. In this situation, determination of particle size using different angles of detection can help us determine the shape of the sample.

As mentioned before, intensity of scattered light is a function of detection angle. This means that measuring at different angles will return values weighted in different ways, with the smaller dimension more present at high angles and the larger dimension more dominant at low angles. Comparison of results obtained at different angles has therefore the potential of giving a hint about the aspect ratio of the investigated particles thus leading to shape data.

While this is a challenging investigation, it provides a valuable approach for understanding non spherical particle samples. We mentioned before that goniometer based light scattering systems are designed exactly for angle dependent measurements. But how do enclosed light scattering instruments deal with non-spherical particle applications? Most enclosed DLS instruments only provide a single angle of detection thus making this investigation impossible. A few enclosed light scattering instruments are now available that offer up to three different angles of detection covering the range from 17° to 173°. These instruments can therefore perform measurement at these set angles and can provide some data on non-spherical particles but nothing approaching the flexible capabilities of a goniometer based light scattering system.

Different approach to software

Any modern Dynamic Light Scattering (DLS) instrument requires software to process data and make results accessible to the user. As such, it is the software component of a system which has the most immediate effect on users. Apart from providing intuitive access to functions via an intuitive graphical user interface, we need to focus on what to expect in terms of fundamental functionality from a software package designed for a Goniometer based system compared to software provided with an enclosed light scattering instrument. Because of the flexible design of a goniometer-based system, software packages will typically provide easy access to all details of the measurement itself, including correlator layout, refractive index of the liquid and particle, and of course all further relevant analytical parameters. Analysis and interpretation of a measurement is most commonly done post-processing after the measurement is completed. In this way goniometer light scattering instrument software can use different analysis algorithms (including cumulants, Contin and NNLS) to give users the highest possible control over the interpretation of the acquired raw data. For enclosed light scattering instruments, the strategy followed by software designers is slightly different. Often such instruments provide limited choices in both parameters for the measurement and analysis methods. To support ease of use for the occasional user, enclosed light scattering instruments will often provide automation capabilities including time or temperature dependent measurements and also support of external autotitrator devices.

This automation strategy leads to little or no post-processing operations, allowing fast but not optimised generation of final results. The two software approaches are starkly different. For goniometer-based systems the software is designed to provide the highest possible degree of freedom and control by the user, while for enclosed light scattering instruments, the software is designed to deliver automated results based on a limited set of parameters and calculation options.

4. Comparing System Components & Consumables

In the sections above we have looked at the similarities and differences between a goniometer-based system and an enclosed light scattering instrument based upon the most commonly appraised parameters. However, many scientists looking to purchase a light scattering system often wish to also evaluate and compare other instrument components including lasers, detectors and measurement cell assemblies.

Figure 3: Consumables for light scattering experiments

The differences between the goniometer-based system and the enclosed instruments are here much smaller than we might at first think. Starting with the measurement cell assembly. In both cases inexpensive measurement cells are used, typically round cells in goniometer-based systems and square cells in many enclosed light scattering instruments.

In both cases, glass or plastic disposable cells are used as standard to ensure that the cost of ownership relating to consumable cells is low. Recycling of used cells is possible, but requires thorough cleaning.
Often factoring in cleaning time costs the case for using a new measurement cell can be easily justified. Both goniometer- based and enclosed light scattering instruments often use Avalanche Photo Diodes (APD) detectors which have replaced the Photomultiplier Tubes (PMT) which were the light scattering detector of choice in past times. APD's offer excellent sensitivity across the whole wavelength range and, most important exhibit little or no tendency to "Afterpulse", a phenomenon associated with PMT's and a major distortion of light scattering measurements. There are however some applications (e.g. measurement of very small particles at very low concentration) where afterpulse still presents a problem. For such challenging applications, goniometer-based light scattering systems uniquely offer a cross-correlation option to solve the problem. Cross correlation uses two detectors simultaneously and the signals are combined into a cross-correlation which eliminates completely any afterpulse effect. A laser is the most fundamental component of a Dynamic Light Scattering (DLS) instrument. Nowadays, suppliers mostly employ diode laser instead of gas lasers which were the preferred option in previous generations of light scattering instruments. Diode lasers offer many advantages over gas lasers including a small footprint, longer lifetime, lower power consumption and they can be frequently switched on and off without damage. Diode lasers are available in a wide range of wavelengths and output power. For general DLS applications, we will mostly find red laser sources at a wavelength of around 640 nm (traditionally close to the 632 nm of the HeNe Lasers) and 40 to 140 mW output power. This is true for both goniometer-based systems and enclosed light scattering instruments. However, the greater design flexibility of goniometer based light scattering systems means that the laser source typically can be much more easily replaced and adapted to different requirements in terms of power and wavelength making them the system of choice for applications requiring other than a standard laser.

5. Static Light Scattering Applications – there is only 1 choice

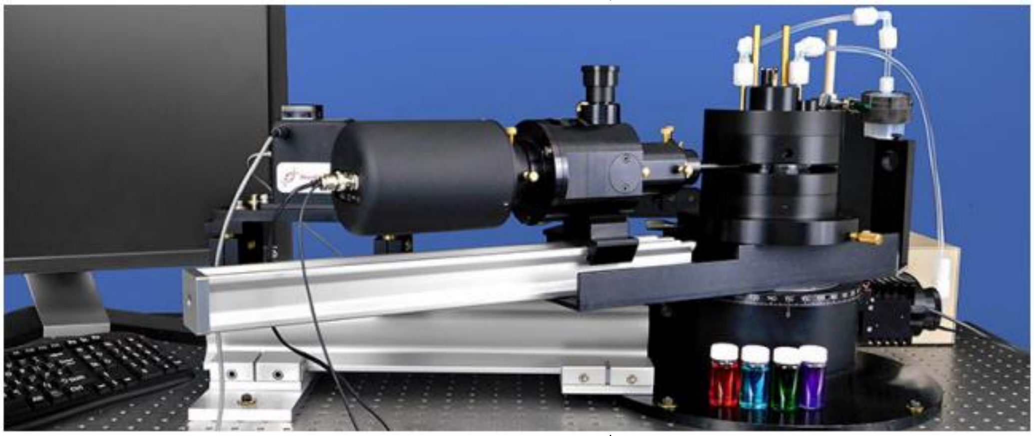

Figure 4: Static Light Scattering measurement using a goniometer-based instrument

The original, but still common light scattering technology is Static Light Scattering (SLS) – a technique performed by measuring integral intensity of scattered light photons at one or more angles of observation. The application of Static Light Scattering is not related to the determination of size of particles in a dispersion, but is the proven and preferred tool to determine molecular weight and gyration radius of polymer molecules dissolved in a solvent. This tells us that by a different interpretation of the signal coming from the detector, we shift our field of application from particle suspensions to molecular solutions. A legitimate question is then how good a fit is a goniometer-based system or an enclosed light scattering instrument for this task?

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As mentioned, SLS requires measurement at multiple angles of detection, and the nature of this approach requires at least seven angles to give accurate data, the more the better. As even the most modern enclosed light scattering instruments only provide three angles of detection, SLS is provided as an option and the data they provide should to be used with great care and doubt. Enabling many angles of light scattering measurement - a goniometer-based system will perfectly fit any SLS requirement and application, delivering absolute molecular weights of any polymer.

Summary

This comparative article clearly shows how different requirements, like flexibility or ease of use, lead to completely different strategies of instrumental realization of the very same technology and physical principles. The conclusion is therefore that the DLS solutions presented above offer different optimized solutions. The outstanding performance and flexibility of goniometer-based light scattering systems make them the perfect R&D tool, whereas the ease of use of the enclosed light scattering instrument offers benefits in a QC environment. The best choice of DLS instrument should therefore not just taken on the basis of specifications, price or "what others use", but on your future planned applications for this powerful technology.

Authored By:

Carlo Dessy* is Managing Director of Testa Analytical Solutions eK, a respected international OEM developer and supplier of instruments, innovative detectors and software for chromatography applications and molecular weight determination.

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