



The Coulter Principle

While under contract to the United States Navy in the late 1940s, Wallace H. Coulter developed a technology for counting and sizing particles using impedance measurements. The technology was principally developed to count blood cells quickly by measuring the changes in electrical conductance as cells suspended in a conductive fluid passed through a small orifice. Presently, over 98% of automated cell counters incorporate this technology, which is referred to as the Coulter Principle. In the past seventy-five years, the technology has also been utilized to characterize thousands of different industrial particulate materials as well. Beckman Coulter® instrument systems which utilize this principle are called COULTER COUNTER® instruments. Drugs, pigments, fillers, toners, foods, abrasives, explosives, clay, minerals, construction materials, coating materials, metals, filter materials, and many other sample types have all been analyzed using the Coulter Principle. It can be used to measure any particulate material that can be suspended in an electrolyte solution. Particles as small as 0.4 μm and as large as 1600 μm in diameter can routinely be measured. Over 8,000 references to the uses of this technology have been documented.

In a COULTER COUNTER instrument, a tube with a small aperture on the wall is immersed into a beaker that contains particles suspended in a low concentration electrolyte. Two electrodes, one inside the aperture tube and one outside the aperture tube but inside the beaker, are placed and a current path is provided by the electrolyte when an electric field is applied (Figure 1). The impedance between the electrodes is then measured. The aperture creates what is called a "sensing zone". Particles in low concentration, suspended in the electrolyte, can be counted by passing them through the aperture. As a particle passes through the aperture, a volume of electrolyte equivalent to the immersed volume of the particle is displaced from the sensing zone. This causes a short-term change in the impedance across the aperture. This change can be measured as a voltage pulse or a current pulse. The pulse height is proportional to the volume of the sensed particle. If constant particle density is assumed, the pulse height is also proportional to the particle mass. This technology thus is also called aperture technology.

Using count and pulse height analyzer circuits, the number of particles and volume of each particle passing through the aperture can be measured. If the volume of liquid passing through the aperture can be precisely controlled and measured, the concentration of the sample can also be determined. In modern COULTER COUNTER instruments, such as Beckman Coulter's Multisizer™3 and Multisizer™4 particle counter and sizing instrument, pulses are digitized and saved with several key parameters that describe each pulse such as pulse height, pulse width, time stamp, pulse area, etc. These parameters enable the instrument to better discriminate between noise and real pulses and between normal pulses and distorted pulses due to various reasons when particles pass through the aperture. The saved pulses can be also used to monitor sample changes over the measurement time period if pulses are arranged in time sequence. In practice, the particle volume is often represented in terms of equivalent spherical diameter. The measured particle volume (or size) can be then used to obtain particle size distribution.

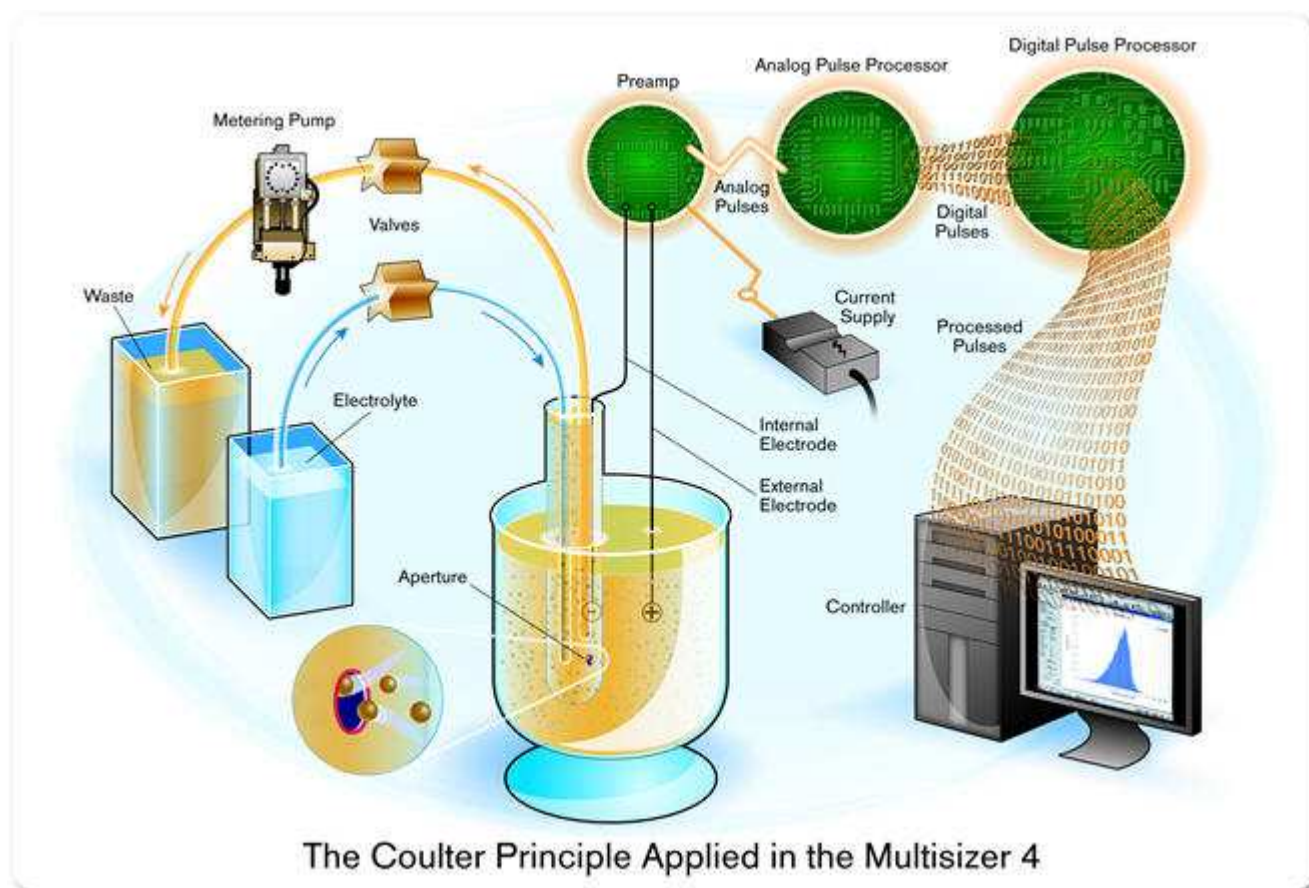


Figure 1. Schematic of a COULTER COUNTER.

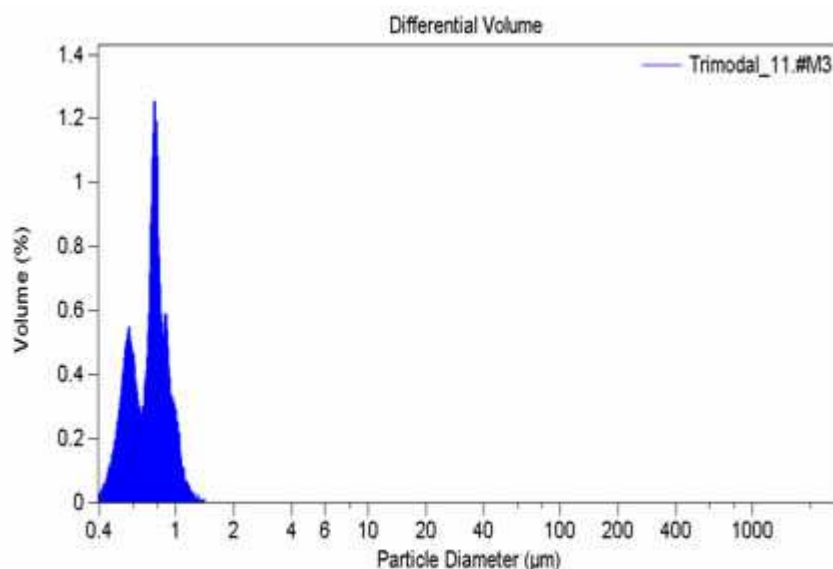
A typical measurement using COULTER COUNTER instruments takes less than a minute, as counting and sizing rates of up to 10,000 particles per second are possible. The accuracy of the size measurements can be better than 1%. Aperture size typically ranges from 20 to 2000 μm . Each aperture can be used to measure particles within a size range of 2 to 80% of its nominal diameter. Therefore, the overall particle size range of 0.4 to 1600 μm is feasible. However, the ability of the technology to analyze particles is limited to those particles that can be suitably suspended in an electrolyte solution. The upper limit therefore may be 500 μm for sand but only 75 μm for tungsten carbide particles. Moreover, the lower size limit is restricted by electronic noise generated mainly within the aperture itself. The selection of the most suitable aperture size is dependent upon the particles to be measured. If the sample to be measured is composed of particles largely within a 30:1 diameter size range, the most suitable aperture can be chosen. For example, a 30 μm aperture can measure particles from about 0.6 to 18 μm in diameter. A 140 μm aperture can measure particles from about 2.8 to 84 μm . If the particles to be measured cover a wider range than a single aperture can measure, two or more apertures have to be used and the test results can be overlapped to provide a complete particle size distribution.

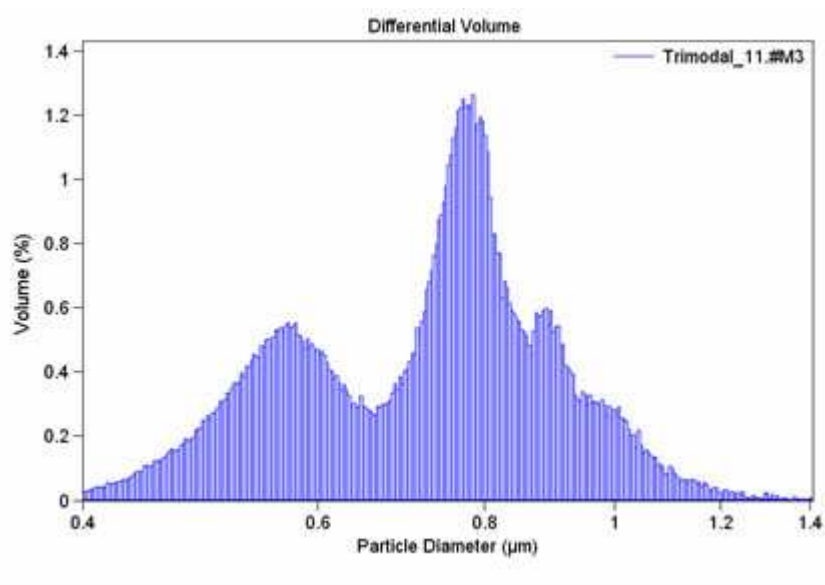
Highest Resolution for Particle Size Analysis

During the Coulter Principle measurement, as a particle passes through the sensing zone when the liquid is drawn from the container, a volume of the electrolyte equivalent to the immersed volume of the particle is displaced from the sensing zone. This causes a short-term change in the resistance across the aperture. This resistance change can be measured either as a voltage pulse or a current pulse. By measuring the number of pulses and their amplitudes, one can obtain information about the number of particles and the volume of each

individual particle. The number of pulses detected during measurement is the number of particles measured, and the amplitude of the pulse is proportional to the volume of the particle. Because this is a single particle measurement process, it yields the highest resolution that any particle characterization technique can achieve. The particle diameter can be determined at the resolution of voltage or current measurement which can be very accurately using current electronics technology. The distribution amplitude can be determined to the accuracy of a single particle.

The advantages of such high resolution are multiple. The most obvious one is to display details of a particle size distribution. In a particle size distribution measurement, typically each distribution, whether is displayed cumulatively or differentially, is composed of a few hundred data points in a pre-set size range. Each data points is called a bin. Since every particle is measured, each bin is a collection of particles in the size range that bin represents. Depending on the distribution broadness, the total size range can be reset to a finer division, therefore showing the distribution details, i.e., each bin can be pre-set to cover a smaller size range. Other advantages include fine differential between two particles and more accurate statistic values calculated from the distribution. The following figures show a sample measured using Beckman Coulter's MS 3 instrument and displayed in different size ranges. The pulse data was resorted into a finer set of bins in the right figure in which more detail of the distribution is displayed.





Digital Pulse Process

In the Coulter Principle instrumentation, the change in electric resistance due to passages of particles through the aperture is determined using fast electronic circuitry. The detected signals are instantaneously digitized at a rate of a few million times per second into digital signals. The digital signal is then recorded for every pulse in the form of pulse parameters, i.e., timing, height, width of pulses, etc. Since most measurements aim at obtaining particle counting or size distribution, the recorded pulse height is converted to particle size using the calibration constant and placed into one of the pre-set size bins. The particle size distribution and counting are the cumulative result of all pulses measured.

All recorded parameters of pulses are still available for purposes other than standard, full-range particle size distribution. These parameters can be subtracted or sorted, i.e., reprocessed differently according to various applications. For example, if one wants to have a zoom-in size distribution showing every detail of the distribution, then a narrower size range can be chosen and all pulses can be sorted and placed into the new set of finer bins. Another example is that when the pulse heights (or sizes) are sorted in a time sequence, for samples of narrow size distribution, such a plot can be used to monitor sample change during measurement. Yet still another example is that one may plot pulse height as a function of pulse width to find information of particle shape.

In summary, the digitized pulse information has made many new applications of the Coulter Principle measurement possible and many more applications are being discovered.

