

ADV Part 4: Measuring Particle Concentration

Introduction. Although primarily used to measure flow velocity, an ADV can be used to monitor concentration of suspended particles in water. To measure velocity, a flow must be seeded with suspended particles so that acoustic waves can bounce off of them. In the process of determining flow velocity, the ADV also tracks information on the backscatter caused by seeded particles. This backscatter, or scattering strength, is what allows us to use the ADV for the secondary purpose of measuring concentration.

Sontek states, “At a single frequency, scattering strength is a function of the particle type, size, and concentration.”³ If particle type and size distributions are constant, scattering strength is directly proportional to concentration. In a laboratory setting, then, where suspended particles in a flow are of consistent size, relative differences in concentration are determined by comparing measured signal levels. Absolute measurement of concentration requires the additional step of calibration.

ADV Setup and Operation. A record of scattering strength is automatically recorded by the ADV when a velocity record is taken (in fact, records can be used to simultaneously monitor scattering strength and velocity). Thus, the ADV is set up and configured as if velocity measurements were being taken.

An important factor in getting good concentration measurements is choosing appropriate particles. They must be of a consistent size distribution. The size distribution will often be known, but this is not always necessary – we simply must be confident that the size distribution will be uniform from sample to sample. Particles also must be large enough to be detected by the probe. The Sontek ADV probes used in the Parsons Lab operate at 10 MHz and measure a minimum particle size of 2 μm in diameter. (Note: other Sontek probes, such as microADV and ADVOcean, or probes made by other manufacturers, may operate at different frequencies and have different detection limits).

Duration of the ADV record depends on requirements of the experiment. ADV software records all velocity and scattering strength data in a binary file. The ‘getamp.exe’ command extracts scattering signal data. This creates a delimited file that can be imported into Excel or Matlab for processing. The output file shows signal data in units of counts. This should be converted to decibels. Sontek states that for their probes, 1 count is equal to 0.43 decibels (Although linear here, the relationship of a count to a decibel is not always so).

The next important fact to note is that units of decibels measure relative difference on a logarithmic scale. To determine the change in concentration, we must convert the decibels to a linear ratio:

$$S - S_0 = 10 \log \left(\frac{C}{C_0} \right) \quad (5)$$

where S and S_0 are scattering strengths measured by the ADV in decibels, and (C/C_0) is the ratio of the concentrations. The factor of 10 appears in the equation because decibels are not a base unit; 10 decibels equal 1 Bel, the base unit for the acoustic logarithmic scale. From this equation, it is easy to see how relative differences in concentration can be measured. Even if we do not know what the absolute concentration is, we can know the ratio of two concentrations just by measuring the two signal levels.

Calibration. Determining absolute concentration with the ADV requires calibration. If we map a particular signal level to an absolute concentration, we can then use additional measured signal levels and equation 5 to estimate additional absolute concentrations. Two ways of doing this are to:

- Extract a water sample from a running experiment, directly measure the concentration, and correlate it to the ADV signal measured when the sample was extracted.
- Produce samples of known concentration and determine the corresponding signal levels.

Example 1: Glass Beads as a Tracer. Let us say we are conducting an experiment investigating lateral diffusion in a flume. We are going to use 10 μm glass beads as a tracer injected upstream. The glass beads are above the detection limit of the ADV, will not settle out, and have a consistent size distribution. They are a good choice to use with the ADV. For simplicity, let us say we are interested in what the concentration of beads is at two points in time, t_1 , and t_2 . We take an ADV record, extract the data, and determine what the signal levels were at t_1 and t_2 . Our signal levels S_1 and S_2 are in counts, so we multiply by 0.43 to convert to decibels. Now, without doing any type of calibration, we can determine the relative relationship of bead concentration between t_1 and t_2 by using equation 5. If $S_1=65$ dB and $S_2=70$ dB, we find that C_2/C_1 is about 3. We can now say that the concentration at time t_2 was three times the concentration at time t_1 .

Example 2: Determining Settling Velocity. An important application of this concentration-measurement method is determining settling velocity of particles. The ADV allows us the luxury of continuously monitoring the concentration at one point in a flow. With this capability, we can take an ADV record, examine how the concentration decays, and then back-calculate what the settling velocity must be for that pattern of decay.

In an experiment conducted at the Parsons Lab, relatively large particles, about 200 μm in diameter, are necessary for an experiment. At this size, they settle out of the flow at a rate great enough to impact the experiment. Thus, the settling behavior has to be monitored somehow. A description of how the ADV can be used to do this follows.

The flume is small (volume about 50 L) with a recirculating flow. Particles are a type of plastic with a specific gravity of 1.02. Before the experiment is run, a known mass of particles is measured out and introduced into the flow. This is important because it allows us to know the concentration in the tank if we assume fully-mixed conditions.

The ADV probe is inserted in the region of interest. The pump is turned on, and the tank is stirred by hand and brought to fully-mixed conditions. Quickly, the ADV is started and allowed to take a record for 40 minutes. This duration allows for all particles to settle out.

After the experiment is complete, scattering strength data is extracted and imported into a spreadsheet. Counts are then converting to decibels, and scattering strength is plotted versus time. In many cases, time will elapse such that all the particles have settled out and no more decay of the signal strength is detectable by the ADV. It is appropriate to truncate the data set at this point. *Figure 3* shows a sample plot of signal versus time, after the data has been converted to decibels and truncated appropriately.

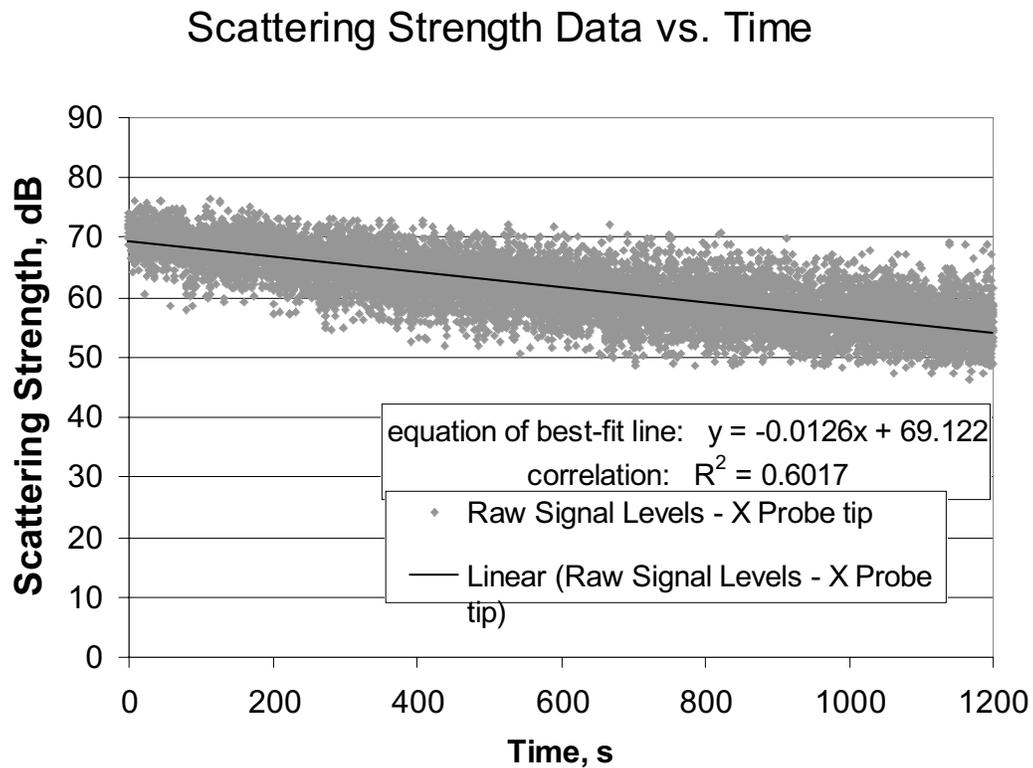


Figure 1: Plot of scattering strength versus time for 200-um plastic particles. From visual inspection, it is obvious that a linear fit is appropriate for this data set. With this information, we can calculate the settling velocity.

Viewing the plot of S vs. t sheds light on settling behavior of particles. In this experiment, data appears to fit a straight line, indicating that an exponential model of decay is appropriate. (Particles in other experimental setups may behave differently, depending on how much mixing is occurring, the residence time in the flume, and other

factors. See notes on particle and bubble transport⁴). By writing an expression for the flux of particles to the flume bed and integrating, we derive the following equation for exponential decay of concentration:

$$\frac{C}{C_0} = e^{-\frac{w_s t}{h}} \quad (6)$$

where t is time, w_s is the settling velocity of the particles (or Stokes' velocity), h is the height of water in the flume, C_0 is the concentration at $t=0$, and C is the concentration at time t .

Equation 6 can now be substituted into equation 5 to find:

$$S_2 - S_1 = 10 \log \left(e^{-\frac{w_s t}{h}} \right) \quad (7)$$

After some algebra, this reduces to:

$$S = [S_0] - \left[10 \frac{w_s}{h} \log(e) \right] t \quad (7)$$

$\log(e)$ is a constant, so the resulting equation is linear. Now, we fit a line to our plot of S versus t , and compute the slope and intercept of the line. The intercept of the line provides an estimate of the initial signal level that corresponds to the well-mixed concentration. The slope of the line is then set equal to $10 * w_s / h * \log(e)$, and settling velocity can be easily calculated. Note that although we do have a method to calibrate concentration (match the initial concentration to the initial signal level), we do not actually need to do so to estimate settling velocity.