New Application of a Density Probe for Determining the Suspended Sediment Concentration

J. Schneider[1], G. Harb[1], G. Klammer[1] H.Fritz[2],
[1]Institute of Hydraulic Engineering and Water Resources Management
Graz University of Technology
8010, Graz
AUSTRIA
E-mail: schneider@tugraz.at

[2]Anton Paar GmbH
Anton-Paar Straße 20
8054 Graz
AUSTRIA

Abstract: *As a natural well known, but badly measured phenomenon fine sediments can be observed in suspension in rivers and lakes. In natural rivers the sediment concentration in the suspension is mostly a function of velocity and turbulence.*
However, measurements of sediment concentrations are necessary, important but difficult. These days especially turbidity probes are used for getting information about sediment concentration continuously over longer periods. A well-known problem of this kind of measurement is its dependency on grain size, form and colour. A new methodology has been tested at Graz University of Technology for determining the sediment concentration in an easy way. A density probe, manufactured by the company Anton Paar GmbH, has been compared with a turbidity probe and conventional gravimetric analyses. The correlations are promising and the probe seems to be suitable to be used in rivers for measurements of suspended sediment concentration.

Keywords: *Suspended sediment concentration, turbidity, density, measurements*

1. INTRODUCTION

Floods occur all over the world. Although they might appear spatial and temporal unequally distributed, they show everywhere more or less the same behaviour like a correlation between the amount of water and the amount of suspended sediment. An example of this correlation is given in Figure 1. However, the correlation coefficient is only 0.41 which shows already the highly stochastic characteristic of the flow.
The ratio between bed load and suspended load is variable, especially because it is depending on boundary conditions like discharge, slope, catchment area, and geology besides others. However, in literature often a ratio of 1:10 between bedload and suspended load is described (Vischer, 1981).
Suspended sediments might have negative impacts on benthic organism and fish. Clogging of gravel bars has a negative impact for spawning and for habitat of benthic organisms too. High sediment concentrations during flushing of reservoirs might have lethal consequences for fish populations. However, these flushings are often necessary in reservoirs where sediments have been settled. These deposits of sediments in reservoirs occur because of the reduction of flow velocities and turbulences.
The above-mentioned indicates the importance of determining the suspended sediment concentration in rivers, lakes, and reservoirs.

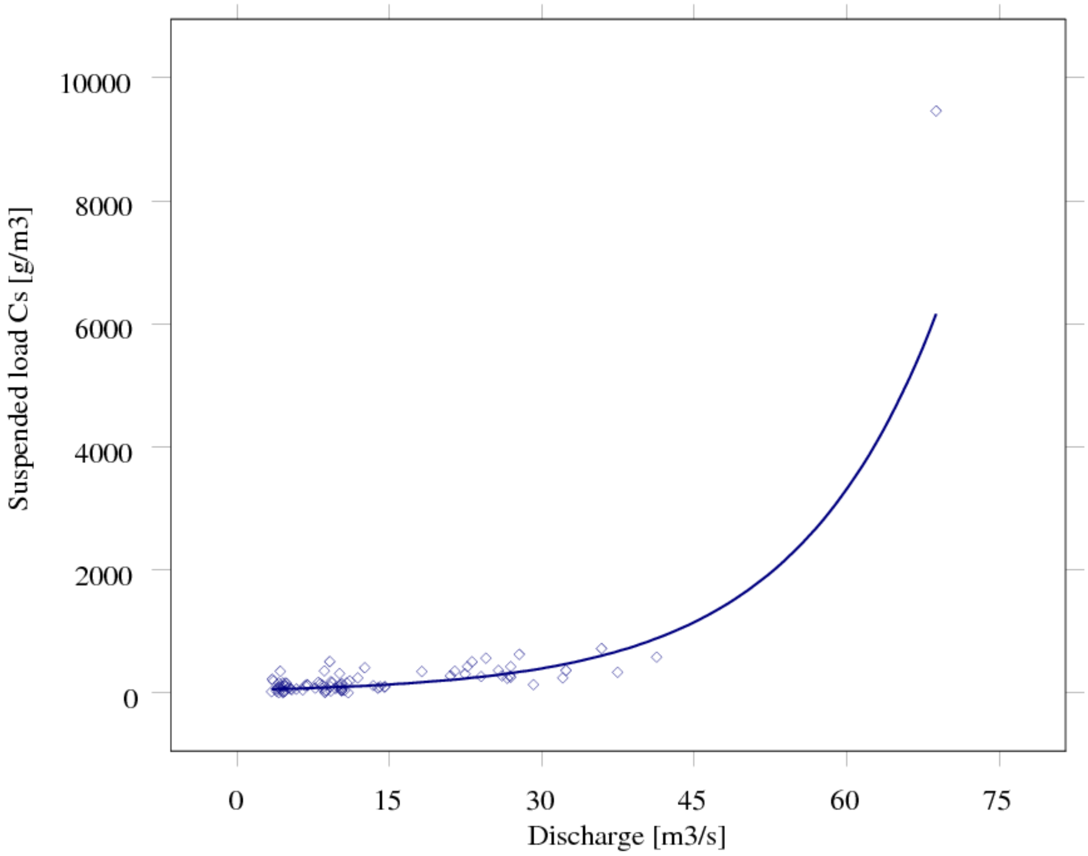

Figure 1 Sediment rating curve (Schneider, 2002)

Turbidity is a natural phenomenon. Fine sediments are eroded in the catchment or in the riverbed and river banks. Due to the turbulence these sediments are kept in suspension and transported downstream. In Alpine rivers suspended sediment concentration of about 10g/l or more are not abnormally (Schneider, 2002). In rivers like the Yellow River concentrations of 35% up to 56% were gauged during flushings (Andreasson & Sellgren, 1986).
As mentioned already the knowledge of the concentration of suspended sediments is needed for many questions like determining the suspended sediment load or evaluating reservoir sedimentation as well as ecological impacts on fish or benthic organisms. Therefore a multiplicity of methods for concentration measurements has been developed. The following methods are known and some of them are widely spread (Wren et al., 2000):

- Acoustic Methods
- Bottle sampling
- Pump sampling
- Focused beam reflectance
- Laser diffraction
- Radiation measurements
- Optical measurements
- Remote spectral reflectance

Every mentioned sediment measurement technique has its advantage and its disadvantage. Today the sampling methods besides optical measurements are mainly used for practical reasons. Optical backscatter methods are state of the art for many applications. However, the calibration of these probes is necessary, time consuming and hence expensive. Therefore a new methodology has been tested in the hydraulic laboratory of Graz University of Technology.

The on-hand paper shows the results of the first tests which were highly satisfactory and show a new way and possibility to get suspension concentration data without calibrating a probe.

2. METHODOLOGY

The following chapters describe procedures to determine the suspended sediment load in the water, as it has been performed in these tests. In the present experiment these are:

- Determination of sediment concentration by using a turbidity probe.
- Determination of sediment concentration by means of density measurements.
- Validation of sediment concentration by laboratory analyses of water samples.

2.1. Turbidity measurements

The measurement of the turbidity of water was performed with a sensor from the industrial measurement technology, mainly used in the wastewater treatment technology. The sensor SOLITAX ts-line, made by the company Hach-Lange (Hach-Lange, 2010), measures the turbidity by means of an infrared dual scatter light (DIN EN 27027). The turbidity is displayed in the unit FNU (Formazine Nephelometric Units), which shows equivalent dilutions of the turbidity standard liquid Formazine. Alternatively the method of dry substance-measurement, according to DIN 38414, is possible. The measured suspended load is shown in g/l. The measuring range covers the range from zero up to a suspended load of 50 g/l and a FNU-value of 4000.
In the present experiment the FNU-value and the suspended load is measured. For a comparison of the FNU-value with the suspended load a laboratory analysis is necessary. The dry solids measurement is interpreted as an additional reference measurement.

The possible influences of the samples to the measurement for turbidity measurements are:

- **Grain size of suspended load:** The source material is subjected to a visual assessment. The grain size of the solid entry is in the range of clay-silt. Small quantities of sand are also found. During the experiment there is a very good mixture of different grain sizes in the water due to the highly turbulent circulation. If the circulation pump is switched off, the larger grain sizes settle faster. The composition of the suspended load changes.
- **Colour of the suspended load:** The colour spectrum of the solid material is in the range gray-brown. According to information from the company Hach-Lange, this spectrum causes problems during the determination of the FNU-value.
- **Temperature:** The change of temperature in winter and summer influences the optical properties of the medium too. In an outdoor measurement this effect will have to be considered.
- **Position of the sensor:** If the sensor is positioned too close to the surface of the medium, a changing of the optical properties occurs due to the influence of sunlight. Sufficient coverage must be ensured.

2.2. Density measurements

The measurement of the density is carried out by means of a sensor which is used in the industrial process measurement. The sensor type DTR 4122 of the company Anton Paar is based on the oscillating U-tube method (Paar, 2010). The following Figure 2 shows the probe, which is mounted in the lab.

Figure 2 The built-in density probe DTR 4122

The sensor determines the frequency of oscillation of a U-shaped tube, Ø22mm, where the liquid flows through. The measured time period of this resonance frequency is a measure of the density of the test sample. The temperature is being compensated by the sensor. The transducer has to be connected to a vibration-free base. The present sensor is designed for high flows and inhomogeneous specimens. Influences of viscosity, pressure, and flow are negligible. The density of clean water is subtracted from the measured density to calculate a concentration of the suspended sediment load (see eq. 1).

$$c_{\text{suspended load}} = \rho_{\text{sample}} - \rho_{\text{water}} \times 10^{6}\ [mg/l]\ (\rho \text{ in } g/cm^3) \qquad (1)$$

The sensor achieves a guaranteed resolution of 0.0001g/cm^3, which means the measurement of the suspended sediment load, can reach an accuracy of 0.1g/l. The fifth decimal place in the density measurement is only a tendency and cannot be used to gain the accuracy.

The following influences of the sample to the measurement have to be mentioned:

- **Density:** The density of water depends primarily on the temperature. Other important factors are the dissolved salts and minerals in the water and the concentration of the suspended sediment load. To take account of the temperature the sensor calculates a compensated density (for 20°C), which is subsequently used as a value for further calculations. The comparative density in equation 1 can therefore not be calculated, but must be determined by means of laboratory measurement of the density of the water without suspended sediment load.
- **Viscosity:** According to Paar (2010) the influence of viscosity is negligible.
- **Surface tension:** The effect of surface tension occurs at free surfaces and particularly at very small gaps (capillary effect). In the present experiment there is a closed pipe system (complete wetting) and a sufficiently large diameter of the pipe. The effect of surface tension is therefore negligible.
- **Solubility of gases:** The influence of chemically dissolved gases has been mentioned already. Air bubbles have a significant influence. The foregoing application of a cyclone should prevent this problem.

- **Compressibility:** The entire experimental setup is not under pressure. Due to the velocity of the water, the internal pressure will be reduced and causes a density decrease. But this will occur in a negligibly small scale.
- **Thermal expansion:** The thermal expansion can take place freely; the influence on the density is minimal. The influence of the thermal expansion is negligible.
- **Vapour pressure:** A measurable change occurs only at significantly increased or reduced pressure. The influence in this experiment is negligible.

2.3. Gravimetric determination

The results of laboratory analysis are used as reference values. During the experiment water samples were taken to confirm the density and the turbidity measurements. The samples were weighed, filtered under vacuum (Filter opening 0,45 μm), and the solid material was determined in g/l.

The possible influences on the accuracy of the laboratory analysis are:

- **Grain density:** The particle density has a significant influence on the density and, subsequently, on the solid material. In the laboratory the mass of the solid material is determined; the particle density has a meaning only for theoretical considerations.
- **Drying process:** In the laboratory the samples were dried for 24 hours at 40°C. The comparison with samples dried for 24 hours at 100°C showed that the differences are not significant.
- **Temperature differences:** Ideally, the analysis of the medium in the laboratory is carried out at the same temperature. Due to the existing small quantities of water and low temperature differences of a few °C, the differences are not significant.

3. THE EXPERIMENTAL SETUP

The tests were performed in a flume which is mainly used for sediment tests. A rough overview of the setup is shown in Figure 3. In a channel water is circulated by a pump between two tanks. In the feeding tank there is the turbidity probe (E) and the water for the density measurement (D) is pumped out from the same location in this tank. For outgassing the water, a cyclone was placed before the density sensor. The tests were performed as solid was added stepwise to the clear water and thus the suspended sediment concentration was increased. After adding the fine material a certain time was elapsed before the turbidity and density values were stored. In total, 14 samples were taken for calibrating the measurements.

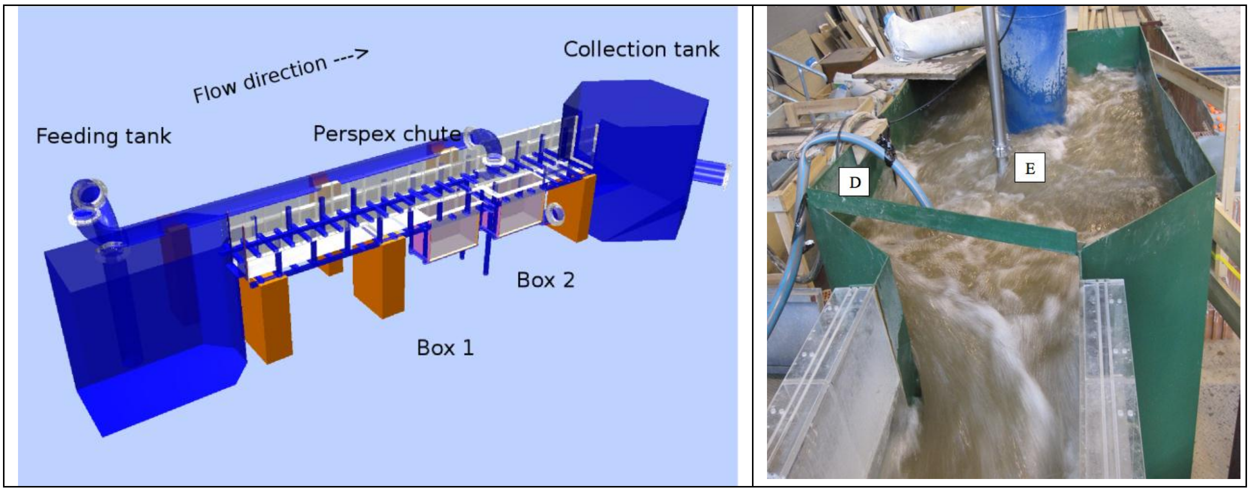

Figure 3 Overview of experimental setup, location of measurements

4. RESULTS

The challenge for density measurements in high turbulent flows, as occurring during floods, is the fact that a 3-phase mixture is prevailing. Besides water and suspended material the air has to be accounted for too. The most promising way to deal with that is to eliminate the air before the measurement is done.

In our case we installed a cyclone before the water enters the density probe. However, it is not possible to eliminate the air completely. Therefore a theoretical density - solids content correlation was calculated and compared with the measured data (see Figure 4).

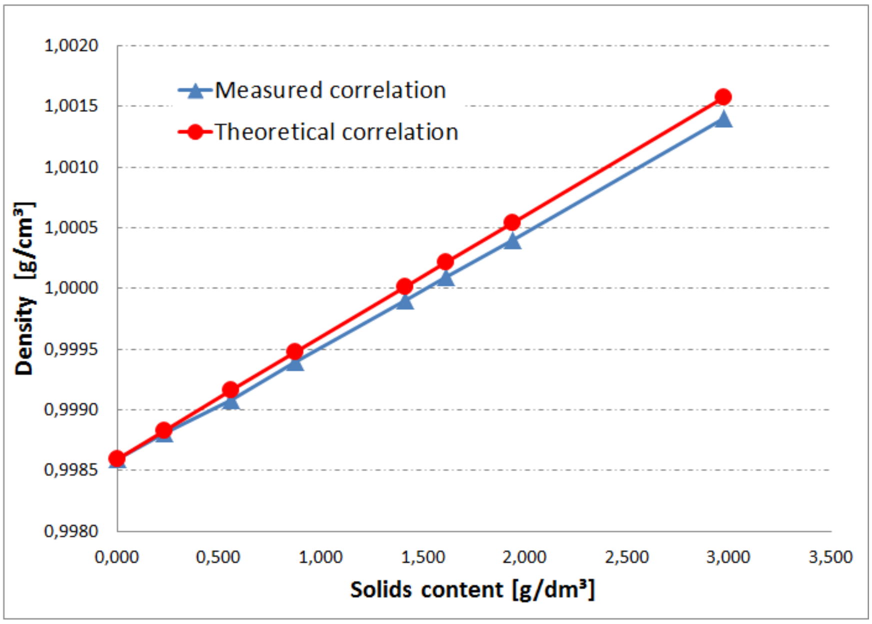

Figure 4 Comparison of the theoretical density without air (dots) and the measured density (triangles)

Based on the shift between theoretical and measured lines a curve for the theoretical air content could be found.

The measured data plotted over time show very good correlations between all three methods (Figure 5). Only the last point of the turbidity measurement is an outlier because of a measurement error.

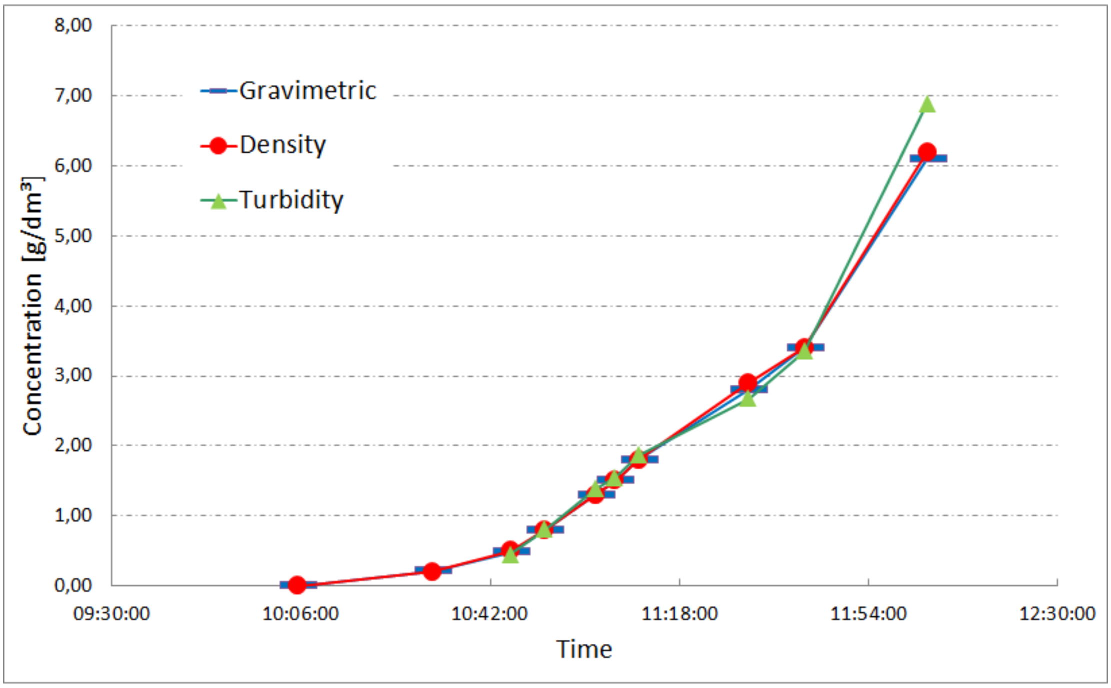

Figure 5 Change of sediment concentrations in the course of the test (gravimetric: dashes, density: dots, turbidity: triangles)

The removal of the time component shows the relation between turbidity and concentration. Figure 6 shows the comparison of all three methods for determining the suspended sediment concentration.

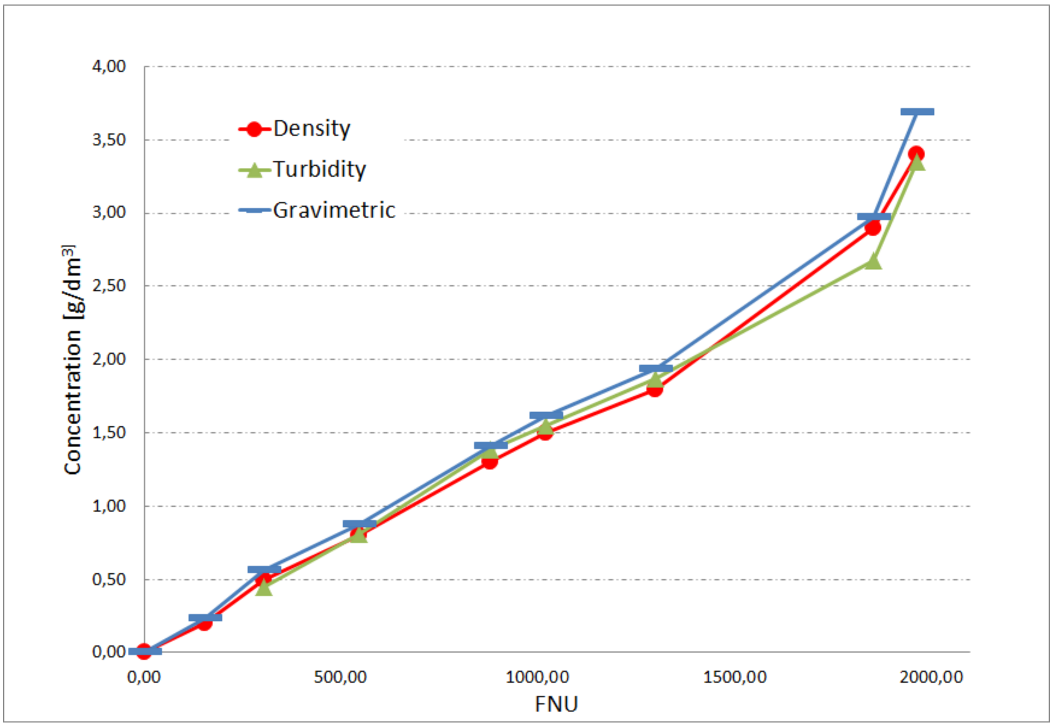

Figure 6 Comparison of the measured solid concentrations, laboratory analysis (dashes), density measurement (dots), and turbidity measurement (triangles)

5. SUMMARY

The first tests show satisfying results. A cyclone for the outgassing of the water is necessary for avoiding the biasing of the data. The turbidity measurements and density measurements give comparable results to the laboratory analyses of the liquid samples.
Thus, it is generally possible to use both methods in the field. If the turbidity measurements are made based on FNU, a calibration is required. If the measurement is based on a dry substance measurement, a calibration might be omitted. However, the test showed that the density measurements require a measured reference density, because the mathematical description of the existing density is not possible. Further tests will be performed in the lab and the follow-up research will be done in the field.

6. REFERENCES

Andreasson, P; Sellgren, A., 1986. River Flow with Excessive Suspended Sediment Load An Evaluation of Turbulent Flow Characteristics. Nordic Hydrology, 17, pp.383-390.

Fa. Hach-Lange, 2010. SOLITAX sc family. Available at: http://www.hach-lange.de.

Paar, A., 2010. Messungen von Konzentrationen, Dichte und Schallgeschwindigkeit in industriellen Prozessen. Available at: http://www.anton-paar.com.

Schneider, J., 2002. Verlandungsproblematik eines alpinen Speichers am Beispiel des Sölkstaus. Dissertation, University of Life Sciences, Vienna

Vischer, D., 1981. Verlandung von Flussstauhaltungen und Speicherseen D. Vischer, ed. Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie: Verlandung von Stauhaltungen und Speicherseen im Alpenraum, ETH Zürich, Vol. 53.

Wren, D.G. et al., 2000. Field Techniques for suspended Sediment measurements. Journal of Hydraulic Engineering, pp.S. 97-104.