



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-L401

Soil Texture Analysis – Hydrometer Method

Standard Operating Procedure

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1. Purpose

This procedure describes the determination of soil particle size distribution using the hydrometer method (ASTM D422). Soil texture (the relative proportions of sand, silt, and clay) is a fundamental physical property that controls water-holding capacity, drainage, nutrient retention, and soil structure. The hydrometer method measures the density of a soil-water suspension at timed intervals as progressively finer particles settle, allowing calculation of the percent sand, silt, and clay and assignment of a USDA textural class.

For a rapid field estimate of texture without laboratory equipment, see [SOP-F401 Texture by Feel](#).

2. Scope

- **Applies to:** Mineral soils with less than approximately 20% coarse fragments (greater than 2 mm). Soils with high organic matter or carbonates require pre-treatment (see Section 6.4).
- **Does not apply to:** Pure gravel, organic soils (histosols), or soils where only a textural class estimate is needed (use [SOP-F401](#) instead)
- **Location:** EA Program laboratory, SGM 133

3. Responsibilities

Role	Responsibility
Lab PI	Approve SOP, ensure training compliance
Lab Manager	Maintain equipment, prepare HMP solution
Trained Personnel	Perform the analysis over multiple sessions
New Students	Complete training before independent use

4. Definitions

- **Clay:** Soil mineral particles with an equivalent spherical diameter less than 0.002 mm (2 μm); slow-settling; comprises the finest soil texture fraction.
- **Dispersion:** The process of separating soil aggregates into individual particles by chemical treatment (sodium hexametaphosphate) and mechanical agitation; essential for accurate hydrometer analysis.

- **ASTM 151H hydrometer:** A standardized glass hydrometer calibrated in g L^{-1} for use in soil texture analysis; reads the density of the suspension at the center of the hydrometer bulb.
- **Sand:** Soil mineral particles with an equivalent spherical diameter of 0.05–2.0 mm; collected on a 0.05 mm sieve after sedimentation.
- **Sedimentation:** The settling of soil particles in suspension under gravity; particle settling velocity follows Stokes' Law: $v = 2gr^2(\rho_s - \rho_l)/(9\eta)$, where r is particle radius, ρ_s is particle density, ρ_l is liquid density, and η is dynamic viscosity.
- **Silt:** Soil mineral particles with an equivalent spherical diameter of 0.002–0.05 mm; intermediate settling rate; calculated as $\text{silt} = 100\% - \text{sand}\% - \text{clay}\%$.
- **Stokes' Law:** The physical law governing particle sedimentation velocity in a viscous fluid; the basis for hydrometer texture analysis; assumes spherical particles of uniform density (2.65 g cm^{-3}).
- **Texture class:** A USDA textural classification (e.g., sandy loam, clay loam, silty clay) based on the relative percentages of sand, silt, and clay; determined from the USDA textural triangle.

5. Safety and Hazards

Hazards

- **Chemical:** Sodium hexametaphosphate (HMP) is a mild skin and eye irritant. Hydrogen peroxide (30%) is a strong oxidizer and causes burns on contact. Hydrochloric acid (1 N) is corrosive.
- **Physical:** The milkshake mixer creates a vigorous vortex; keep loose clothing and hair clear. Hot plates and drying ovens pose burn risk.

5.1. Required PPE

- ☐ Safety glasses (chemical-safety goggles when using H_2O_2 or HCl)
- ☐ Lab coat
- ☐ Nitrile or latex gloves
- ☐ Hearing protection not required but recommended near the mixer

5.2. Emergency Procedures

For H_2O_2 or HCl splashes, flush with water for at least 15 minutes. For HMP powder inhalation, move to fresh air. Refer to [SOP-L003 Hazardous Materials Handling](#).

6. Equipment and Materials

6.1. Equipment

Item	Notes
No. 10 sieve (2 mm mesh)	For removing gravel
No. 200 sieve (0.075 mm mesh)	For sand fraction recovery
Milkshake mixer and dispersion cup	For mechanical dispersion
151H hydrometer	ASTM standard
1 L sedimentation cylinder with No. 13 stopper	Glass or polycarbonate
Stopwatch or timer	For recording settling times
Thermometer (0.5 C resolution)	For temperature corrections
Analytical balance (0.01 g)	See SOP-L102
Drying oven (110 C)	See SOP-L105
Hot plate	For pre-treatment heating
250 mL and 400 mL beakers	For pre-treatment and weighing
Soil tins (pre-weighed)	For moisture determination
Mortar and pestle	For breaking up air-dried aggregates
Squeeze bottle (DI water)	For quantitative transfers

6.2. Reagents

Reagent	Preparation / Notes
Sodium hexametaphosphate (HMP)	40 g/L solution in DI water; prepare fresh weekly
Hydrogen peroxide, 30% (CAS 7722-84-1)	For organic matter removal (pre-treatment)
Hydrochloric acid, 1 N (CAS 7647-01-0)	For carbonate removal (pre-treatment)
Distilled or deionized water	From SOP-L11

7. Procedure

The analysis spans multiple lab sessions. Plan accordingly:

Session	Tasks	Time Required
1	Air-dry 200 g of soil	24+ hours (passive)
2	Sieve through No. 10; subsample for moisture	1–2 hours
3	Calculate DW_e ; pre-treat and/or disperse	2–3 hours + 16 h soak
4	Conduct hydrometer readings	24+ hours (intermittent)
5	Recover sand on No. 200 sieve; complete data entry	1–2 hours

7.1. Air-Drying the Soil

1. Spread approximately 200 g of field-moist soil in a labeled tin or beaker

2. Allow to equilibrate with laboratory air for 24 hours or more. Very wet soils may require several days.
3. Break up large clods periodically to promote even drying

7.2. Sieving Through the No. 10 Sieve

Soil is defined as particles less than 2 mm. Gravel must be removed before analysis but quantified.

1. Homogenize the air-dried soil by thorough mixing
2. Weigh approximately 65 g (silt/clay soils) or 120 g (sandy soils) of air-dried soil and record the mass
3. Using a mortar and pestle, gently break up aggregates so that individual particles pass the No. 10 sieve. Do not crush primary mineral grains.
4. Sieve the soil through the No. 10 sieve (2 mm)
5. Weigh and record the mass of soil that passed through the sieve
6. Calculate the percent passing:

$$\text{Percent passing No. 10} = \frac{M_{\text{passed}}}{M_{\text{total}}} \times 100$$

7.3. Determining Hygroscopic Moisture Content

Air-dried soil still contains hygroscopic water adsorbed to clay surfaces, salts, and organic matter. This must be measured and corrected for.

1. Select a soil tin; record the tin number and tare mass
2. Transfer a 10–15 g subsample of the air-dried, sieved soil to the tin and record the air-dried mass (tin + soil)
3. Dry in the oven at 110 C for approximately 24 hours
4. Cool in a desiccator and record the oven-dried mass (tin + soil)
5. Calculate hygroscopic moisture:

$$\text{Moisture}_H = \frac{M_{\text{air-dry w/ tin}} - M_{\text{oven-dry w/ tin}}}{M_{\text{air-dry w/ tin}} - M_{\text{tin}}}$$

Note

The standard drying temperature of 105–110 C is somewhat arbitrary. Clay minerals may retain 10–15% water (dry basis) at 400 C. Organic components also release volatiles over a range of temperatures. The key is to specify and consistently use the same temperature.

7.4. Calculating Oven-Dry Equivalent Mass (DW_e)

The target oven-dry equivalent mass for the hydrometer test is 50 g for fine-textured soils or 100 g for coarse-textured soils (greater than approximately 70% sand).

Since air-dried soil contains hygroscopic water, the actual mass of air-dried soil to weigh out is:

$$DW_{\text{air}} = \frac{DW_e}{1 - \text{Moisture}_H}$$

where $DW_e = 50$ g or 100 g.

7.5. Pre-Treatment (If Required)

Pre-treatment is necessary for soils high in organic matter, carbonates, iron oxides, or soluble salts. If the soil is low in all of these, proceed directly to Section 6.6.

1. Transfer DW_{air} g of soil to a 400 mL beaker
2. **Carbonate removal:** Add 50 mL DI water and sufficient 1 N HCl to reduce the pH to 3.0–4.0. Stir and allow to equilibrate for 10 minutes until effervescence ceases.
3. **Organic matter removal:** Carefully add 30% H_2O_2 a few milliliters at a time, allowing frothing to subside between additions. If necessary, acidify the suspension with a few drops of 1 N HCl (H_2O_2 oxidation requires an acidic medium). When frothing subsides, heat to 90 C and continue adding H_2O_2 until no further reaction occurs. Rinse down the beaker walls and continue heating until excess H_2O_2 is consumed.
4. **Iron oxide removal (if needed):** Add 150 mL citrate-bicarbonate buffer. Add 3 g sodium hydrosulfite ($\text{Na}_2\text{S}_2\text{O}_4$) gradually (may froth). Heat in a water bath at 80 C for 20 minutes.
5. **Soluble salt removal (if needed):** Transfer soil to a centrifuge tube, add 100 mL DI water, and centrifuge at 1,500 rpm for 10 minutes. Decant the supernatant. Repeat until the supernatant is clear.

Warning

Handle 30% H_2O_2 in the fume hood. It is a strong oxidizer that causes skin burns on contact. Add it slowly to avoid violent frothing.

7.6. Dispersing the Soil Sample

1. Weigh DW_{air} g of pre-treated (or untreated) soil into the dispersion cup and record the mass to 0.1 g
2. Add 125 mL of 40 g/L sodium hexametaphosphate solution
3. Stir until the slurry is thoroughly wetted
4. Cover and soak for at least 16 hours (overnight)
5. Add distilled water to the first indentation mark on the dispersion cup
6. Attach the cup to the milkshake mixer and mix for 5 minutes (sandy soils) or 15 minutes (fine-textured soils)

7.7. Conducting the Hydrometer Test

Blank preparation:

1. Prepare a blank cylinder: add 125 mL of HMP solution and fill to the 1,000 mL mark with distilled water
2. Record the blank hydrometer reading and temperature. If the zero mark is below the meniscus surface, record the correction as a negative number. Read at the top of the meniscus (the suspension is opaque).

Sample measurement:

1. Transfer the dispersed soil suspension to a sedimentation cylinder, using a squeeze bottle to rinse all material from the dispersion cup
2. Fill the cylinder to the 1,000 mL mark with distilled water
3. Stopper the cylinder (No. 13) and invert 180 degrees and back in a steady 2-second cycle for one full minute. Vigorously agitate during the first two inversions to loosen settled material.
4. Set the cylinder upright and start the timer immediately
5. At 20 seconds elapsed, slowly lower the hydrometer into the suspension (spinning gently to dislodge air bubbles) and read at 40 seconds. Remove, rinse, and dry the hydrometer.
6. Repeat the inversion and 40-second reading two more times (three total readings at 40 s) for accuracy
7. After the final 40-second reading, lower a thermometer into the suspension and record the temperature

! Important

The hydrometer must be removed, rinsed, and dried between every reading. Particles accumulate on the glass surface and progressively bias subsequent readings if not cleaned.

8. Continue taking hydrometer and temperature readings at the following schedule:

Reading	Time After Inversion	Temperature?	Blank Reading?
0	Before inverting	Yes	Yes
1	40 seconds (x3)	Yes (after)	–
2	2 minutes	–	–
3	5 minutes	Yes	Yes
4	15 minutes	–	–
5	30 minutes	–	–
6	60 minutes	Yes	Yes
7	2 hours	Yes	Yes
8	3 hours (optional)	Yes	Yes
9	6–8 hours (optional)	Yes	Yes
10	24 hours	Yes	Yes

9. Place the cylinder in a stable, undisturbed location between readings

7.8. Recovering Sand on the No. 200 Sieve

The hydrometer method does not resolve sand subfractions well. Sieve analysis of the sand fraction provides this detail.

1. After the final hydrometer reading, pour the cylinder contents through a No. 200 sieve (0.075 mm)
2. Using tap water (with a sediment trap in the sink), wash the material on the sieve until the rinse water is clear
3. Select a soil tin; record the tin number and tare mass
4. Carefully wash the retained sand from the sieve into the tin using a squeeze bottle. Do not use a brush or metal tool on the sieve mesh.
5. Dry at 110 C for 24 hours
6. Cool and weigh the tin plus dried sand; record the mass

Tip

The No. 200 sieve screens are delicate. Forcing particles through or scrubbing with a brush can stretch or distort the mesh. Always use a gentle water stream or squeeze bottle.

8. Quality Control and Acceptance Criteria

8.1. Calculations

The key calculated quantities for each hydrometer reading are:

Corrected hydrometer reading:

$$R_c = R_{\text{actual}} - R_{\text{blank}}$$

Effective particle diameter (D_e , mm) at each reading time is calculated from Stokes' Law, accounting for temperature-corrected viscosity and density of the suspension fluid.

Percent finer at each reading:

$$PF = \frac{R_c \times a}{DW_e} \times 100$$

where a is a correction factor based on the specific gravity of soil particles (typically 2.65 for mineral soils).

Textural class is determined by plotting the calculated percent sand, silt, and clay on the USDA textural triangle.

8.2. Bias and Interference Sources

Source	Effect	Correction
Temperature and viscosity	Cold water increases viscosity, slowing settling	Temperature correction factor applied to each reading
Temperature and density	Water density varies with temperature	Density correction in Stokes' Law
Hygroscopic moisture	Air-dried soil mass overestimates oven-dry mass	DW_e correction (Section 6.4)
Incomplete dispersion	Aggregates settle as single large particles; underestimates clay	Use HMP + mechanical mixing; pre-treat if needed
Meniscus reading	Opaque suspension prevents reading at bottom of meniscus	Read at top of meniscus; apply meniscus correction
Flocculation	Ca^{2+} and Al^{3+} bridge clay particles	HMP displaces polyvalent cations; Na^+ hydrates clay surfaces

8.3. QC Requirements

- Run a duplicate analysis on at least 10% of samples
- Duplicate results should agree within one textural class
- Include a blank cylinder (HMP + water, no soil) with every batch
- Record all temperatures; temperature drift greater than 2 C during the reading series indicates an unstable environment
- Cross-check a subset of hydrometer results against field texture-by- feel estimates ([SOP-F401](#))

9. Waste Disposal

Waste Type	Disposal Method
Soil suspension (no pre-treatment chemicals)	Settle, decant water, dispose of soil in standard trash
HMP solution (spent)	Drain with copious water (low hazard)
H_2O_2 waste (from pre-treatment)	Dilute and drain, or collect for EH&S if concentrated
HCl waste (from pre-treatment)	Neutralize with NaHCO_3 and drain, or collect per SOP-L003
Sieve washings	Use a sediment trap; dispose of trapped soil in standard trash

10. References

- ASTM D422-63(2007)e2. *Standard Test Method for Particle-Size Analysis of Soils*. ASTM International, West Conshohocken, PA. (Withdrawn 2016; replaced by D7928, but D422 remains widely used in teaching and soil science.)
- Gee, G.W. & Or, D. (2002). Particle-size analysis. In: Dane, J.H. & Topp, G.C. (Eds.), *Methods of Soil Analysis, Part 4: Physical Methods*. SSSA Book Series No. 5. pp. 255–293.
- Wilde, S.A., Corey, R.B., Iyer, J.G., & Voigt, G.K. (1979). *Soil and Plant Analysis for Tree Culture*. Oxford and IBH Publishing Co., New Delhi. pp. 12–13.
- Anderson, J.M. & Ingram, J.S., eds. (1993). *Tropical Soil Biology and Fertility: A Handbook of Methods*. 2nd ed. CAB International, Wallingford, UK. pp. 93–94.
- Soil Science Division Staff. (2017). *Soil Survey Manual*. USDA Handbook No. 18. USDA-NRCS.

11. Training Record

Before performing hydrometer analysis independently, personnel must:

1. Read this SOP in full
2. Complete [SOP-L002 Laboratory Safety](#), [SOP-L003 Hazardous Materials Handling](#), and [SOP-L400 Soil Moisture](#) training
3. Observe a trained operator perform the full multi-session analysis
4. Demonstrate proper soil dispersion, hydrometer reading technique, and temperature recording under supervision
5. Complete one full analysis (all sessions) with acceptable duplicate precision
6. Be signed off by the PI or lab manager

12. Appendix A: Example Calculations in R

```
library(tidyverse)

# --- Hygroscopic moisture correction ---
tin_mass_g <- 15.32
air_dry_w_tin_g <- 27.45
oven_dry_w_tin_g <- 27.18

moisture_H <- (air_dry_w_tin_g - oven_dry_w_tin_g) /
              (air_dry_w_tin_g - tin_mass_g)

cat(sprintf("Hygroscopic moisture: %.4f g/g\n", moisture_H))

# --- Oven-dry equivalent mass ---
DW_e <- 50 # g; use 100 for sandy soils
```

```
DW_air <- DW_e / (1 - moisture_H)

cat(sprintf("Air-dried soil to weigh: %.2f g\n", DW_air))

# --- Hydrometer readings ---
# Example data: time (min), hydrometer reading, temp (C), blank reading
readings <- tibble(
  time_min = c(0.67, 2, 5, 15, 30, 60, 120, 1440),
  R_actual = c(38, 32, 27, 22, 19, 16, 13, 8),
  temp_C = c(23, 23, 23, 22, 22, 22, 22, 21),
  R_blank = c(5, 5, 5, 5, 5, 5, 5, 5)
)

# Corrected readings
readings <- readings %>%
  mutate(
    R_corrected = R_actual - R_blank,
    # Simplified percent finer (a = 1 for Gs = 2.65)
    percent_finer = (R_corrected / DW_e) * 100
  )

# Sand, silt, clay from key readings
# Percent sand: 100 - PF at 40 sec (0.67 min)
# Percent clay: PF at 1440 min (24 h)
pct_sand <- 100 - readings$percent_finer[readings$time_min == 0.67]
pct_clay <- readings$percent_finer[readings$time_min == 1440]
pct_silt <- 100 - pct_sand - pct_clay

cat(sprintf("\nSand: %.1f%%  Silt: %.1f%%  Clay: %.1f%%\n",
  pct_sand, pct_silt, pct_clay))

# Plot particle size distribution curve
ggplot(readings, aes(x = time_min, y = percent_finer)) +
  geom_point(size = 3) +
  geom_line() +
  scale_x_log10() +
  labs(
    x = "Settling time (minutes, log scale)",
    y = "Percent finer (%)",
    title = "Hydrometer Particle Size Distribution"
  ) +
  theme_minimal()
```

13. Appendix B: USDA Textural Classes

Once percent sand, silt, and clay are determined, assign the textural class using the USDA textural triangle. The 12 classes are:

Class	Sand (%)	Silt (%)	Clay (%)
Sand	85–100	0–15	0–10
Loamy sand	70–90	0–30	0–15
Sandy loam	43–85	0–50	0–20
Loam	23–52	28–50	7–27
Silt loam	0–50	50–88	0–27
Silt	0–20	80–100	0–12
Sandy clay loam	45–80	0–28	20–35
Clay loam	20–45	15–53	27–40
Silty clay loam	0–20	40–73	27–40
Sandy clay	45–65	0–20	35–55
Silty clay	0–20	40–60	40–60
Clay	0–45	0–40	40–100

14. Appendix C: Troubleshooting

Symptom	Probable Cause	Corrective Action
Clay content seems too low	Incomplete dispersion	Extend soaking time; increase mixer time; verify HMP concentration
Readings inconsistent at 40 s	Insufficient mixing; uneven settling	Ensure vigorous, consistent inversions; repeat three times
Temperature drifts more than 2 C	Lab temperature unstable	Move cylinder away from heat sources; consider a water bath
Blank reading changes over time	HMP solution degrading	Prepare fresh HMP solution weekly
Sand fraction sums do not match hydrometer	Soil lost during sieve transfer	Rinse quantitatively; check for cracks in the sieve
Percent finer exceeds 100% or is negative	Data entry or calculation error	Double-check raw readings, blank correction, and DW_e