

MICROTRAC PARTICLE-SIZE ANALYZER: AN ALTERNATIVE PARTICLE-SIZE DETERMINATION METHOD FOR SEDIMENT AND SOILS

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ABSTRACT

The Microtrac method is particularly well suited to particle-size analysis of suspended sediment samples having low concentrations and limited quantities, because quantities of 0.01 g may be routinely analyzed. Major advantages of the Microtrac method are the speed and ease with which the measurements are performed and the speed with which the results, in a usable form, are presented.

We compared the sieve-pipette and Microtrac methods of particle-size analysis for 10 soils representing the common range of size distribution found in soils and sediment. The effect of organic constituents on the comparison of laser and pipette analyses was investigated by removal of organic matter from replicate samples.

Regression analysis may be used to convert Microtrac results to those of the sieve-pipette method with an acceptable degree of accuracy; however, this is best achieved when done by particle-size ranges. The agreement between the two methods was highest for the two size ranges from 62 to 31 μm and 31 to 16 μm , with a correlation of 0.92 for both. The agreement for all size ranges improved when sieve data from 62 to 176 μm were removed from the comparison.

INTRODUCTION

Particle-size distributions have been used to describe similarities and differences among soils for about 100 years. Osborne (1887) developed the beaker method of mechanical analysis of soils to separate, or determine, that fraction of the soil mass considered important in the chemical behavior of soils. Numerous scientists investigated methods of mechanical analyses from the 1920s through the 1960s. Combinations of mechanical sieving and fall of particles in a liquid formed the basis of most analyses. Sample preparation and dispersion are important factors for satisfactory analysis (Tyner 1939; Kilmer and Alexander 1949). Improved methods of sample preparation were the objective for many investigators, in order to achieve truly disperse systems necessary to approximate the fundamental assumptions underlying Stokes' law (1851) for determining particle fall velocity. The sieve-pipette method of particle-size analysis

has become the favored method and is often used as a standard with which to measure particle-size distribution (Jennings et al. 1922; Krauss 1923; Robinson 1922). Laboratory techniques for sediment particle-size analysis (U.S. Interagency Committee 1957) have developed along the same general lines as that for soils. That is, sieving-pipetting is an accepted method with well-established procedures. Also, the method is consistent with that for analysis of residual soil and sediment particle size, which can be related directly to particle-size distribution of soils. There are several problems associated with pipette analysis of water quality samples, namely (1) sediment content of the sample is often too low for accurate measurement; (2) the technique is too time consuming for the number of samples to be analyzed; (3) sample preparation may destroy or alter sediment characteristics of interest; and (4) results are highly dependent on laboratory technique. The pipette method requires a minimum of 1 g of soil (Guy

1969), with larger amounts needed for greater accuracy. Particle shape (Heywood 1947), distance between vessel walls, Brownian motion and solids concentration (Koglin 1972), Reynolds number or flow regime (Allen and Baudet 1977), and convection currents (Muta and Watanabe 1972) all affect the settling rate and thus influence the reported particle size.

One of the assumptions of Stokes' law is that particles must be rigid and smooth. Soil particles are not smooth spheres, and electron microscopes have been used successfully to characterize the shape of clay particles (Shaw and Humbert 1941). Although clay particle shapes do not meet the assumption of Stokes' law, this limitation was somewhat circumvented by assuming an "equivalent" diameter. X-ray diffraction techniques have been developed for clay mineral identification and crystal structure analysis (Brown 1961).

Interest in water quality associated with runoff and sediment has created a need for more sediment particle information than merely that for primary sand, silt, and clay (Knisel 1980). Organic matter, clay content, and soil aggregates are important in the transport of adsorbed chemicals. Sediment sample preparation for pipette analysis typically includes oxidation of organic matter and dispersion of the sediment to single grain particles. Analysis by the pipette method of sediment samples from high organic soils, such as the Irvinton fine, sandy loam in Florida (USDA-SCS 1969), is practically meaningless. Because the method of preparation negates determination of aggregates in sediment transport, new methods of particle size and aggregate analysis are needed for rapid analysis of large numbers of small samples. Whatever methods or instruments are used, they must be comparable with existing methods and data.

Clearly, a method that will overcome the disadvantages of pipette analysis is needed for rapid particle-size determination of soil and sediment samples. Weiss and Frock (1976) described such a method using an instrument that employs the principle of laser light scattering to measure particle-size distribution. The instrument, a Microtrac manufactured by Leeds and Northrup¹, was reported to be highly precise in determination and reproducibility of results.

¹ Trade names are included for the readers' information; their mention does not constitute endorsement by the USDA.

Haverland and Cooper (1981) discussed sample preparation and working capabilities of the instrument for a wide range of soil textures.

An experiment was designed to compare the Microtrac analysis with the common sieve-pipette analysis. Soils having a wide range of characteristics were used to determine regression equations for relating the methods of analysis. Additionally, the influence of organic constituents on the determination of particle-size distribution was investigated, and correlations were developed.

MATERIALS AND METHODS

Ten soils were selected; their soil series, textural classification, and great groups are given in Table 1, and their mineralogy in Tables 2 and 3. Comparisons of percentages of total sample lying within specified particle-size ranges were made between Microtrac and pipette methods for all soils. Standard procedures for pipette analysis were followed (Day 1965), and comparative relations by regression analysis were developed between the two methods. The use of standard procedures and the development of relationships provide comparative results for past and future sample analyses.

General description and operation of the Microtrac

The Microtrac measures particle size by the low-angle forward-scattering of laser light that has passed through a sample cell (Wertheimer

TABLE 1
Characteristics of the 10 soils used

Soil series (state)	Texture class	Soil great group
Superstition (Arizona)	Sand	Calciorthid
Rositas (Arizona)	Sand	Torripsamment
Vinton (Arizona)	Loamy sand	Torrifluent
Comoro (Arizona)	Sandy loam	Torrifluent
Ida (Iowa)	Silt loam	Udorthent
Laveen (Arizona)	Loam	Calciorthid
Cecil (Georgia)	Loam	Hapludult
Mohall (Arizona)	Sandy clay loam	Haplargid
Cecil (Georgia)	Clay	Hapludult
Houston (Texas)	Clay	Chromudert

TABLE 2
X-ray diffraction data summary <62 μm separate

Soil	Size range																	
	62-31 μm						31-16 μm						16-1.9 μm					
	Q ^a	F	Mi	K	Ca	H	Q	F	Mi	K	Ca	H	Q	F	Mi	K	Ca	Do
Houston	4 ^b	2	0	0	2	0	4	2	0	0	2	0	3	1	0	0	3	0
Laveen	4	3	1	0	2	0	4	3	2	0	2	0	3	3	2	2	2	0
Ida	3	3	1	1	2	0	4	3	1	1	0	0	3	3	2	2	0	2
Vinton	3	4	1	0	0	0	3	3	1	0	0	0	3	3	2	2	0	0
Rositas	4	4	1	1	0	0	4	3	1	1	0	1	3	3	2	2	0	0
Cecil loam	4	3	1	1	0	0	4	2	2	2	0	0	4	2	2	3	0	0
Superstition	4	3	0	0	1	0	3	3	1	1	1	0	3	3	2	2	1	0
Cecil clay	4	2	2	3	0	0	3	1	1	2	0	0	3	0	2	4	0	0
Mohall	3	4	1	0	0	0	3	4	1	0	0	0	2	3	2	2	0	0
Comoro	4	3	2	0	1	1	3	3	2	0	0	0	3	3	3	0	0	0

Soil	Size range less than 1.9 μm									
	M ^a	V	C	Mi	K	G	Q	F	H	
Houston	5 ^b	0	0	1	2	0	1	0	0	
Laveen	3	0	0	2	2	0	2	0	2	
Ida	5	0	0	2	2	0	2	0	0	
Vinton	4	2	0	2	2	0	2	1	0	
Rositas	4	0	0	2	2	0	2	0	0	
Cecil loam	0	0	2	2	4	1	2	0	2	
Superstition	4	0	0	2	2	0	2	0	0	
Cecil clay	0	0	0	2	4	1	2	0	2	
Mohall	4	0	0	3	3	0	2	0	0	
Comoro	3	0	0	3	3	0	2	0	0	

^a Q = quartz; F = feldspar; Mi = mica; K = kaolinite; Ca = calcite; H = hematite; Do = dolomite; M = montmorillonite; V = vermiculite; C = chlorite (chloritic inter-grade); G = gibbsite.

^b 5 = dominant; 4 = large amount; 3 = medium amount; 2 = small amount, 1 = trace amount; 0 = looked for, but not detected.

et al. 1978) (Fig. 1). Two sample cells are available for use, depending upon sample quantity. A 4-L mixing chamber with flow-through cell can be used for quantities ranging from 8 to 0.1 g with an approximate concentration range of 2000 to 25 mg/L of soil, and a smaller 250-ml chamber can be used for quantities of less than 0.1 g with an approximate concentration range of 400 to 25 mg/L of soil. The 4-L unit is used with the sample continuously pumped from the chamber between parallel glass lenses where the laser is intercepted. Sample mixing is accomplished in the 250-ml chamber by a mechanical stirring rod or by magnetic stirrers. The 4-L chamber was used for the Microtrac analyses throughout this study for convenience of sampling and handling, although the 250-ml chamber produces equally accurate results for samples of low quantity or low concentration. The range of particle size measured by the instrument is nominally 1.9 to 176 μm . This range is divided into 13 segments as follows (in μm): 176 to 125,

125 to 88, 88 to 62, 62 to 44, 44 to 31, 31 to 22, 22 to 16, 16 to 11, 11 to 7.8, 7.8 to 5.5, 5.5 to 3.9, 3.9 to 2.8, and 2.8 to 1.9. These size ranges correspond to one-half phi intervals of the Udden-Wentworth scale as expressed by Krumbein (1934). This notation is widely used in sediment analysis. An internal microcomputer automatically converts the signal to a printer. The printout includes a cumulative graph, a relative volume graph, cumulative and histogram data, and summary data (Fig. 2). Microtrac summary data consist of the calculated 10th, 50th, and 90th percentile particle size, mean diameter, mean specific surface area, and sample concentration (shown as dv in Fig. 2). Particle scanning time can be selected between 3 to 800 s.

Sample preparation and test procedure

The pipette analysis can be used only for particles smaller than 62 μm , and the remainder

TABLE 3
Particle-size data from sieve-pipette and Microtrac methods

Size ranges (μm) Soil series	Data in percentages within size range																				
	176-125			125-62			62-31			31-16			16-7.8			7.8-3.9			3.9-1.9		
	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c	m ^a	m ^b	p ^c
Superstition	26.2	22.2	35.6	51.1	51.5	50.1	12.4	16.3	12.7	0.9	3.8	1.1	5.9	5.2	0.2	2.6	0.3	0.2	0.6	0.7	0.1
Rositas	29.2	37.5	66.7	56.4	50.2	31.2	4.1	4.9	1.8	5.8	3.6	0.2	3.8	2.7	0.1	0.3	1.7	0.0	0.0	0.1	0.1
Vinton	19.6	20.1	31.9	38.7	39.0	42.5	17.9	18.8	15.6	8.5	8.5	5.1	5.1	6.3	2.8	4.8	3.6	0.5	4.8	3.3	1.6
Comoro	6.8	13.4	30.2	22.8	27.2	25.0	15.6	17.9	22.7	14.4	10.2	9.7	15.9	12.3	8.4	11.9	9.8	0.4	12.2	8.6	3.7
Ida	0.0	0.0	0.2	7.0	9.6	1.0	32.5	35.7	46.3	26.6	26.8	33.2	14.4	11.4	12.4	9.4	8.4	6.4	9.4	7.4	0.3
Laveen	5.3	6.6	13.9	20.6	23.8	19.9	21.0	21.3	27.6	12.3	12.4	12.4	10.9	10.4	8.2	12.7	9.8	9.3	16.5	15.2	8.6
Cecil loam	4.7	9.0	39.2	14.2	15.3	1.7	9.2	8.9	10.1	14.0	14.8	14.9	21.2	18.6	15.5	18.0	17.8	14.0	18.0	19.0	4.6
Mohall	7.9	10.4	20.6	23.1	23.5	20.8	15.9	17.2	31.2	10.4	13.2	5.0	10.8	7.4	12.7	14.3	11.7	8.0	16.8	16.0	1.7
Cecil clay	3.1	5.5	16.8	13.2	12.6	15.9	9.5	13.9	11.9	16.1	11.9	14.5	20.8	18.2	15.3	19.9	17.8	12.9	16.7	19.6	12.8
Houston	3.1	0.6	8.9	11.4	15.1	10.7	11.8	16.3	16.8	9.9	11.1	17.1	12.8	11.3	13.3	17.7	13.3	16.5	32.6	31.7	16.5

^a Microtrac volume %; no organic and soluble salt removal.

^b Microtrac volume %; organic and soluble salt removal.

^c Sieve-pipette weight %; organic and soluble salt removal.

of the analysis is commonly conducted gravimetrically, after separation by sieving. Particles larger than 62 μm and smaller than the 176- μm upper limit of the Microtrac were analyzed gravimetrically. Pipette samples were taken at times corresponding to fall diameters of 31, 16, 7.8, 3.9, and 1.9 μm .

Soil samples were dispersed, sieved, and split, with one subset undergoing soluble salt and organic removal by treatment with hot, distilled water followed by H_2O_2 , to test for the effect of this treatment on particle-size distribution. Sample dispersion was accomplished by a combination of a chemical dispersant and the subsequent application of ultrasonic energy. The chemical dispersant was prepared by dissolving 53.52 g of $\text{Na}_3\text{P}_2\text{O}_7$ and 4.24 g of Na_2CO_3 in 1 L of distilled water (Lameris 1964) and was added to the soil in a ratio of 1 ml dispersant/1 g soil. Ultrasonic energy was then applied for 30 s, using a 350-W, 20-kHz ultrasonic probe with a 1/2-in. disruptor horn. After this dispersion, each sample was wet-sieved at 176 μm and then split, achieving subsamples for both the Microtrac and sieve-pipette methods.

MINERAL ANALYSIS

Mineralogical analysis was carried out by x-ray diffraction on particle-size separates having the following size ranges: 62 to 31, 31 to 16, 16 to 1.9, and 1.9 μm . Gravity and centrifugation techniques were used for the particle-size separations (Jackson 1956). The samples of the various size separates were prepared for x-ray analysis using conventional procedures (Thiessen and Harward 1962; Hutchinson 1974; Brown 1961; Dixon and Weed 1977). X-ray analyses were carried out with a Phillips XRG-3000 x-ray generator. The results of the x-ray diffraction analyses are summarized in Tables 2 and 3. These results represent a qualitative to semi-quantitative estimate of the relative quantities in each of the soil separates analyzed.

Computation and data treatment

Because the range of Microtrac Model 7991-0 is 1.9 to 176 μm , the fraction of the sample shown by pipetting to be less than 1.9 μm was mathematically eliminated from the data before comparison with the Microtrac data. Data for materials analyzed gravimetrically (62 to 176 μm) were in certain comparisons (Table 5) combined with the pipette data for correlation with

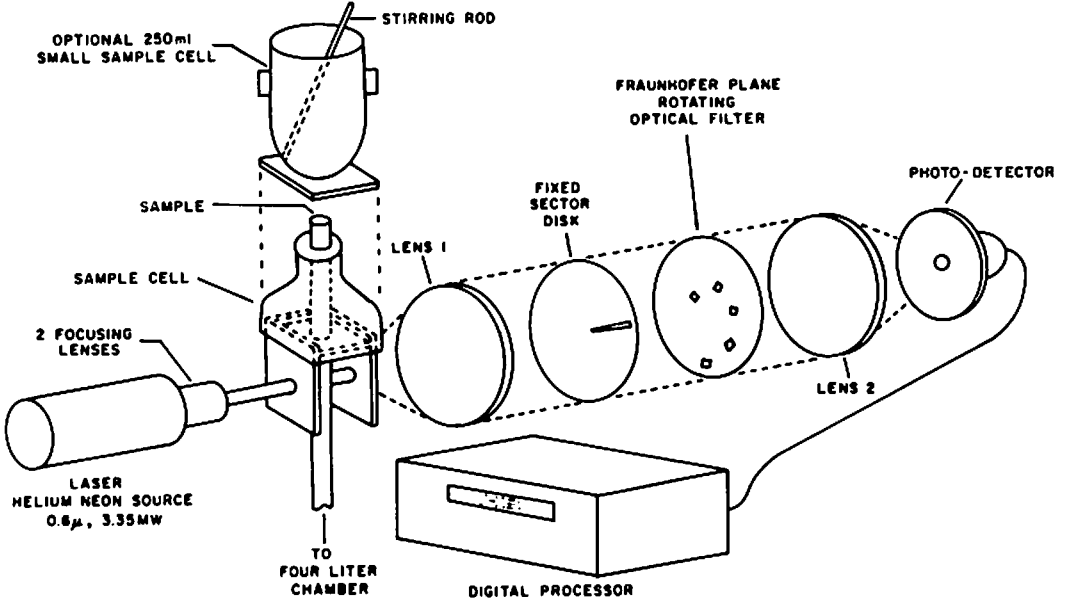


FIG. 1. Exploded view of the Microtrac system.

HOUSTON CLAY			IDA SILT LOAM			ROSITAS SAND			
176	-----	0	176	-----	0	176	-----	0	} Cumulative Graph (% Smaller than Shown)
125	-----	98	125	-----	0	125	-----	54	
88	-----	88	88	-----	97	88	19		
62	-----	69	62	-----	89	62	15		
44	-----	63	44	-----	75	44	8		
31	-----	60	31	-----	56	31	8		
22	-----	55	22	-----	39	22	6		
16	-----	51	16	-----	29	16	6		
11	-----	45	11	-----	22	11	6		
7.8	-----	40	7.8	16	7.8	3	7.8	3	
5.5	-----	35	5.5	14	5.5	3	5.5	3	
3.9	-----	24	3.9	9	3.9	2	3.9	2	
2.8	15		2.8	5	2.8	0	2.8	0	
150	9		150	0	150	-----	0	} Relative Volume Graph (Maximum Channel = 100%)	
106	-----	48	106	14	106	-----	78		
75	-----	0	75	-----	41	75	10		
53	-----	28	53	-----	68	53	14		
38	16		38	-----	0	38	0		
27	-----	27	27	-----	87	27	4		
19	-----	21	19	-----	47	19	0		
13	-----	28	13	-----	36	13	0		
9.4	-----	28	9.4	-----	31	9.4	7		
6.6	-----	22	6.6	11	6.6	0	6.6		0
4.7	-----	55	4.7	-----	25	4.7	1		
3.3	-----	50	3.3	-----	24	3.3	4		
2.4	-----	78	2.4	-----	26	2.4	0		
176	100.0	1.8	176	100.0	.0	176	100.0	45.0	} Cumulative and Histogram Data
125	98.1	9.4	125	100.0	2.7	125	54.9	35.1	
88	88.7	19.4	88	97.2	8.0	88	19.7	4.5	
62	69.3	5.6	62	89.2	13.4	62	15.1	6.4	
44	63.7	3.1	44	75.8	19.3	44	8.7	.0	
31	60.6	5.2	31	56.2	17.1	31	8.7	2.1	
22	55.3	4.2	22	39.1	9.2	22	6.6	.2	
16	51.1	5.3	16	29.9	7.1	16	6.3	.0	
11	45.5	5.5	11	22.7	6.1	11	6.3	3.2	
7.8	40.0	4.2	7.8	16.6	2.2	7.8	3.0	.0	
5.5	35.7	10.8	5.5	14.3	4.5	5.5	3.0	.8	
3.9	24.9	9.7	3.9	9.8	4.7	3.9	2.1	2.1	
2.8	15.2	13.2	2.8	5.1	5.1	2.8	.0	.0	
.861	CS		.489	CS	Specific Surface Area	m ² /cc	.126	CS	} Summary Data
36.4	MV		31.8	MV	Mean Diameter (Volume)	Microns	112.	MV	
91.8	PH		64.2	PH	90th Percentile	Microns	162.	PH	
14.4	PM		27.3	PM	50th Percentile	Microns	117.	PM	
2.44	PS		3.93	PS	10th Percentile	Microns	46.9	PS	
.091	dV		.325	dV	Uncalibrated Sample Volume Data	Concentration	.360	dV	

FIG. 2. Typical Microtrac printouts for three soil textures.

the Microtrac data. Data for materials larger than the upper limits of both the pipette and Microtrac ($>176 \mu\text{m}$) were not used in the comparison. Linear regression was used to relate Microtrac and sieve-pipette percentages.

TABLE 4

Relationship between particle sizes determined by sieve-pipette and Microtrac methods for 10 soils (176 to 1.9 μm)

Soil	Linear regression equation*	Correlation coefficient, r
Superstition	$Y = -0.92 + 1.06 X$	0.956
Rositas	$Y = -0.73 + 1.04 X$	0.830
Vinton	$Y = -3.37 + 1.24 X$	0.957
Comoro	$Y = -2.92 + 1.21 X$	0.683
Ida	$Y = -6.06 + 1.43 X$	0.973
Laveen	$Y = 2.70 + 0.81 X$	0.718
Cecil loam	$Y = 36.22 - 1.49 X$	-0.521
Mohall	$Y = 5.73 + 0.60 X$	0.304
Cecil clay	$Y = 17.63 - 0.23 X$	-0.626
Houston	$Y = 11.33 + 0.21 X$	0.572

* X = Microtrac volume %; organic and soluble salt removal. Y = sieve-pipette weight %; organic and soluble salt removal.

RESULTS AND DISCUSSION

Table 3 lists the percentages for particle size ranges for all soils as analyzed by Microtrac and pipette. In Table 4, the relationship of sieve-pipette to Microtrac analyses is determined by linear regression for each individual soil. Generally, the coarser textured samples showed much better correlation than soils with greater percentages of fines. This is probably due to the finer fractions containing higher percentages of kaolinite, mica, and other platy or elongated minerals. Table 5 shows the linear regression equations for the percentage in a given size range and for all sizes combined (sieve-pipette versus Microtrac) and for 62 to 1.9- μm sizes (pipette versus Microtrac). Also given are correlation coefficients and the standard deviation from regressions. The upper part of Table 5 compares Microtrac data, without soluble salt or organic removal, with pipette data. In the lower part of Table 5, Microtrac data are for samples with soluble salts and organic matter removed. All sieve-pipette samples had soluble salts and organic matter removed.

The relationship described by the data for samples with soluble salt and organic removal

TABLE 5

Particle-size relationship between sieve-pipette and Microtrac methods for defined size classes

Channel range, μm	Linear regression equations*	Correlation coefficient, r	Standard deviation from regression
Organic matter and soluble salts removed only in pipette			
176-125	$Y = 1.44X + 11.10$	0.800	11.97
125-62	$Y = 0.81X + 1.01$	0.860	8.70
62-31	$Y = 1.51X - 3.01$	0.930	4.96
31-16	$Y = 1.28X - 3.90$	0.903	4.43
16-7.8	$Y = 0.86X - 1.56$	0.881	3.00
7.8-3.9	$Y = 0.82X - 2.36$	0.879	3.20
3.9-1.9	$Y = 0.50X - 1.32$	0.835	3.37
All sizes (180-1.9)	$Y = 0.89X + 1.69$	0.693	9.95
All sizes (62-1.9)	$Y = 1.01X - 2.39$	0.769	6.26
Organic matter and soluble salts removed in all samples			
176-125	$Y = 1.42X + 9.18$	0.878	9.54
125-62	$Y = 0.95X - 3.51$	0.899	7.47
62-31	$Y = 1.44X - 4.93$	0.917	5.37
31-16	$Y = 1.37X - 4.64$	0.921	4.00
16-7.8	$Y = 0.97X - 1.13$	0.844	3.40
7.8-3.9	$Y = 0.89X - 1.53$	0.858	3.46
3.9-1.9	$Y = 0.50X - 1.10$	0.867	3.05
All sizes (176-1.9)	$Y = 0.98X + 0.40$	0.766	8.87
All sizes (62-1.9)	$Y = 1.05X - 2.37$	0.819	5.62

* X = Microtrac volume %. Y = sieve-pipette weight %.

in both methods of particle-size analysis was slightly better than the relationship achieved when organics were left in Microtrac-analyzed samples. The agreement between the two methods was much better at all individual size classes than the agreement for all sizes (sieve-pipette versus Microtrac). A comparison of pipette and Microtrac data for size classes $<62 \mu\text{m}$ and $>1.9 \mu\text{m}$ (thereby omitting sieve data) showed a better correlation than the comparison for all sizes with sieve data included. The sieve data consistently showed a higher percentage of material for the combined classes from 176 to 125 μm and 125 to 62 μm than the Microtrac. The Microtrac consistently showed greater percentages of fine silt and very coarse clay than those calculated from the pipette analysis. The most similarity in percentage data by pipette and Microtrac was in the range from 62 to 16 μm . Because the relationship varies with size, the poorer correlation for sieve-pipette versus Microtrac for all sizes combined is to be expected. Correlation between the two methods was greatest ($r = 0.92$) for the 62 to 31- μm and 31 to 16- μm size classes.

As seen in Table 5, the relationship between sieve-pipette and Microtrac methods for the 3.9 to 1.9- μm size class is distinctly different from the relationship obtained for coarser size classes. Samples with a large percentage of material in the coarser size classes essentially follow the relationship for the coarser size classes. However, samples that also have an appreciable accumulation of fine material (3.9 to 1.9 μm) have an overall equation (Table 4) influenced by the relationship in the 3.9 to 1.9- μm size class, as well as by the relationships for the coarser size classes. Hence, a poorer correlation for the finer textured samples is to be expected.

The greater differences between the Microtrac and pipette analyses of the fine silt and very coarse clay (16 to 1.9 μm) might be explained on the basis of the mineralogical compositions. Generally, separates larger than 1.9 μm contain quartz and feldspars as the most abundant minerals (Table 2). Mica minerals and kaolinite, however, are more prevalent in the fine silt and very coarse clay separate (16 to 1.9 μm) than in the coarser silt separates. The plate-shaped nature of mica and kaolinite grains causes them to behave hydraulically as much smaller particles (nonspherical particles have smaller settling velocities than corresponding spherical particles),

producing a greater deviation from Stokes' law. Turbulence is maintained in the Microtrac system during analysis, by pumping action in the 4-L chamber system or by means of a mechanical stirring rod in the small 250-ml chamber. The turbulence causes the particles to approach a random orientation relative to the laser beam after multiple passes through the system. This feature minimizes any hydraulic effect on the size analysis due to particle shape. It would be expected that samples high in micaceous and other platy and elongated minerals would result in a greater deviation between the Microtrac and pipette methods of analysis. The presence of large quantities of heavy minerals would also be expected to cause deviations between the two methods, because Stokes' law is dependent upon the specific gravity of particles. It should also be noted that hydrated particles can have densities much less than the specific gravity in the anhydrous state (Jackson 1956). Hematite, a heavy mineral, has a specific gravity range of 4.9 to 5.3 and thus would experience a faster fall velocity than quartz, which has a specific gravity of 2.65.

The poorest agreement between Microtrac and pipette analysis occurred in the 3.9 to 1.9- μm size fraction. Table 3 shows that Microtrac concentrations (percentages) were greater for all soils except Rositas, with the largest difference for Houston, Ida, Cecil, and Mohall. X-ray diffraction data in Tables 2 and 3 show that the Houston has the largest amounts of montmorillonite and calcite. The Ida, which also showed a large difference between Microtrac and pipette in the 3.9 to 1.9 range, is dominantly montmorillonitic and dolomitic, as determined by x-ray diffraction (Table 2). Montmorillonite is an expanding-lattice clay. Drying and rehydration, as well as exchange capacity of the clay mineral, have significant influence on the determination of particle size. The Cecil soil contains a large amount of kaolinite and hematite and contains no montmorillonite, unlike the other soils in the study. This may explain the negative correlation obtained for the Cecil soils in Table 4. The Mohall soil contains significant amounts of montmorillonite and kaolinite in the fraction $<1.9 \mu\text{m}$ (Table 2).

SUMMARY AND CONCLUSIONS

Ten soils were analyzed by sieve-pipette and Microtrac to obtain an initial comparison between the two methods. The Microtrac range is

from 176 to 1.9 μm , and wet-sieving was performed to gain data from 176 to 62 μm to be combined with pipette data for comparison with Microtrac results. The methods were correlated at eight individual sizes, for all sizes combined (sieve-pipette versus Microtrac), and for the six size classes smaller than 62 μm (pipette versus Microtrac).

The poorest agreement for a size range was on Microtrac samples with no organic or soluble salt removal when correlated for all sizes combined (176 to 1.9 μm), with a correlation coefficient of $r = 0.69$. The best agreement was from 62 to 31 μm and 31 to 16 μm , with a correlation in both cases of 0.92. The combined correlation for 62 to 1.9 μm was better than the combined correlation for 176 to 1.9 μm , which included sieve data. This most likely occurs because the pipette and sieve methods each has its own theoretical concepts embraced in the data. Thus, although the Microtrac may correlate well with either method, it is unlikely to achieve as high a correlation to a combination of both pipette and sieve methods. Hence, the treatment may be viewed as unnecessary in most cases.

Our work has shown 100 s to be ample measurement time for optimum analysis, and a 50-s analysis produces results nearly as reproducible. An initial analysis may be conducted without sample dispersion, and subsequently the sample may be retained for aggregate breakup and reanalyzed to give single-grain particle size. Differences in results between analyses provide a measure of aggregation.

The minimum required sample quantity for the Microtrac is approximately 0.01 g, much less than the minimum quantities reported for other methods (0.5 g for the Sedigraph and 1 g for the pipette (Welch et al. 1979)). Suspended sediment samples are often of low concentrations or of low quantities, and frequently, it would be an unnecessary complication to switch analysis methods at a given concentration.

The Microtrac can process approximately 10 prepared samples per hour. The same number of samples would require approximately 3.5 h for x-ray sedimentation analysis (Welch et al. 1979). Electronic analysis by the Coulter counter is about twice as fast as the pipette method (Pennington 1979), and 10 samples by pipette would require a full 8-h day.

Reproducibility of results appears to be very good with the Microtrac. Well-mixed and dis-

persed subsamples can be reanalyzed numerous times with very nearly exact results.

The Microtrac Model 7991-0 has a lower limit of 1.9 μm . There is no known fast, yet accurate, method of analysis for the entire clay fraction. The Microtrac Model 7991-3, not used in this study, is capable of rapid analysis to 0.12 μm . The best choice of analytical methods depends on the exact nature and purpose of the research being conducted.

The Microtrac "sees" more clay and fine silt particles than the pipette in the 3.9 to 1.9- μm size range. Differences between pipette and Microtrac percentages are influenced by clay content and clay mineralogy.

Microtrac surface area values appear to convert to those obtained by the EGME method with an acceptable degree of accuracy (Haverland and Cooper 1981). Further comparison research on particle-size distribution and surface area data needs to be done on additional soils.

Results of this experiment show: (1) the Microtrac particle-size analyzer provides a rapid method of particle-size determination; (2) small samples can be analyzed accurately with the Microtrac, but not the pipette method; and (3) some difficulty will be experienced in relating Microtrac results to previous pipette results.

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