Effect of hydrometer type on particle size distribution of fine grained soil

A. Kaur* & G.C. Fanourakis
University of Johannesburg, Johannesburg, South Africa

ABSTRACT: The particle size distribution of soils, including clay content is of utmost importance in the field of Geotechnical Engineering. The hydrometer analysis is the most widely used technique for analyzing the particle size distribution of the fine grained fraction of soil. The various hydrometer test methods (internationally) generally vary mainly in the use of the prescribed dispersing agent. In addition, certain methods vary with the use of the prescribed hydrometer. The purpose of this study was to establish the optimum concentration and volume of the three dispersing agents (calgon, sodium pyrophosphate decahydrate and sodium tetra pyrophosphate) using the ASTM Hydrometer 152H: E100 (instead of the Bouyoucos hydrometer 152H) for three soil classes, selected for their varying activity. The results indicated that the ASTM hydrometer 152H: E100 generally yielded lower results than hydrometer 152H in terms of percentage fines, with the differences varying from 38% to -65% for all the soils and the dispersing agents.

1 INTRODUCTION

Although seemingly simple, the determination of the soil particle size is one of the most problematic areas in the geotechnical engineering. Differences in the laboratory results are still common and substantial, which reinforces the need that the field data should be collected very carefully by the surveyors. The particle size analysis is a method of separation of the mineral part of the soil into various size fractions and the determination of proportions of these fractions. The mechanical or sieve analysis is performed to determine the distribution of the coarser, large-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

As the clay content of the soil is used to determine the activity of a soil, which in turn is used for design purposes, it is very important to accurately determine the clay content of the soils. Inaccurate clay content determinations have resulted in inappropriate design solutions which have even led to unacceptable damage to the structures.

Sedimentation analysis (Hydrometer analysis) is based on Stoke's law, according to which the velocity of free fall of grains is directly proportional to the square of the particle's diameter. The expression used to determine the particle diameter in the sedimentation analysis is based on this settling velocity. Hence the individual soil particles must be dispersed to enable the determination of particle size distribution accurately. However, the finer grains of soil carry charges on their surface and hence have a tendency to form flocs. Thus, if the floc formation is not prevented, the grain diameter obtained would be the diameter of flocs and not of the individual grain (Ranjan, 1991). Hence in hydrometer analysis which is a type of sedimentation analysis, deflocculating agents are added to prevent fine soil particles or clay particles in suspension from coalescing to form flocs.

Dispersing agents can either act as a protective colloid on the solid particle or alter the electrical charge on the particle to prevent the formation of flocs (Sridharan et al., 1991). The various hydrometer test methods (internationally) generally vary mainly in the use of the prescribed dispersing agent. In addition certain methods vary with regards to the prescribed hydrometer type. The 152H hydrometer (TMH1 1986, ISRIC 2002), the ASTM Hydrometer 152H: E100 (SANS 3001, ASTM D422-63) and the Specific Gravity hydrometer (IS 2720, 1985 and Lambe, 1951) are some of the most commonly used hydrometers for the sedimentation analysis of the soils. To date, many researchers (Means & Parcher (1963), Herd (1980), Sridharan et al (1991) and Bindu & Ramabhadran (2010)) have researched the effect of different dispersing agents on the particle size analysis. However, the effect of other factors such as the hydrometer type, stirrer type, stirring time, stirring speed, soaking time and the sample size, on which hydrometer analysis depends on, appear to be still unexplored.

The current study focuses on the variation in the results of the sedimentation analysis with the change

*A Kaur (Effect of hydrometer type on Grain size distribution of the soil) in the hydrometer type from the 152H to the ASTM 152H: E100 on 3 different soil samples selected with varying activity. The soil samples were treated with the three different dispersing agents. The tests were performed originally with the Bouyoucos hydrometer 152H and the optimum quantity for each concentration (calgon: - 35:7, 40:10, 60:10, 70:10 & 80:10, sodium pyrophosphate decahydrate: - 3.6%, 5%, 6% and 7% and sodium tetra pyrophosphate: - 3.6%, 5%, 6% and 7%) was determined. In this study the results for the optimum quantity and concentration obtained by the Bouyoucos hydrometer 152H were compared with the results obtained when using the other hydrometer i.e. hydrometer 152H:E100 while following the TMH1 guidelines.

2 EXPERIMENTAL DETAILS

2.1 *Material used*

Three soil samples were collected from various parts of South Africa. The one was a black soil from the town of Brits in the Northwest Province, the second was a light brown sample collected from Linksfield in the Gauteng area and the last one was a red sample from Springfield in the Gauteng area. The Atterberg Limits and Activity of these soils were determined in accordance with the TMH1 (1986) method. The clay content was determined by means of the hydrometer analysis (Method A6 of TMH1 – 1986) with a deviation in the prescribed dispersing agent type, quantity and adjustment in the readings by subtracting the hydrometer readings obtained on the "blank" companion specimens to account for the effect of the dispersing agent. TMH1 (1986) Method A6 prescribes 5 ml of sodium silicate and 5 ml of sodium oxalate as the dispersing agent. The activities of the soils used for current study were computed by using the clay content obtained from the hydrometer analysis when 125 ml of calgon 35:7 (a solution comprising 35 grams of sodium hexametaphosphate (NaHMP) and 7 grams of sodium carbonate (Na_2CO_3) in 1 litre of distilled water) is used.

Table 1. Atterberg Limits and Activity of the soils sampled

Properties	Black Soil	Brown Soil	Red Soil
Liquid Limit (LL)	56	32.8	28.3
Plastic Limit (PL)	22	24.3	15.1
Plasticity Index (PI)	34	8.5	13.2
Clay Content (%)	32	5.7	29
Activity (A)	1.07	1.5	0.5

The optimum concentration and volume of the three dispersing agents (calgon, sodium pyrophosphate and sodium tetra pyrophosphate) was established using the ASTM 152H: E100 hydrometer instead of the 152H hydrometer. Concentrations of 4.2%, 5%, 7%, 8% and 9% solution of calgon, 3.6%, 5%, 6% and 7% solution of sodium pyrophosphate and 3.6%, 5%, 6% and 7% solution of sodium tetra pyrophosphate were prepared by mixing the required quantity in 1000 ml of distilled water. The quantities of chemicals added for the preparation of the stock solutions are given in Table 2.

Table 2. Quantity of chemicals added for preparation of Calgon, Sodium pyrophosphate and Sodium tetra pyrophosphate solution

Solution of	Calgon		NaPP	NaTPP
Concentration (%)	Quantity of NaHMP Added (g)	Quantity of Na_2CO_3 Added (g)	Quantity of NaPP Added (g)	Quantity of NaTPP Added (g)
3.6	-	-	36	36
4.2	35	7	-	-
5	40	10	50	50
6	-	-	60	60
7	60	10	70	70
8	70	10	-	-
9	80	10	-	-

2.2 *Test series description*

For each of the three soil types, hydrometer analyses were conducted with both the 152H and 152H: E100 hydrometers at each concentration of the three dispersing agents and for various volumes.

2.3 *Testing procedure and calculations*

For all the tests performed, 50 grams of the soil sample passing through 425 micron sieve was mixed with the desired quantity of dispersing agent and about 400 ml of distilled water in a canning jar. The soil-water mixture was allowed to stand overnight. After the mixture had been allowed to stand, it was dispersed for 15 minutes with a standard paddle. The paddle was washed with distilled water, allowing the wash water to run into the container with the suspension.

The suspension was then poured into the Bouyoucos Cylinder and the canning jar was rinsed with distilled water from the wash bottle. The cylinder was then filled with distilled water to the 1130 ml mark with the hydrometer (152H: E100) inside. Then, the hydrometer was removed and the cylinder was inverted a few times using the palm of one hand as a stopper over the mouth of the cylinder to ensure that the temperature was uniform throughout. After bringing the cylinder to the vertical position, stop watch timing was initiated. The hydrometer was inserted and the readings were taken at 18 seconds and 40 seconds without removing the hydrometer from the cylinder. The hydrometer was then taken out and rinsed with water and it was again inserted into suspension when the elapsed time was 2 minutes. The reading was noted and the hydrometer was removed and placed in distilled water. This procedure was repeated for taking readings at elapsed times of 5 minutes, 15 minutes, 30 minutes, 1 hour, 4 hours and 24 hours. After taking each hydrometer reading, the temperature was also recorded and used to correct the readings.

Companion hydrometer tests were conducted on blank solutions comprising only distilled water and dispersing agent with no soil in the identical proportions as solutions prepared with those containing soil. In the case of these blank solutions, the dispersing agent and water mixture was also soaked overnight as done for solutions containing soil. The hydrometer readings taken on the solutions containing soils were reduced by subtracting the hydrometer readings obtained on the companion blank solutions. TMH1 does not make any provision for an adjustment to the hydrometer readings to account for the effect of the dispersing agent on these readings. It was observed that the effect of dispersing agent on the hydrometer reading was significant, as in the case of some solutions the hydrometer readings (in grams per litre) exceeded the mass of the soil used in the test (50 grams).

The calibration curve was plotted. The percentage finer than 0.075 mm, 0.05 mm, 0.04 mm, 0.026 mm, 0.015 mm, 0.01mm, 0.0074 mm, 0.0036 mm and 0.0015 mm were respectively calculated by the readings taken at 18 sec, 40 sec, 2 min, 5 min, 15 min, 30 min, 1 hour, 4 hour and 24 hours, by means by Equation 1.

$$P = \frac{C \times Sf}{Sm} \quad (1)$$

Where, P = Percentage finer than relevant size,
S_m = Mass of soil fines used in analysis (50 grams),
S_f = Percentage soil fines in total sample (<0.425 mm),
C = Corrected hydrometer reading

The percentage clay content present in each sample was obtained from the particle size distribution curve.

3 RESULTS AND DISCUSSION

3.1 *Black soil*

The effect of various hydrometers on optimum values of concentration and volume of all three dispersing agents (calgon, sodium pyrophosphate and sodium tetra pyrophosphate) for the black soil are shown in Figures 1, 2 and 3, respectively. Table 3 shows the clay contents determined by the various concentrations and volumes. 152 H hydrometer test results yielded the maximum clay content of 35.2% with NaPP as dispersing agent while maximum clay content was 28.2% when the tests were performed with 152H: E100 hydrometer with calgon as dispersing agent.

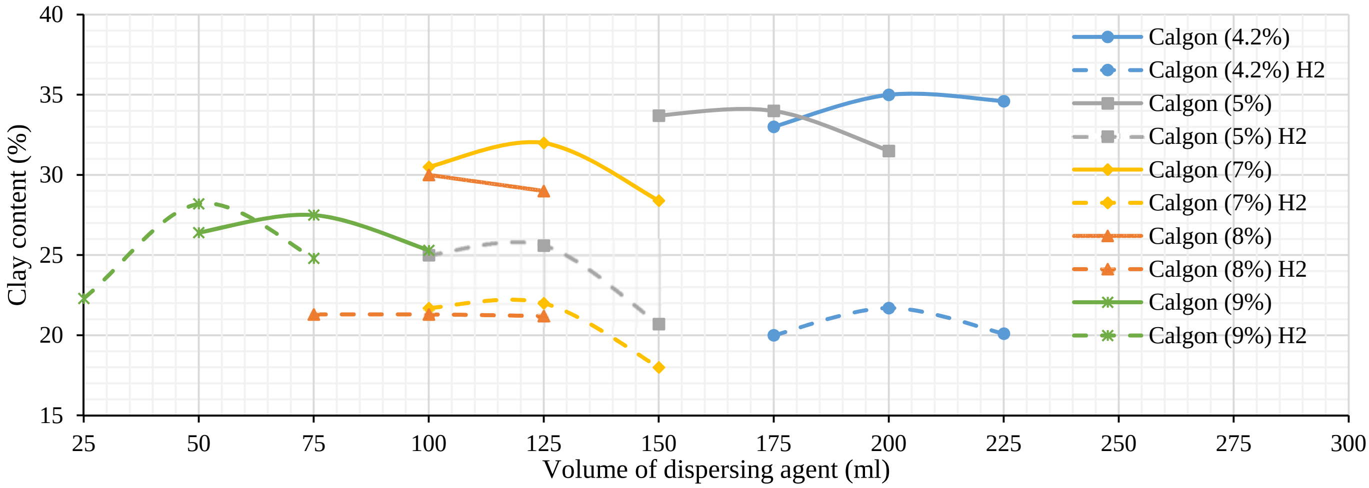

Figure 1. Effect of hydrometers on the optimum values of concentration and volume of Calgon in determining the clay content of the black soil.

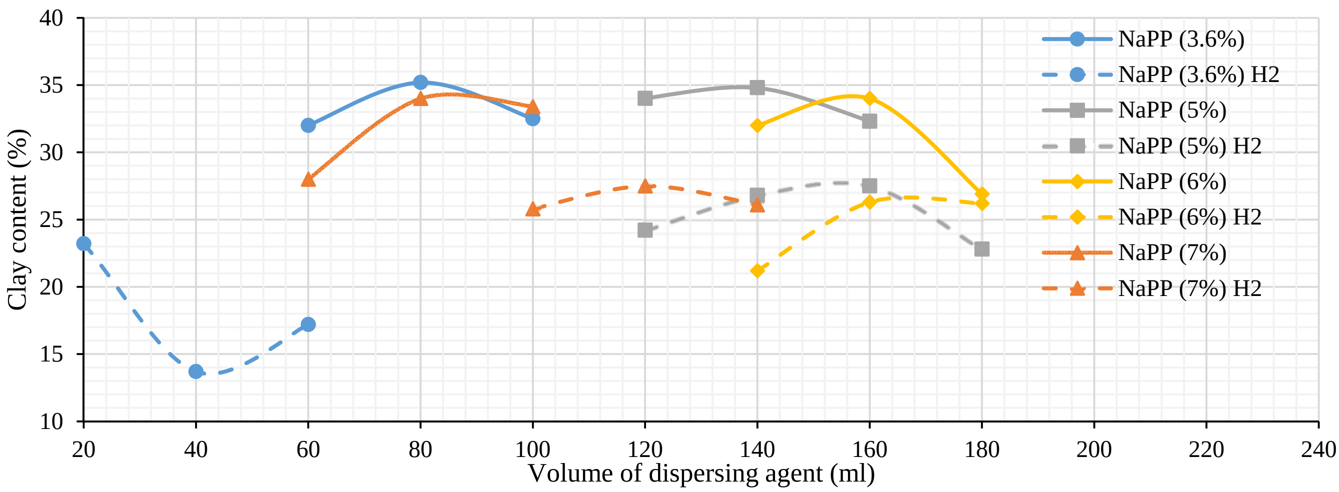

Figure 2. Effect of hydrometers on the optimum values of concentration and volume of Sodium Pyrophosphate in determining the clay content of the black soil.

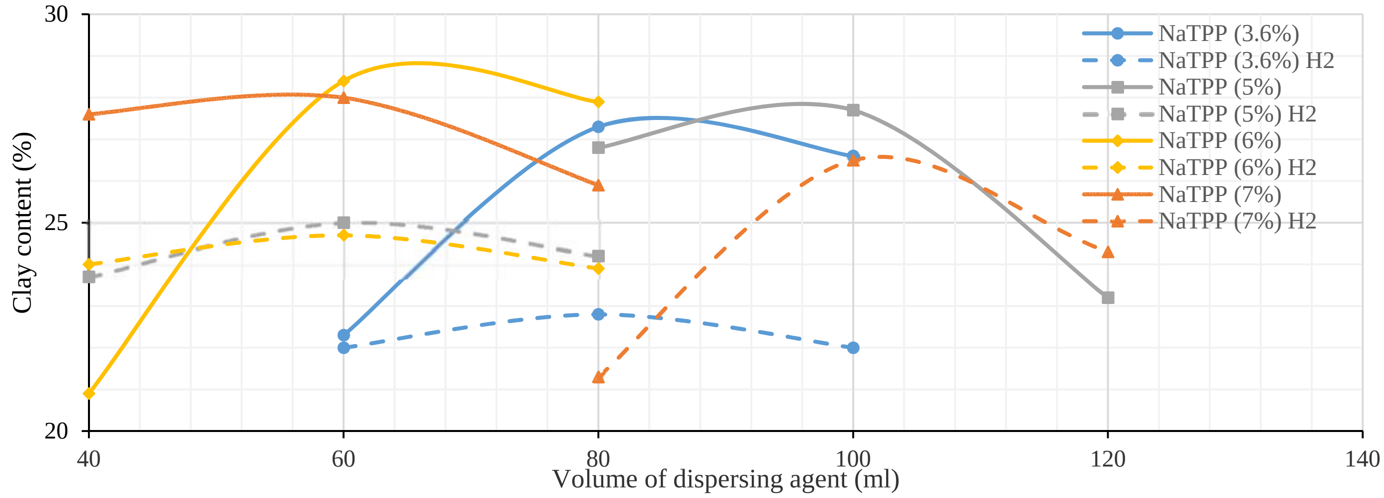

Figure 3. Effect of hydrometers on the optimum values of concentration and volume of Sodium Tetra Pyrophosphate in determining the clay content of the black soil.

The following is evident in case of the black soil, from Figures 1, 2 and 3 and Table 3:

- The ASTM hydrometer 152H: E100 (H2) yielded lower clay contents than the 152H hydrometer (H) in the case of all the tests. This percentage difference for the two hydrometers ranged from 38% to -2.54% (The negative percentage shows that the hydrometer H2 yielded higher clay contents than the 152H hydrometer). In the case of all three dispersing agents, the percentage difference at the optimum volume for the different concentrations generally decrease with an increase in the concentration. The range in percentage decrease for the calgon, NaPP and NaTPP were 38% to -2.5%, 34.1% to 19.1% and 16.5% to 5.4%, respectively. The average percentage decrease for the three dispersing agents was 24.1%, 24.2% and 11.2% respectively.

Table 3. Variation of clay content depending on hydrometer type on the concentration and volume of dispersing agents added to black soil

DA Type	Volume of DA (ml)	3.6% H	3.6% H2	4.2% H	4.2% H2	5% H	5% H2	6% H	6% H2	7% H	7% H2	8% H	8% H2	9% H	9% H2
	25														22.3
	50													26.4	28.2
	75												21.3	27.5	24.8
Calgon	100						25			30.5	21.7	30	21.3	25.3	
	125						25.6			32	22	29	21.2		
	150					33.7	20.7			28.4	18				
	175			33	20	34									
	200			35	21.7	31.5									
	225			34.6	20.1										
	20		23.2												
	40		13.7												
	60	32	17.2						21.2	28					
	80	35.2							26.3	34					
	100	32.5							26.2	33.4	25.8				
NaPP	120					34	24.2				27.5				
	140					34.8	26.8	32			26.1				
	160					32.3	27.5	34							
	180						22.8	26.9							
	40						23.7	20.9	24						
	60	22.3	22				25	28.4	24.7						
NaTPP	80	27.3	22.8			26.8	24.2	27.9	23.9	27.6	21.3				
	100	26.6	22			27.7				28	26.5				
	120					23.2				25.9	24.3				

- For the hydrometer tests performed with the 152H hydrometer, 80ml of NaPP (3.6%) yielded the maximum clay content of 35.2% while 200ml of calgon (4.2%) yielded a maximum clay content of 35%. In the case of tests performed with hydrometer 152H: E100, 50ml of calgon (9%) yielded 28.2% while 160ml of NaPP (5%) yielded 27.5%.
- In the case of the 152H hydrometer results, when comparing clay contents at the optimum volumes, an increase in the concentration of dispersing agent generally resulted in a decreased clay content. This trend was most prominent in the solutions containing calgon where the optimum volume decreased with an increase in the sodium hexametaphosphate content.
- Hydrometer 152H: E100 is prescribed by two known methods (SANS 3001 and ASTM 1965),

where 125ml of sodium hexametaphosphate (4%) is the prescribed dispersing agent. So, two additional tests were also conducted with both the hydrometers i.e. 152 H and 152H: E100 with 4% of sodium hexametaphosphate while following TMH1 guidelines. The 152H and 152H: E100 hydrometers yielded clay contents of 28.8% and 27.3% respectively.

3.2 *Light brown soil*

The effect of the 152H and 152H: E100 hydrometers on the optimum concentration and volume of all three dispersing agents (calgon, sodium pyrophosphate and sodium tetra pyrophosphate) for the light brown soil is shown in Figures 4, 5 and 6, respectively. The clay contents determined by the different concentration and volume combinations are shown in Table 4. 152H hydrometer test results yielded the maximum clay content of 8.1% with NaTPP as dispersing agent while maximum clay content was 7.5% when the tests were performed with 152H: E100 hydrometer with calgon as dispersing agent.

Figure 4, 5 and 6 and Table 4 show the following.

- ASTM hydrometer 152H: E100 (H2) generally yielded lower clay contents than the 152H hydrometer (H) in the case of most of the tests. This percentage difference for the two hydrometers ranged from 16.1% to -22.8%. In the case of all three dispersing agents, the percentage difference at the optimum volume for the different concentrations generally decrease with an increase in the concentration. The range in percentage decrease for the calgon, NaPP and NaTPP were 14.5% to -22.8%, 10% to 2.7% and 16.1% to -19.1%, respectively. The average percentage decrease for the three dispersing agents was -1.4%, 5.6% and -1.5% respectively.
- For the hydrometer tests performed with the 152H hydrometer, 80 ml of NaPP (3.6%) yielded the maximum clay content of 35.2% while 200ml of calgon (4.2%) yielded a maximum clay content of 35%. In the case of tests performed with hydrometer 152H: E100, 50ml of calgon (9%) yielded 28.2% while 160ml of NaPP (5%) yielded 27.5%.
- In the case of both the hydrometers i.e. 152H and 152H: E100, with an increase in concentration of dispersing agent beyond optimum concentration, clay content generally decreased.
- Also, when the tests are performed with 125 ml of sodium hexametaphosphate (4%), both hydrometers 152H and 152H: E100 yielded the maximum clay content of 8.2%.

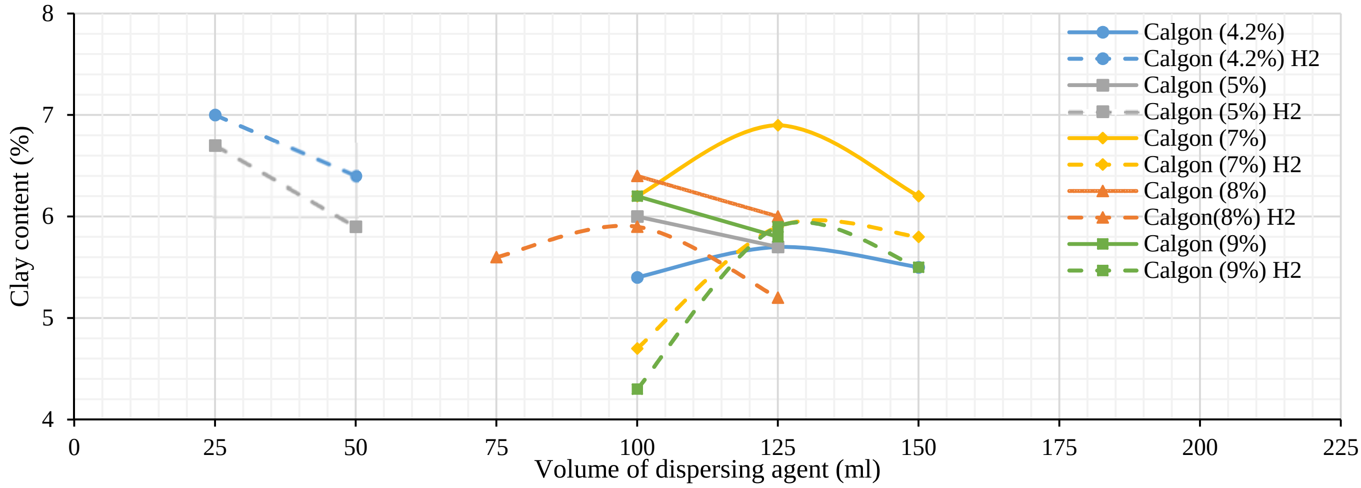

Figure 4. Effect of hydrometers on the optimum values of concentration and volume of Calgon in determining the clay content of the light brown soil.

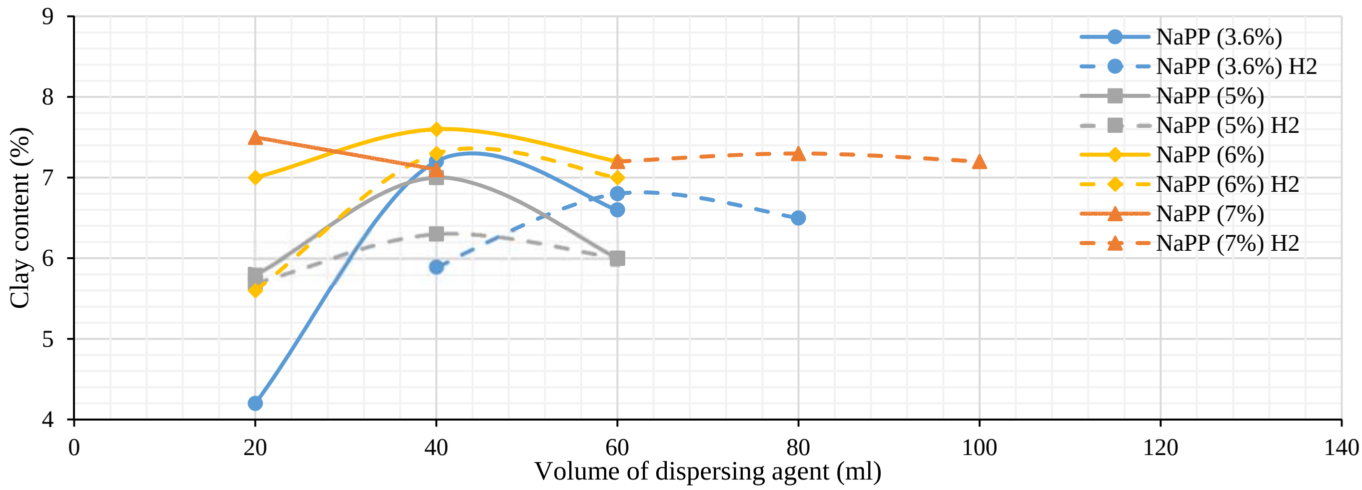

Figure 5. Effect of hydrometers on the optimum values of concentration and volume of Sodium Pyrophosphate in determining the clay content of the light brown soil.

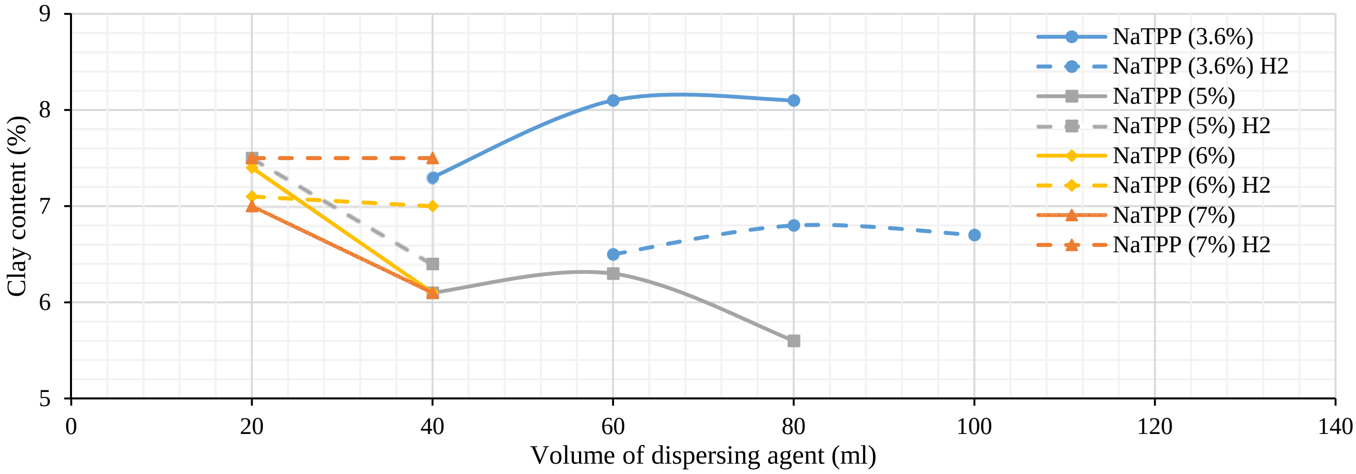

Figure 6. Effect of hydrometers on the optimum values of concentration and volume of Sodium Tetra Pyrophosphate in determining the clay content of the light brown soil.

Table 4. Variation of clay content depending on hydrometer type on the concentration and volume of dispersing agents added to light brown soil.

DA Type	Volume of DA used (ml)	Concentration of dispersing agent 3.6% H	3.6% H2	4.2% H	4.2% H2	5% H	5% H2	6% H	6% H2	7% H	7% H2	8% H	8% H2	9% H	9% H2
Calgon	25				7		6.7								
	50				6.4		5.9								
	75												5.6		
	100			5.4		6				6.2	4.7	6.4	5.9	6.2	4.3
	125			5.7		5.7				6.9	5.9	6	5.2	5.8	5.9
	150			5.5						6.2	5.8				5.5
	20	4.2				5.8	5.7	7	5.6	7.5					
	40	7.2	5.9			7	6.3	7.6	7.3	7.1					
NaPP	60	6.6	6.8			6	6	7.2	7		7.2				
	80		6.5								7.3				
	100										7.2				
	20						7.5	7.4	7.1	7	7.5				
	40	7.3				6.1	6.4	6.1	7	6.1	7.5				
NaTPP	60	8.1	6.5			6.3									
	80	8.1	6.8			5.6									
	100		6.7												

3.3 *Red soil*

The effect of the hydrometers 152H and 152H: E100 on the optimum concentration and the volume of all three dispersing agents (calgon, sodium pyrophosphate and sodium tetra pyrophosphate) for the red soil are shown in Figures 7, 8 and 9, respectively. The clay contents determined by the different concentration and volume combinations are shown in Table 5. 152H hydrometer test results yielded the maximum clay content of 32.3% with NaTPP as dispersing agent while maximum clay content was 33% when the tests were performed with 152H: E100 hydrometer with calgon as dispersing agent.

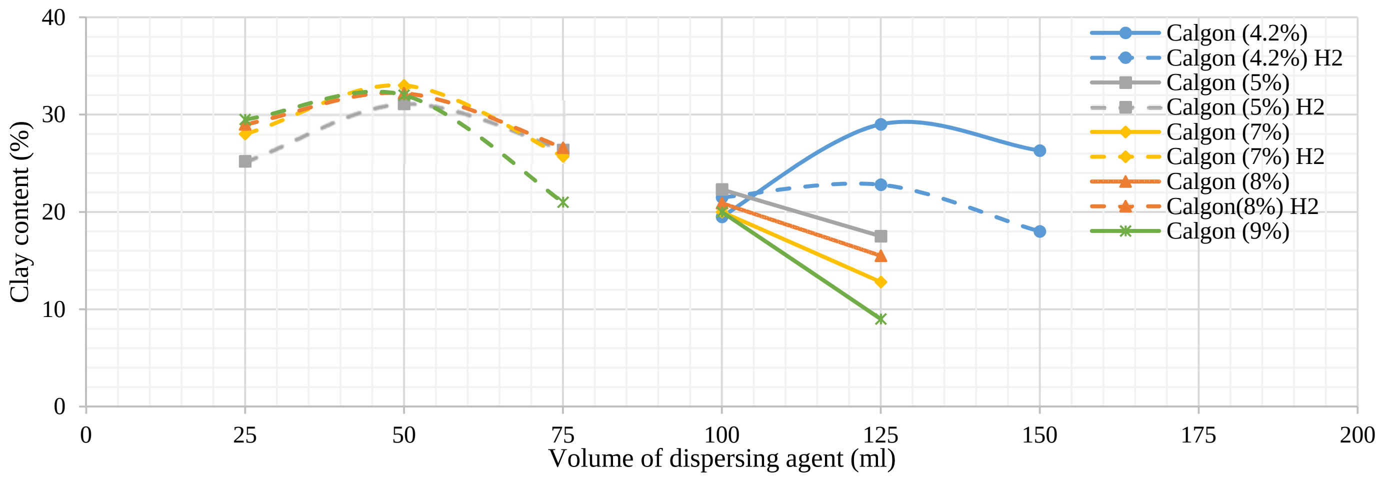

Figure 7. Effect of hydrometers on the optimum values of concentration and volume of Calgon in determining the clay content of the red soil.

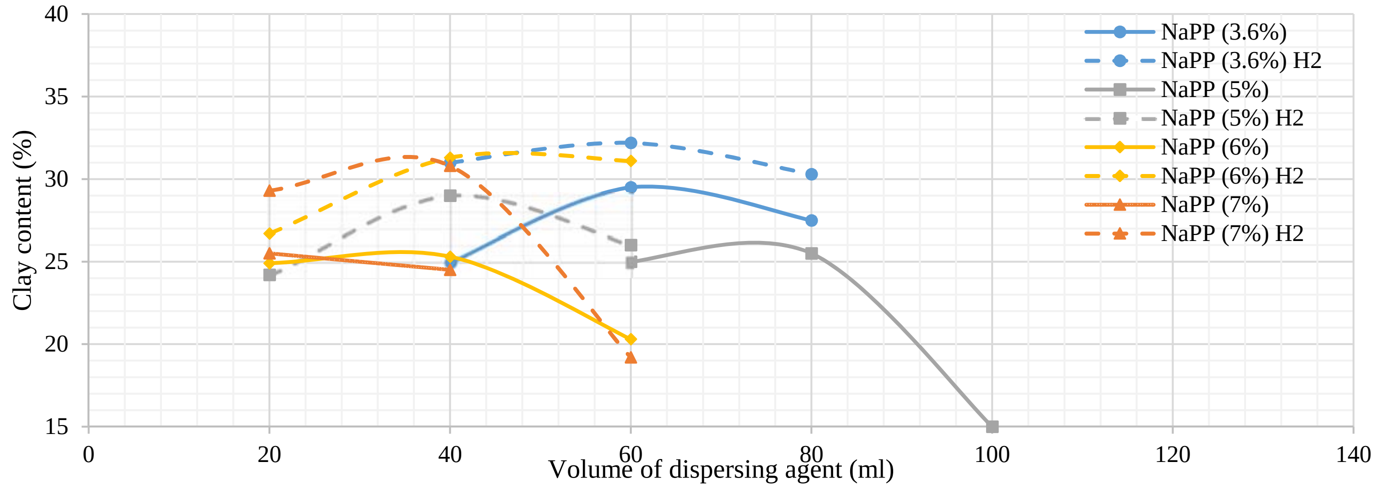

Figure 8. Effect of hydrometers on the optimum values of concentration and volume of Sodium Pyrophosphate in determining the clay content of the red soil.

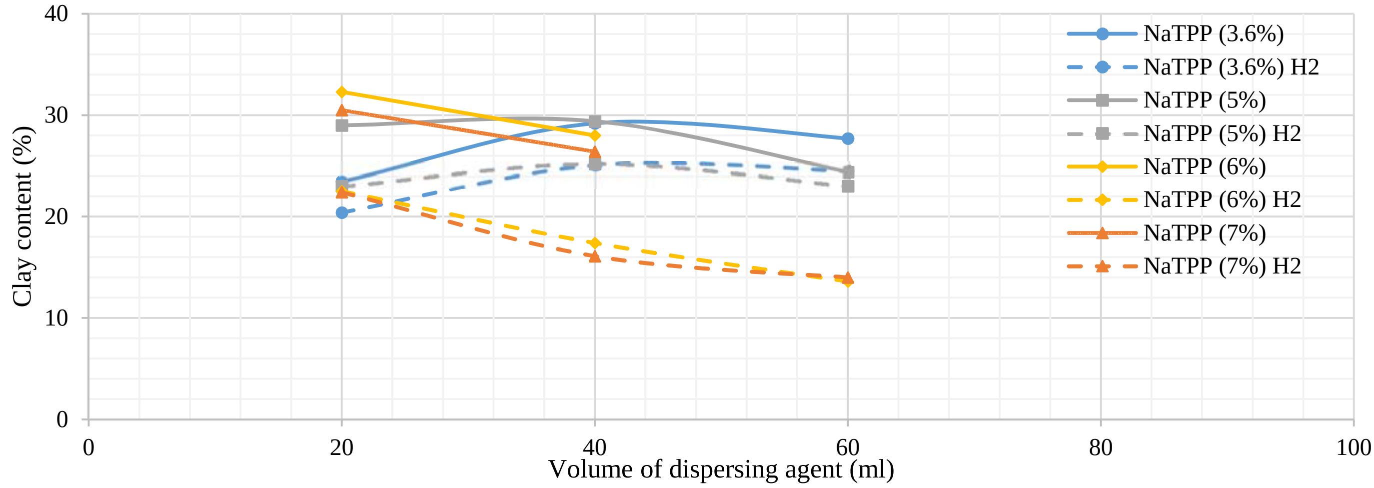

Figure 9. Effect of hydrometers on the optimum values of concentration and volume of Sodium Tetra Pyrophosphate in determining the clay content of the red soil.

Table 5 Variation of clay content depending on hydrometer type on the concentration and volume of dispersing agents added to red soil.

DA Type	Volume of DA (ml)	Concentration of dispersing agent 3.6%		4.2%		5%		6%		7%		8%		9%	
		H	H2	H	H2	H	H2	H	H2	H	H2	H	H2	H	H2
	25						25.2				28		29		29.5
	50						31.1				33		32.2		32
Calgon	75						26.4				25.7		26.6		21
	100			19.5	21.5	22.3				20		20.9		20	
	125			29	22.8	17.5				12.8		15.5		9	
	150			26.3	18										
	20						24.2	24.9	26.7	25.5	29.3				
NaPP	40	25	31				29	25.3	31.3	24.5	30.8				
	60	29.5	32.2			25	26	20.3	31.1		19.2				
	80	27.5	30.3			25.5									
	100					15									
	20	23.5	20.4			29	23	32.3	22.5	30.5	22.4				
NaTPP	40	29.2	25.1			29.4	25.2	28	17.4	26.4	16.1				
	60	27.7	24.5			24.4	23		13.6		14				

From Figure 7, 8 and 9 and Table 5, the following is evident.

- In the case of the red soil, ASTM hydrometer 152H: E100 (H2) generally yielded more clay contents than the 152H hydrometer (H) when calgon and NaTPP are used as dispersing agents, but in the case of NaPP ASTM hydrometer 152H: E100 (H2) yielded lower clay contents than the 152H hydrometer (H). The percentage difference for the two hydrometers ranged from 30.3% to -65%. In this case the results for the percentage difference at the optimum volume of all three dispersing agents and for all the different concentrations are insignificant. The range in the percentage decrease for calgon, NaPP and NaTPP were 21.4% to -65%, -9.2% to -

23.7% and 30.3% to -14%, respectively. The average percentage decrease for the three dispersing agents was -39.4%, -16.9% and 21.3% respectively.

- For the hydrometer tests performed with the 152H hydrometer, the best dispersing agent is 20 ml of NaTPP (6%) which yielded 32.3% of clay content while 60ml of NaPP (3.6%) yielded a maximum clay content of 29.5%. In the case of tests performed with hydrometer 152H: E100, 50ml of calgon (7%) yielded 33% while 60ml of NaPP (3.6%) yielded 32.3%.
- When the tests are performed with 125 ml of sodium hexametaphosphate (4%), hydrometers 152H and 152H: E100 yielded clay content of 20.5% and 21.8% respectively.

From the results discussed above, it has been observed that for the red, black and light brown soil with activities 0.5, 1.07 and 1.5 respectively, the maximum clay content obtained for 152H hydrometer and H2 hydrometer are 32.3%, 35.2% & 8.1% and 33%, 28.2% and 7.5% respectively. When the tests are performed with hydrometer H2, the maximum clay content obtained is higher for more active soil and it decreased for less active soils.

4 CONCLUSIONS

The following conclusions were drawn from the study conducted:

- In the case of the black soil for all three dispersing agents as the concentration increases beyond optimum concentration, the difference in the clay contents yielded by the two hydrometers generally decreases, with H2 hydrometer always yielding lower clay contents. Also, the average of the difference in clay content percentage yielded by the two hydrometers was highest in NaPP solutions (24.2%) and lowest in NaTPP solutions (11.2%).
- When the light brown soil was treated with any of the three dispersing agents, the difference in the clay contents yielded by the two hydrometers generally decreased as the concentration of the dispersing agent increased beyond optimum concentration and the average of the difference in clay content percentage yielded by the two hydrometers was highest in NaPP solutions (5.6%) and lowest in calgon (-1.47%).
- When the red soil was treated with calgon and NaPP, with an increase in the concentration beyond optimum concentration, the difference in the clay contents yielded by the two hydrometers generally increased with H2 hydrometer always yielding greater clay contents. In the case of NaTPP, as the concentration increases beyond optimum concentration, the difference in the clay contents yielded by the two hydrometers generally increased with H2 hydrometer always yielding lower clay contents. Also, the average of the difference in clay content percentage yielded by the two hydrometers was highest in NaTPP solutions (21.3%) and lowest in calgon (-39.4%).
- The results of this investigation confirm the findings of Means & Parcher (1963) that different dispersing agent types are more effective with certain clay types.
- For tests performed with hydrometer 152H: E100, 125ml of NaHMP (4%) yielded a lower clay content than the best dispersing agent in case of the black and the red soil and the same clay content in case of the light brown soil.
- When the tests are performed with hydrometer H2, the maximum clay content obtained is greater for more active soil and it decreased for less active soils.
- Finally, the effect of the type of hydrometer on the hydrometer readings was considerable and the clay content obtained by H2 hydrometer is lower for more active soil.

5 REFERENCES

ASTM. 1965. *Grain size analysis of soils*. ASTM Designation D422-63, ASTM, Philadelphia.

Bindu, J. & Ramabhadran, A. 2010. Effect of concentration of dispersing agent on the grain size distribution of fine grained soil. *Proceedings, Indian Geotechnical Conference*, Mumbai, 275-278.

Head, K.H. 1980. *Manual of Soil Laboratory Testing*, Vol. I, Pentech Press, London.

Indian Standard IS. 1985. *Methods of tests for soils.* IS Designation 2720 Part IV, BIS, New Delhi.

International Soil Reference and Information Centre. 2002. *Procedures for soil analysis. Technical paper 9*, The Netherlands.

Lambe, T.W. 1951. *Soil testing for engineers*, New York: John Wiley & Sons, Inc.

Means, R.E. & Parcher, J.N. 1963. *Physical properties of soils*. Ohio: Charles E. Merrill Book Co.

Ranjan, G. & Rao, A.S.R. 1991. *Basic and applied soil mechanics*, Wiley Eastern Limited, New Delhi.

SANS. 2014. *Civil engineering test methods.* SABS Standard Division Designation 3001 Part GR3, SABS, Pretoria.

Sridharan, A., Jose, B.T. & Abraham, B.M. 1991. Determination of clay size fraction of marine clays. *Geotechnical Testing Journal*, 14(1): 103-107.

TMH1.1986. *Standard methods of testing road construction materials. Method A6*. Pretoria: National Transport Commission.