

Assessment of the Effect of Sodium Hexametaphosphate and Sodium Carbonate on Particle Size Distribution of Soils with Varying Plasticity

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Abstract

Accurate determination of particle size distribution (PSD) is fundamental in geotechnical engineering because soil classification governs the prediction of permeability, compressibility, shear strength, settlement behavior, pavement performance and foundation design. Conventional hydrometer analysis assumes complete dispersion of soil particles before sedimentation. However, naturally occurring fine-grained soils possess electrochemical attractions that promote aggregation, thereby producing inaccurate PSD results when dispersing agents are inadequately selected or improperly dosed. Although international standards recommend the use of sodium hexametaphosphate (SHMP) combined with sodium carbonate (Na_2CO_3), a constant dosage is commonly applied irrespective of soil mineralogy or plasticity characteristics. This practice may lead to considerable errors in the measured clay and silt fractions.

This article explores soil classification methods and the influence of using dispersing agents in various amounts for the soil particle size analysis. Laboratory testing with different dispersing agents was conducted to analyze the effects of sodium hexametaphosphate and sodium carbonate for four different soils with plasticity indices indicating one to be with (PI = 10.7 %), (PI=16%), (PI=19%) and the other with high plasticity (PI = 36 %). The article highlights differences in the granulometric fractions reported for each soil and usage of the same dispersing agent but in various amount. Thus, the classification of soils is influenced by the amount of the used dispersing agents, recommendations of standards being different in time and countries. These findings contribute to a better understanding of the anticipated behavior of fine soils and provide useful insights for various geotechnical applications.

This study evaluated the influence of sodium hexametaphosphate and sodium carbonate on the particle size distribution of soils with varying plasticity. Laboratory investigations were performed on representative fine-grained soils collected from different locations exhibiting high, medium and low plasticity characteristics. Soil characterization included natural moisture content determination, Atterberg limits, specific gravity, wet sieve analysis and hydrometer analysis conducted under varying dispersing-agent concentrations. Different combinations of sodium hexametaphosphate and sodium carbonate were investigated to determine their effectiveness in promoting complete particle dispersion.

Results demonstrate that dispersing-agent concentration significantly influences measured particle size distribution, particularly for highly plastic soils. Insufficient dispersing-agent dosage resulted in incomplete deflocculation, leading to underestimation of clay-sized particles and overestimation of silt fractions. Conversely, excessive concentrations caused minor instability within the suspension, affecting

sedimentation behavior. An optimum dispersing-agent concentration was identified for each plasticity category, producing consistent and repeatable PSD curves. Highly plastic soils required substantially greater dispersing-agent concentrations than soils exhibiting medium or low plasticity.

The findings indicate that a universal dispersing-agent dosage cannot accurately characterize all fine-grained soils. Instead, dispersing-agent selection should account for soil plasticity and mineralogical characteristics. The study contributes towards improving hydrometer testing procedures and recommends revision of conventional laboratory practice to enhance the reliability of soil classification and geotechnical design.

Keywords: Particle Size Distribution, Hydrometer Analysis, Sodium Hexametaphosphate, Sodium Carbonate, Soil Plasticity, Fine-Grained Soil, Dispersing Agent, Geotechnical Engineering.

1. Introduction

The particle size distribution of a soil is an important assessment that is used in determining the suitability of a soil for various purposes. This includes determining the suitability of a soil as a construction material for various purposes or as a founding material. The accuracy of soil grading results is particularly relevant in assessing hydraulic conductivity (Boadu, 2000) and other properties as well as for soil classification. The clay content (percentage finer than 0.002 mm) for example, is used in various analyses and designs. The consequences of designs based on incorrect particle size distributions have often been unacceptable and even led to failures. Hence, the accurate determination of the particle size distribution of a soil is imperative.

Fine-grained soils, consisting predominantly of silts and clays, present unique challenges during laboratory characterization because their particles possess extremely small diameters, typically less than 75µm. At these dimensions, gravitational forces become relatively insignificant compared with electrochemical attractive forces acting between adjacent particles. These attractive forces cause particles to flocculate or agglomerate into larger clusters instead of remaining individually suspended within water. Such behaviour directly violates one of the primary assumptions underlying sedimentation analysis and therefore introduces considerable errors during hydrometer testing.

Hydrometer analysis remains the internationally accepted laboratory method for determining particle size distribution of soils passing the 75µm sieve. The method is based upon Stokes' Law, which relates sedimentation velocity to particle diameter under laminar flow conditions. However, the validity of Stokes' Law depends upon complete dispersion of soil particles before sedimentation commences. Failure to achieve complete dispersion causes particle aggregates to settle as larger particles, thereby underestimating the true clay fraction while overestimating silt-sized material. Such inaccuracies may subsequently influence soil classification, pavement design, foundation design and earthwork specifications.

To overcome this problem, dispersing agents are routinely introduced into soil suspensions before hydrometer testing. Sodium hexametaphosphate (NaPO_3)₆, commonly referred to as SHMP, is widely recognized as one of the most effective dispersants because of its ability to sequester calcium and magnesium ions responsible for interparticle attraction. Sodium carbonate (Na_2CO_3) complements SHMP by increasing the alkalinity of the suspension and promoting electrostatic repulsion between soil particles. Together, these chemicals form the well-known Calgon solution adopted by numerous national and international laboratory standards.

Despite their widespread application, most laboratory standards prescribe a single dispersing-agent concentration for all soils regardless of mineralogical composition or plasticity. This assumption ignores the considerable variability exhibited by natural soils. Highly plastic clay soils generally contain larger quantities of expansive clay minerals possessing greater cation exchange capacities than low-plasticity silts. Consequently, identical dispersing-agent dosages may not produce equivalent dispersion efficiencies across different soil types.

Several previous investigations have reported significant discrepancies in measured particle size distributions resulting from inappropriate dispersing-agent concentrations. Under-dispersion causes persistent particle aggregation, whereas excessive chemical concentrations may alter suspension chemistry and influence sedimentation behaviour. These effects become particularly important in tropical residual soils where mineralogical compositions vary considerably even within relatively short geographical distances.

In Tanzania, hydrometer analysis is extensively employed during highway investigations, building foundation design, dam construction and slope stability assessments. Nevertheless, laboratory practice continues to apply uniform dispersing-agent dosages without considering soil plasticity characteristics. This limitation creates uncertainty regarding the accuracy of particle size distributions used during engineering design and highlights the necessity for a comprehensive investigation into the relationship between dispersing-agent concentration and soil plasticity.

This article aims to provide a comprehensive understanding of the methods used for the classification of the soil and the effects of using dispersing agents to break down finer soil particles for the accuracy of the testing methodology. The article will provide an overview of the classification of soils standards, methods for determining the particle size distribution, dispersing agents and a comparative analysis between hydrometer and the pipette methods. The hydrometer analysis for the soil classification is conducted in this study using different dispersing agents and the results are discussed.

2. Materials and Methods

2.1 Research Design

According to study an attempt was made to differentiate between categories of soils based on their plasticity index (PI), specifically soils with $PI \leq 10\%$, 11-24 and $PI > 24\%$. The purpose of this classification was to study the influence of the dispersing agent on the percentages of granular fractions of the soils. Laboratory investigations were carried out in accordance with the methodology specified in BS 1377 (1990) for determining the plasticity limits. Four distinct soil samples were taken from different locations and tested. The Sample A was taken from an open excavation at a depth of 2 m in Chekereni. The Sample B was taken from borrow pit Itende from a depth of 1.2 m sample C from Iugumbwi and sample D from Iwala. The plasticity index was determined for both samples according to BS 1377 (1990) and is presented in Table 1 below.

Table 2.1: Atterberg limits

No	Sample	Liquid limit	Plastic limit	Plastic Index
1	Sample B	28.3	17.6	10.7
2	Sample D	32	16	16
3	Sample C	37.8	18.1	19.7

4	Sample A	73.5	38.5	35
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2.2 Study Area and Soil Sampling

Representative disturbed soil samples were collected from selected locations within Tanzania to capture soils exhibiting **low, medium, and high plasticity**. The selection of sampling sites was based on visual field observations, previous geotechnical information where available, and the anticipated variation in clay mineral composition.

Approximately 60–80 kg of soil was collected from each sampling location after removing the upper organic layer (approximately 150–200 mm thick) to eliminate vegetation, roots, and organic debris. Soil was excavated from depths where natural subsoil conditions prevailed to minimize contamination from surface materials.

Each sample was placed in labelled airtight polyethylene bags and transported to the Geotechnical Engineering Laboratory at Mbeya University of Science and Technology for laboratory testing. During transportation, care was taken to prevent excessive drying or moisture contamination that could alter the natural characteristics of the soils.

The disturbed sampling procedure complied with the requirements of **BS 1377 (1990)** for laboratory identification and classification testing.

2.3 Sample Preparation

Upon arrival at the laboratory, soil samples were air-dried under room temperature until friable. Oven drying was deliberately avoided prior to hydrometer analysis because excessive heating may alter the physicochemical characteristics of clay minerals.

Large aggregates were gently broken using a rubber pestle to preserve the natural particle sizes while avoiding artificial crushing. Visible organic matter, roots, gravel fragments, and foreign materials were manually removed.

Prepared samples were passed through a 2.0 mm sieve before laboratory classification tests. Material retained on the sieve was discarded because the investigation focused exclusively on fine-grained soils.

Representative test portions for each laboratory determination were obtained using the quartering method in accordance with **BS 1377 Part 2 (1990)**. This sampling procedure ensured that every specimen possessed the same particle-size characteristics as the original bulk sample while minimizing sampling bias.

2.5 Specific Gravity Determination

The specific gravity of soil solids was determined using the density bottle method in accordance with **BS 1377 Part 2 (1990)**. Approximately 50 g of oven-dried soil passing the 2.0 mm sieve was placed into a calibrated density bottle.

Distilled water was added to fill the bottle, and entrapped air bubbles were removed using gentle agitation and vacuum application where necessary.

Specific gravity was calculated from measured masses using the standard equation:

$$G_s = \frac{W_s}{W_s + W_w - W_{sw}}$$

where:

- W_s = dry soil mass
- W_w = mass of water
- W_{sw} = combined mass of soil and water

Specific gravity values were later used during hydrometer analysis calculations.

2.6 Wet Sieve Analysis

Wet sieve analysis was conducted to separate particles larger than 75 μm from finer fractions.

Approximately 500 g of prepared soil was washed through a No. 200 (75 μm) sieve using clean water until the effluent appeared clear.

Material retained on the sieve was oven dried and subjected to conventional sieve analysis using the standard series of sieves specified by BS 1377.

The percentage passing the 75 μm sieve represented the material subjected to hydrometer analysis.

2.7 Preparation of Dispersing-Agent Solutions

Sodium hexametaphosphate (NaPO_3)₆ and Sodium carbonate (Na_2CO_3) are delivered in powder form when in their pure state and are used to prepare soil samples according to BS 1377. To prepare the solution, 40g of powder is dissolved in 1000 of distilled water.

Different concentrations were prepared according to the experimental program described in table below. Distilled water was used throughout preparation to eliminate interference from dissolved ions. Each solution was freshly prepared before testing to minimize chemical degradation.

The dispersing-agent concentrations investigated represented values below, equal to, and above the conventional laboratory dosage, thereby enabling determination of the optimum concentration for soils exhibiting different plasticity characteristics.

Table 2.2: Percentage composition of dispersing agent

Dispersing agent	50%	75%	100%	125%	150%
NaHMP (gm.)	16.5	24.75	33	41.25	49.5
Na_2CO_3 (gm.)	3.5	5.25	7	8.75	10.5
Total (gm.)	20	30	40	50	60

2.8 Hydrometer Analysis

Hydrometer analysis constituted the principal experimental procedure of the investigation.

Approximately 50 g of soil passing the 75 μm sieve was transferred into a dispersion cup.

The predetermined quantity of dispersing-agent solution was added before mechanical mixing for approximately 15 minutes using a high-speed mixer. The dispersed suspension was transferred into a one-liter sedimentation cylinder and diluted to exactly 1000 mL using distilled water.

The suspension was thoroughly agitated by repeated inversion before placing the cylinder vertically on a vibration-free laboratory bench. Hydrometer readings were recorded at predetermined time intervals including 0.5 min, 1 min, 2 min, 4 min, 8min, 15min, 30min, 1hr, 2hr, 4hrs, 8hrs, 24hrs

Temperature corrections and meniscus corrections were applied to every hydrometer reading in accordance with BS 1377 procedures. Particle diameters corresponding to each observation time were calculated using Stokes' Law after applying the appropriate correction factors.

3. Results and Discussion

3.1 Introduction

This chapter presents the laboratory results obtained from the experimental investigation on the effects of sodium hexametaphosphate (SHMP) and sodium carbonate (Na_2CO_3) on the particle size distribution (PSD) of soils with varying plasticity. The results are organized according to the study objectives and

include soil classification, Atterberg limits, specific gravity, wet sieve analysis, and hydrometer analysis under different dispersing-agent concentrations.

The discussion focuses on how variations in dispersing-agent concentration influence soil particle dispersion and the resulting PSD curves. Comparisons are made between soils exhibiting low, medium, and high plasticity to evaluate the influence of plasticity on dispersion efficiency. Where appropriate, the findings are interpreted in the context of established soil mechanics principles and compared with published literature.

3.2 Engineering Properties of the Tested Soils

Before evaluating the effects of dispersing agents, the engineering characteristics of the selected soils were determined to establish baseline conditions. The characterization included natural moisture content, liquid limit, plastic limit, plasticity index, specific gravity, and particle size distribution.

The results confirmed that the selected soils represented distinct plasticity classes, thereby providing an appropriate basis for investigating the influence of dispersing-agent concentration on PSD determination. The Atterberg limits indicated considerable variation in plasticity among the tested soils. High-plasticity soils exhibited substantially larger liquid limits and plasticity indices than medium- and low-plasticity soils, reflecting increased clay mineral activity and stronger physicochemical interactions between particles.

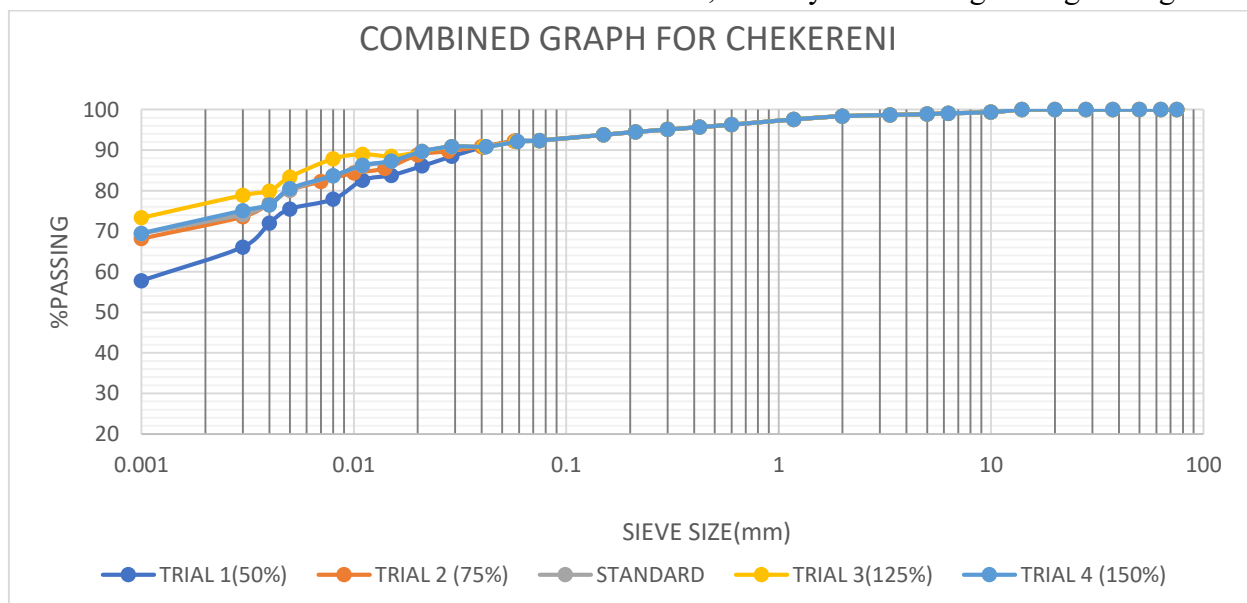
Specific gravity values remained within the normal range expected for inorganic fine-grained soils, indicating that the soils were mineralogically suitable for hydrometer analysis.

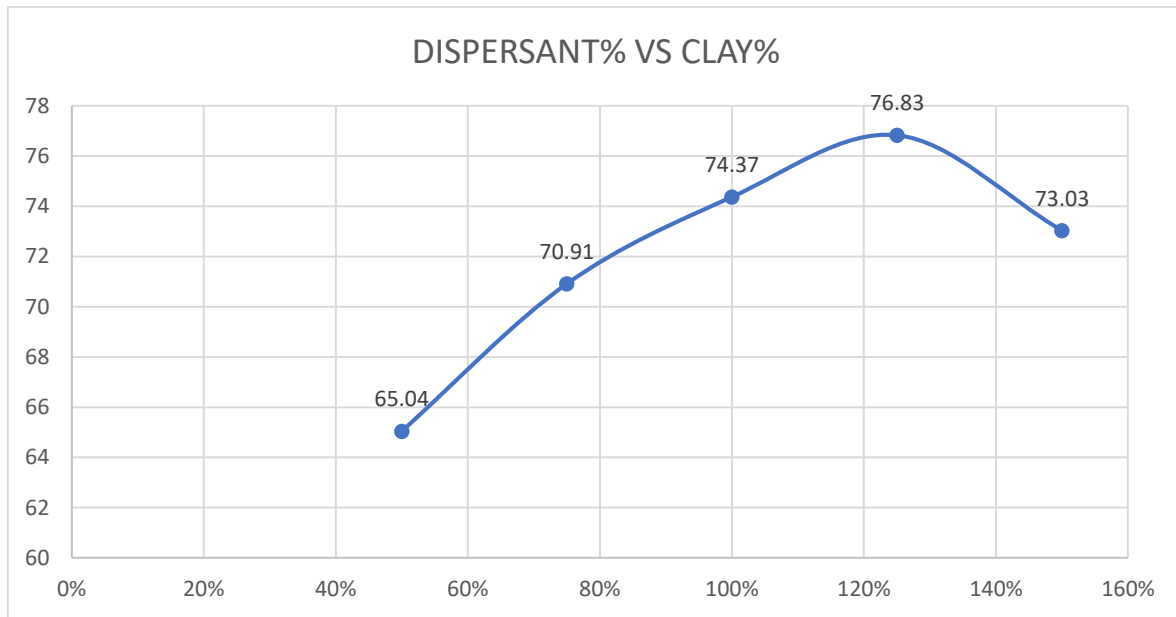
The preliminary laboratory tests therefore confirmed that the selected soils adequately represented different plasticity conditions required for the experimental programme.

3.4 Effect of Soil Plasticity

The influence of dispersing-agent concentration varied considerably according to soil plasticity.

First sample (soil Sample A with PI > 24%) for the five different quantities of dispersing agent are presented in Table 2.2. The percentages of granular fractions are presented graphically in Fig. 1. The predominant fraction for the amount of silt (21.49%). As the amount of dispersing agent increases, the clay fraction begins to become predominant. The maximum point of the clay fraction (76.83%). After this point, with the increase of the amount of dispersing agent, there is a slight decrease to 73.03% of the clay fraction and an increase in silt fraction. Above this amount, the clay fraction begins to grow significantly.





The graph illustrates a significant increase in clay content as the concentration dispersing agent rises to 125%, followed by a subsequent decrease in clay content. For soil sample of Chekereni which exhibits a high clay percentage of 76.8%, the optimal dispersing agent concentration is identified as 125%.

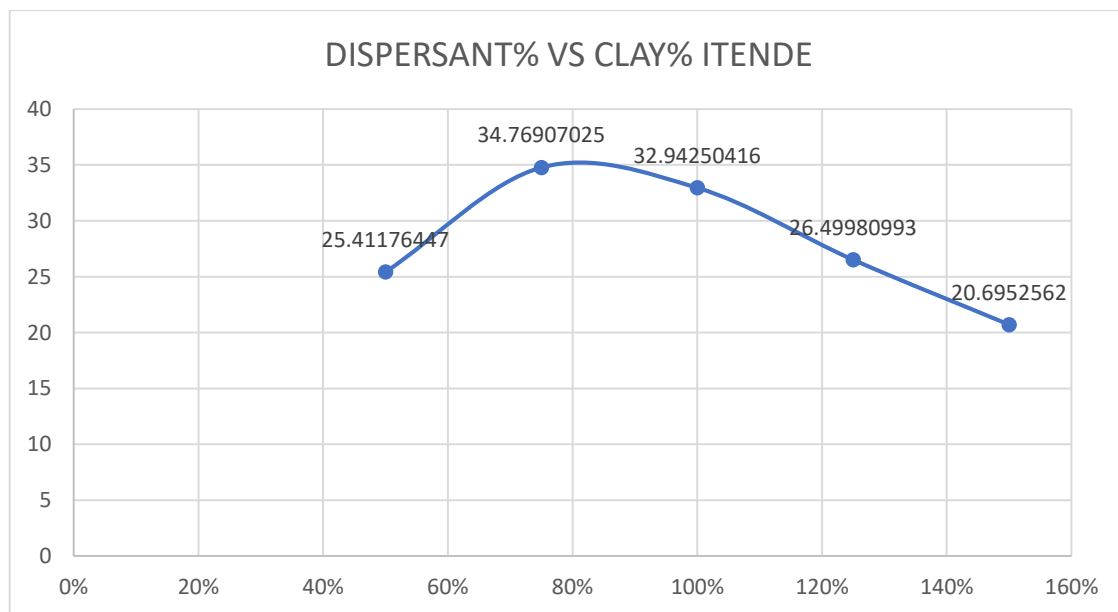
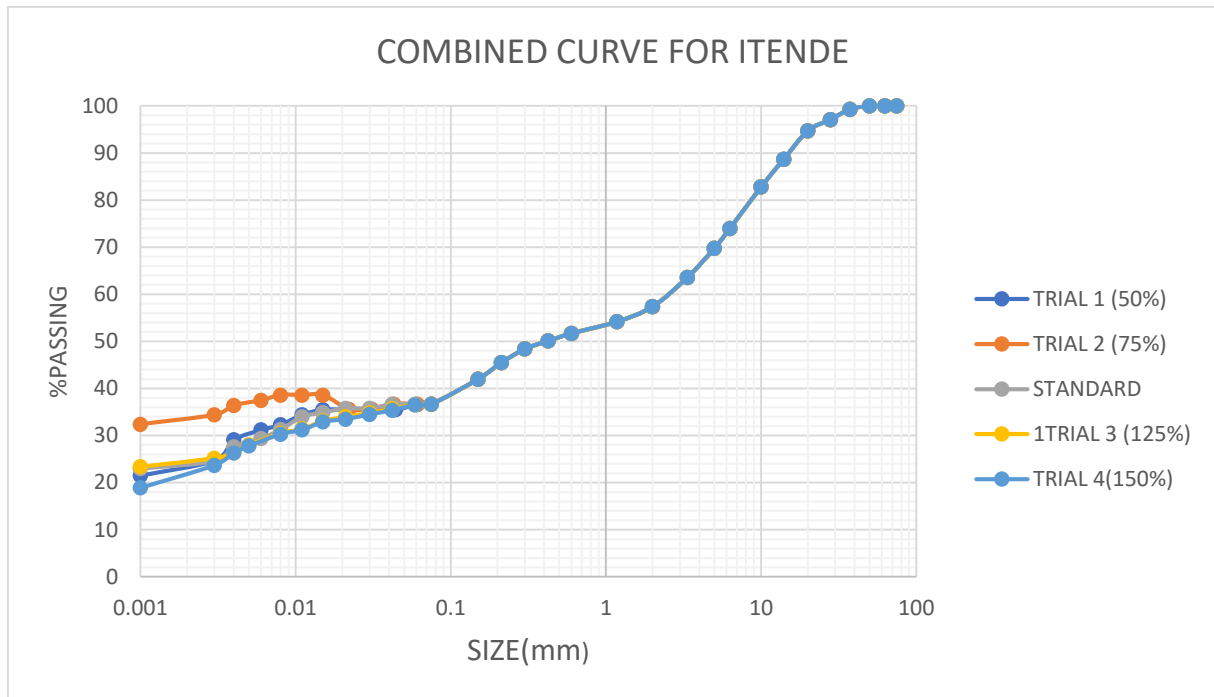
The composition of the dispersing agent at 125% concentration can be calculated as follows:

1. Sodium hexametaphosphate (NaHMP): $125\% \times 33 \text{ grams} = 41.25 \text{ grams}$, approximately 41 grams.
2. Sodium carbonate (Na_2CO_3): $125\% \times 7 \text{ grams} = 8.75 \text{ grams}$, approximately 9 grams.

Thus, for soil sample 1, the optimal dispersing agent solution consists of approximately 41 grams of NaHMP and 9 grams of Na_2CO_3 mixed in 1 liter of distilled water

Highly plastic soils exhibited the greatest response to increasing dispersing-agent concentration. These soils contain relatively large proportions of expansive clay minerals possessing high cation exchange capacities and extensive specific surface areas.

Sample B with $\text{PI} = 10.7$ for the five different quantities of dispersing agent are presented in Table 2.2. The percentages of granular fractions are presented graphically in Fig. 1. The predominant fraction for the amount of silt (1.93%). As the amount of dispersing agent increases, the clay fraction begins to become predominant. The maximum point of the clay fraction (34.77%). After this point, with the increase of the amount of dispersing agent, there is a slight decrease to 32.94% of the clay fraction and an increase in silt fraction. Above this amount, the clay fraction begins to grow significantly.



The graph illustrates a significant increase in clay content as the concentration of dispersing agent rises to 92%, followed by a subsequent decrease in clay content. For soil sample B, which exhibits a high clay percentage of 34.77%, the optimal dispersing agent concentration is identified as 92%.

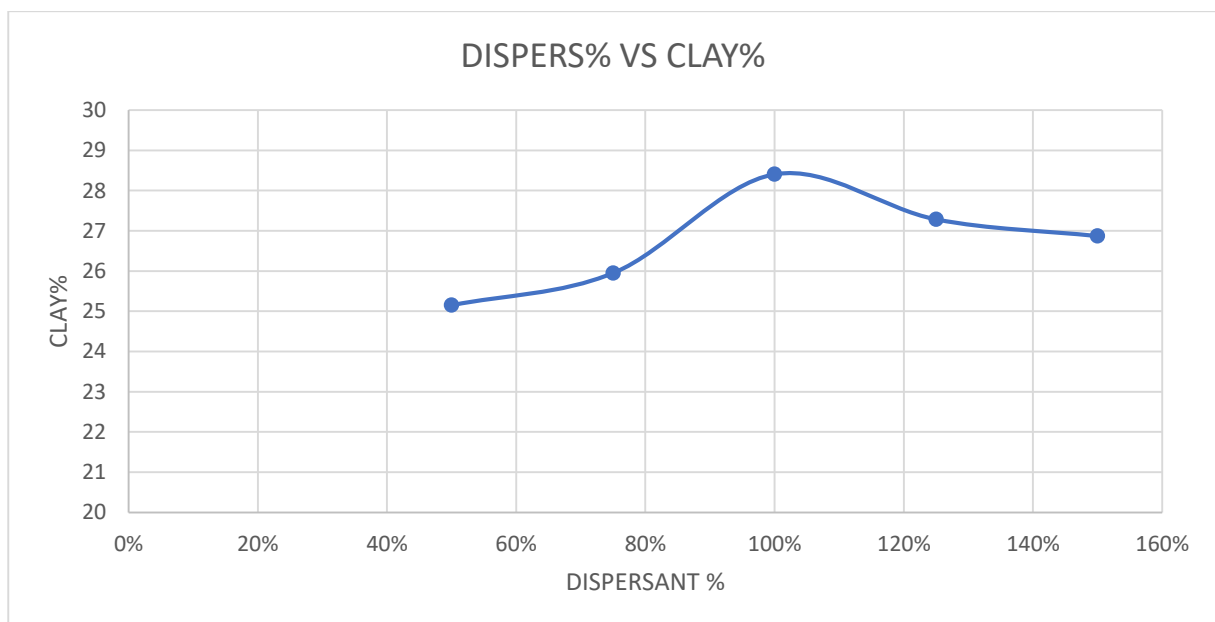
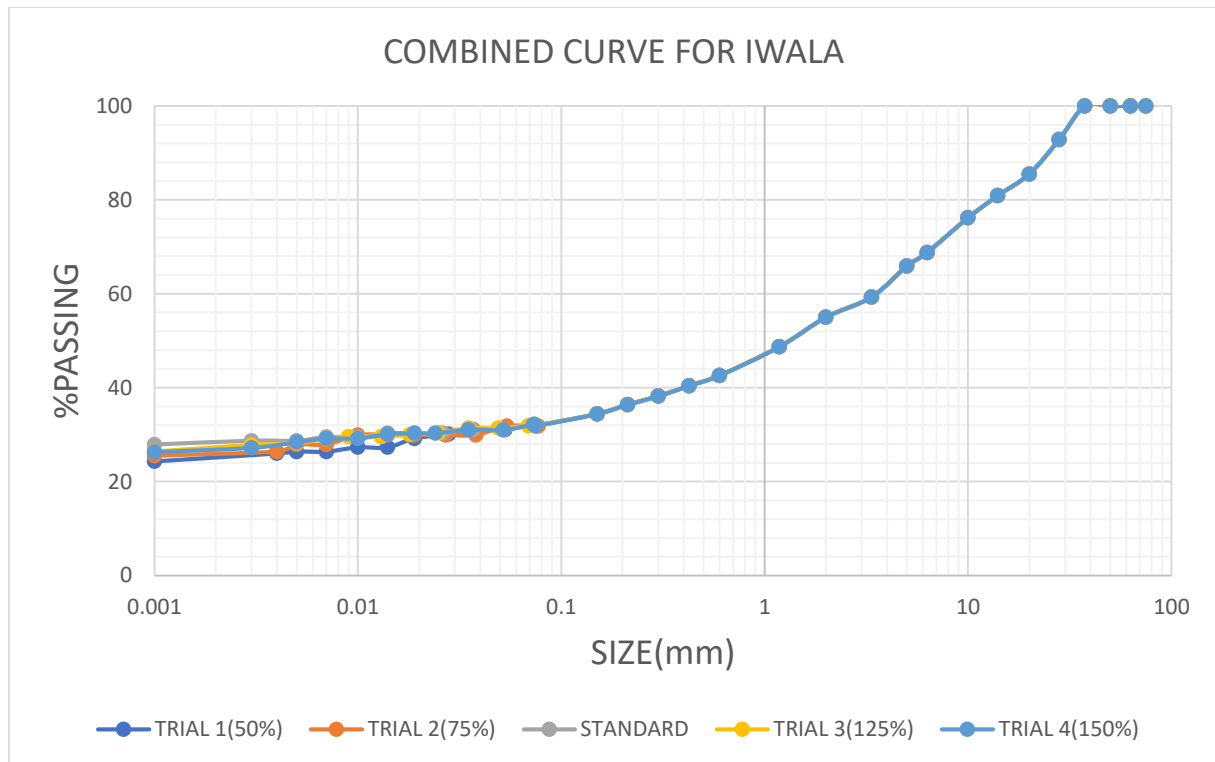
The composition of the dispersing agent at 92% concentration can be calculated as follows:

- Sodium hexametaphosphate (NaHMP): $92\% \times 33 \text{ grams} = 30 \text{ grams}$, approximately 30 grams.
- Sodium carbonate (Na_2CO_3): $92\% \times 7 \text{ grams} = 6 \text{ grams}$, approximately 6 grams.

Thus, for soil sample 3, the optimal dispersing agent solution consists of approximately 30 grams of NaHMP and 6 grams of Na_2CO_3 mixed in 1 liter of distilled water

Low-plasticity soils exhibited comparatively small changes in particle size distribution. Because these soils contained lower proportions of active clay minerals, particle aggregation was naturally less pronounced.

Sample C and D with PI = 19.7 and 16 for the five different quantities of dispersing agent are presented in Table 2.2 for this two sample it has happened that they all lie within the standard Moderate concentrations of dispersing agents produced satisfactory dispersion, although the sensitivity to concentration changes was considerably smaller than that observed for highly plastic soils. Particle size distributions stabilized more rapidly as dispersing-agent concentration increased.



The graph illustrates a significant increase in clay content as the concentration of dispersing agent rises to 100%, followed by a subsequent decrease in clay content. For Idugumbwi soil sample which

exhibits a high clay percentage of 28.4%, the optimal dispersing agent concentration is identified as 100%.

The composition of the dispersing agent at 100% concentration can be calculated as follows:

- Sodium hexametaphosphate (NaHMP): $100\% \times 33 \text{ grams} = 33 \text{ grams}$, approximately 33 grams.
- Sodium carbonate (Na_2CO_3): $100\% \times 7 \text{ grams} = 7 \text{ grams}$, approximately 7 grams.

Thus, for soil sample 2, the optimal dispersing agent solution consists of approximately 33 grams of NaHMP and 7 grams of Na_2CO_3 mixed in 1 liter of distilled water

3.5 Optimum Dispersing-Agent Concentration

A principal objective of this investigation was identifying the optimum dispersing-agent concentration. The results indicate that no single concentration is universally applicable. Instead, optimum dosage depends primarily upon soil plasticity.

Highly plastic soils required greater quantities of SHMP and sodium carbonate before complete particle dispersion was achieved. Conversely, low-plasticity soils required considerably smaller quantities.

Beyond the optimum concentration, further increases produced negligible improvements in PSD while increasing chemical consumption. From an engineering perspective, application of excessive dispersing agent offers no practical advantage and may unnecessarily increase laboratory costs.

Application of inappropriate dispersing-agent concentrations may lead to: incorrect soil classification, inaccurate permeability estimates, inappropriate pavement design, erroneous foundation recommendations, increased construction costs, reduced infrastructure performance.

The study therefore demonstrates that dispersing-agent selection should become an integral component of laboratory quality assurance rather than a routine fixed procedure.

3.6 Comparative Analysis with Previous Studies

The present investigation demonstrates that dispersing-agent concentration significantly affects the measured particle size distribution of fine-grained soils, particularly those exhibiting high plasticity. This observation is consistent with earlier studies reporting that sodium hexametaphosphate enhances the separation of clay particles by complexing calcium and magnesium ions responsible for flocculation. Previous researchers similarly observed that chemically dispersed suspensions produce higher measured clay contents and lower apparent silt fractions than inadequately dispersed samples, indicating improved representation of the soil's true grading characteristics.

The response of high-plasticity soils observed in this study can be attributed to their larger specific surface area and higher cation exchange capacity. These characteristics increase interparticle attractive forces, making complete dispersion more difficult to achieve. Consequently, higher concentrations of dispersing agents are required before particle aggregates disintegrate into their primary particles.

Medium-plasticity soils exhibited intermediate behavior, while low-plasticity soils reached stable PSD results with comparatively smaller dispersing-agent dosages. This trend indicates that plasticity is an important parameter influencing dispersion efficiency and supports the argument that a universal dispersing-agent dosage is unlikely to provide optimum results for all soil types.

These findings reinforce the need to consider soil plasticity during laboratory preparation for hydrometer analysis rather than relying exclusively on a single standard dosage.

3.7 Limitations of the Study

Although the investigation provides valuable insight into the influence of sodium hexametaphosphate and sodium carbonate on particle size distribution, several limitations should be acknowledged.

1. The study considered soils representing selected plasticity classes and may not encompass the full range of mineralogical variability encountered in tropical residual soils.
2. The investigation focused on laboratory-controlled conditions; field environmental factors were not considered.
3. Only the dispersing agents specified in the study were evaluated, whereas other commercially available dispersants may exhibit different performance.
4. Mineralogical analyses such as X-ray diffraction (XRD) or scanning electron microscopy (SEM) were not undertaken to directly identify clay mineral types and observe particle morphology.

These limitations should be considered when interpreting the results and applying them to broader geotechnical contexts.

3.8 Summary of Findings

The experimental investigation demonstrated that:

1. Dispersing-agent concentration significantly influences measured particle size distribution.
2. High-plasticity soils require greater dispersing-agent concentrations than low-plasticity soils to achieve complete particle dispersion.
3. Improved dispersion increases the measured clay fraction while reducing the apparent silt fraction by separating aggregated particles into their primary sizes.
4. A single universal dispersing-agent dosage is unlikely to provide optimum results for soils with different plasticity characteristics.
5. Incorporating soil plasticity into laboratory preparation procedures has the potential to improve the accuracy and consistency of hydrometer analysis.

4. Conclusions and Recommendation

4.1 Conclusion

This study investigated the influence of sodium hexametaphosphate (SHMP) and sodium carbonate (Na_2CO_3) on the particle size distribution of fine-grained soils exhibiting varying plasticity characteristics. Laboratory investigations comprising Atterberg limits, specific gravity, wet sieve analysis, and hydrometer analysis were conducted using different dispersing-agent concentrations to evaluate their effectiveness in promoting particle dispersion. Based on the experimental programme, the following conclusions are drawn:

1. Dispersing-agent concentration has a significant influence on particle size distribution. The results demonstrated that the measured percentages of clay and silt fractions depend strongly on the effectiveness of chemical dispersion prior to hydrometer analysis. Inadequate dispersion resulted in particle aggregation, causing underestimation of the clay fraction and overestimation of the silt fraction.
2. Soil plasticity controls the amount of dispersing agent. Highly plastic soils exhibited the greatest sensitivity to dispersing-agent concentration because of their larger specific surface areas, higher cation exchange capacities, and stronger electrochemical attractions between particles. These soils required higher concentrations of SHMP and sodium carbonate to achieve complete dispersion than medium- and low-plasticity soils.
3. Sodium hexametaphosphate and sodium carbonate act synergistically. SHMP effectively complexes calcium and magnesium ions responsible for particle flocculation, while sodium carbonate increases

suspension alkalinity and enhances electrostatic repulsion. Their combined use promoted more complete particle separation than either chemical alone.

4. The conventional practice of using a single dispersing-agent dosage for all soils is not optimal. The findings indicate that a fixed dosage does not provide consistent dispersion across soils with different plasticity characteristics. This may lead to inaccurate particle size distributions and, consequently, incorrect soil classification and engineering interpretation.
5. Accurate particle size distribution improves geotechnical characterization. Because PSD is fundamental to soil classification, permeability estimation, compressibility assessment, pavement design, and foundation engineering, improving dispersion during hydrometer analysis enhances the reliability of subsequent engineering decisions.

Overall, the study demonstrates that consideration of soil plasticity during preparation of hydrometer test specimens can significantly improve the accuracy, consistency, and engineering usefulness of particle size distribution analyses.

4.2. Recommendations

Based on the findings of this investigation, the following recommendations are proposed:

1. Geotechnical laboratories should consider soil plasticity when selecting dispersing-agent concentrations for hydrometer analysis rather than applying a universal dosage.
2. National laboratory guidelines and testing standards should be reviewed to allow adjustment of dispersing-agent concentrations according to soil characteristics where appropriate.
3. Preliminary laboratory trials should be performed to establish the optimum dispersing-agent concentration for unfamiliar soil types before routine particle size distribution testing.
4. Future studies should investigate a wider range of tropical residual soils from different geological formations to establish generalized relationships between soil plasticity and optimum dispersing-agent concentration.
5. Mineralogical analyses using techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) should be incorporated in future research to better explain the mechanisms governing soil dispersion.
6. Additional investigations should evaluate other dispersing agents and compare their performance with the sodium hexametaphosphate–sodium carbonate system.
7. Future work should examine the influence of dispersing-agent concentration on other engineering properties, including permeability, compressibility, consolidation, and shear strength.

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