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Utilization of Water Turbidity Meter Devices in Estimating the Aggregate Stability of Artificially Stabilized Soils

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Abstract: This study is designed to utilize portable turbidity meters, usually available in most water analysis laboratories, in developing of a quick Dispersion Ratio test (DR, %) as an index of soil stability. The work includes: first, the use of different stabilizers (Bitumen, Lime and Cement) in the preparation of artificially stabilized lead contaminated soils; second, the measurements of scouring depth (SD, in mm), critical shear stress (τ_c, pa) and erodibility coefficient (k_d, cm^3/kN.s) by using a "Mini" Jet Erosion Test; and finally, the comparison between dispersion ratio (DR, %) values of soils, as estimated by the portable turbidity meter and by the gravimetric method. The results showed that all stabilizers can markedly improve the stability of soil; either as (SD, τ_c, and k_d) or as (DR, %) and cement was the best stabilizer. In general, good correlations were found between the turbidity (NTU) and suspended solids (mg/l) of the stabilized soils; (R= 0.99, 0.96 and 0.97) for bitumen, lime and cement respectively. The turbidity DR (%) appears to have a higher correlation with both lime (R= -0.98) and bitumen (R= -0.96) and in a lesser extent with cement (R= -0.87); because only 3% cement could sharply reduce DR(%) of the untreated soil from 7.03 to 2.54%, compared with 4.9 and 4.25% for lime and bitumen respectively. Moreover, the turbidity DR (%) seems to be highly correlated with the k_d of soils (R= 0.99, 0.96 and 0.90 for cement, bitumen and lime, respectively) and cement was the best in the reduction of both k_d and DR (%) even at 3%. It could be concluded that the turbidity DR (%) can be easily utilized to be as a successful index of soil stability. The turbidity method is quick, easy and cost effective and of results that are highly correlated with other erodibility parameters and this may suggest and recommend the use of the turbidity devices in estimating the stability of artificially stabilized soils and other similar soils.
Keywords: Erodibility parameters, turbiditymeter devices, dispersion ratio, soil stabilization.

1. Introduction

In recent years, the stabilization of heavy metal contaminated soils by available, low cost and eco-friendly materials has become an important worldwide issue. The control of heavy metals mobility in soil is defiantly affected by soil erodibility and also by the interferences of these pollutants in the soil aggregate stability. In this respect, Salah and Al-Madhhachi [1] investigated the influenced of lead (Pb) pollution on the erodibility of cohesive soil using a "mini" JET device. Their results showed that the high lead concentration in soil causing an increase in soil erodibility. They found that polluted soil is less stable than clean soils. Hence, the need to develop a quick and a low cost method to estimate the soil aggregate stability and erodibility of such soils is very important.

The true erodibilty of soil is determined in the field by measuring the true amount of eroded soil during natural rainstorms or under carefully regulated artificial water application. However, this is costly and time consuming procedure, so low costs and quick methods are needed to give useful predictions. Many attempts to define a proper index for soil erodibility by water, by both field and laboratory studies, have been conducted. For field studies, Chorly [2] calculated an erodibilty index by measuring both soil mean shearing resistance and soil permeability with the assumption that when both are high in soil, the soil has lower erodibility. Wischmeier et al. [3] developed a monograph to determine the K factor depending on four soil properties: texture, OM content, soil structure and soil permeability. The laboratory methods, however, fall in two general groups [4]. First, tests aimed at measuring intra-aggregate bond strength by special chemical procedures. These tests designed to measure the proportion of soil materials vulnerable to dispersion in water (usually clay and silt) by: Dispersion Ratio [5-6], Clay Ratio (%sand+%silt) / %clay [7] and the amount of dispersed clay after the dispersion of certain amount of soil in water [8-9], soil aggregates "coherent test" in water [10]. Second, tests which subject aggregates to force designed to simulate fields under rain impact in the laboratory but in different rainfall tests [11], percentage of 0.5mm water stable aggregates after subjecting to rain simulation [12], water drop test assessing percentage aggregates destroyed by Pre-selected number of impacts by a standard raindrop of a fixed height [13] and the Wet Sieving method developed by Tulin in 1928 [14].

Recently, the concentration of the dispersed materials has been estimated by colorimetric and light absorption meters. Williams *et al*., [15] used 0.25g soil aggregates in 20ml water and the mixture was shaken. The suspension

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was allowed to stand until all particles of diameter greater than 2 microns settled down. Allenn [16] measured the percentage light transmission using a Sybron Brikmann PC 700 Colorimeter at a wavelength of 620 nm and the same procedure was also followed by Pojasc and kay, [17]. Mutter [9] has modified the procedure that was developed by Gupta *et al*., [8] and read the dispersed materials at 420 nm wavelength on a (4049 LKB) spectrophotometer.

The objective of this study is to utilize water turbidity meter devices in developing a quick, low cost and easy dispersion ratio test (as DR, %) useful in estimating soil aggregate stability against water erosion. The work includes: first, the use of a “mini” Jet test to estimate the erodibilty parameters of different soils that are stabilized by many common soil stabilizers (cement, lime and bitumen); second, the measurement of suspended soil materials (as DR, %) in the (1:2 soil:water) suspensions of these treated soils by both water turbidity meter device and also by the gravimetric method for the purpose of accurate comparisons.

2. Turbidity and Dispersion Ratio

Turbidity is a measure of water suspended solids (SS). These SS are represented by large substances (like sand, silt, etc.) and by microscopic matters (colloids < 1 micron). Colloids are matters which constitute water turbidity once large SS have settled. Some turbid meters measure both of transmitted and scattered light intensity, and indicate a medium value. The word “turbid meter” means the whole range of photometers measuring turbidity. Measurement of total suspended solids (TSS, in no filterable residue) is important in many turbid samples. Chemical or physical changes in the process may result in an increase in turbidity. Thus, solids analyses is usually completed by gravimetric methods; although it may be difficult to obtain a representative sample and it is time consuming and may take two or four hours or more to complete [18].The accuracy and precision of spectrophotometric method depends on three major factors: 1) instrumental limitations, 2) chemical variables and 3) operation skill. Under ideal conditions it is possible to achieve relative standard deviations in concentrations as low as about 0.5% which enables the determination in the range of micro quantities. The precision of spectrophotometric method also depends on concentration of the determinant [19]. Visual methods generally give results with a precision 1-10%. The precision of the photometric method is of course, higher and varies from 0.5-2% under suitable measuring conditions. The common but unrecognized problem in measuring the absorbance is stray light error. All wavelength isolation devices tend to produce some low intensity radiations at wavelength other than the desired one. This is usually due to the optical imperfections, or simply from scattered light due to dust particles on optical surfaces. Thus the stray light errors will result in a negative bias for absorbance readings [20].

DR is well known to give a reliable estimation for soil erodibility [4-21]. The micro-aggregation or dispersion technique developed by Middleton [5] has since been used as index of aggregate stability. The term "dispersion ratio" refers to matter suspended in water or in soil solution, and is related to the percentage of clay (<0.002mm) in soil sample. Dispersed solids includes both total suspended solids; the portion of total solids retained by a filter, and total dissolved solids; the portion that passes through a filter [22]. Dispersed solids can be measured by evaporating a soil-water mixture in a weighed dish, and then drying the residue in an oven at 103 to 105° C. The increase in weight of the dish represents the dispersed solids and hence soil erodibility.

3. Materials and Methods

3.1 Soil Samples

In this study, a Lean Clay (Silt Clay Loam, USDA classification) soil samples Table 1 is used to carry out the experiments; acquired from depths of (0.0 to 90 cm) from Al-Taji region, north of Baghdad city. The soil samples were tested and analyzed according to the ASTM standards [23]. Other soil properties, including erodibility parameters of lead contaminated soil in relation to stabilizers percentages concern in this study, are also listed in Tables 2 to 4.

Table 1 The physical and chemical properties of studied soil

Soil Properties	Value
Sand (%)	13
Silt (%)	57
Clay (%)	30
Specific gravity	2.48
Organic matter (%)	1.09
$CaCO_3$ (%)	0.3
$CaSO_4$ (%)	0.6
Soil Suspension (1:2 soil: water) Chemical Properties	
pH	7.4
EC (mS/cm)	1.03
SAR	7.11
Water soluble Pb (ppm)	19.5

3.2 Stabilizing Materials

Three common stabilizers were utilized in this study; cement, lime and bitumen which are all available in the local market as building materials. The type of cement used in this study is the ordinary Portland cement (OPC) and the type of lime is the hydrated lime $Ca(OH)_2$, which is locally named as “Nora”. The bitumen used in this study, which is locally named as “flank coat” is an UAE product under the name “Prakcoat” which is made by the Oasis Grease & Lubricants Company. Bitumen features are: cold applied, easy to apply, adhere to (concrete, metal, wood), nonflammable, resist the chloride and sulphate salts attack in soil, and economical.

4. Experimental Work

4.1 Soil Samples Tests

Most physical and engineering properties were determined at the Hydraulic laboratory of the Environmental Engineering Department, Engineering College, Al-Mustansiriyah University according to the ASTM standards [23]. However, scouring depth (SD), erodibility coefficient (k_d) and critical shear stress (τ_c) of soils were determined by a "mini" Jet Erosion device developed by Al-Madhhachi *et al*., [24]. The data obtained from the "mini" Jet were analyzed with a linear model using Blaisdell solution technique to derive τ_c and k_d. Digital Shore-D durometer (0.0 to 100 scale) was used to measure the degree of hardness at the Materials Department laboratory, Engineering College, Al-Mustansiriyah University. Soil samples were prepared according to the following steps:

1- All the soil samples were air-dried, broken into small sizes and sieved through a 4.75 mm sieve according to ASTM standard. The sieving was performed to ensure that the soil was of uniform grade.

2- The artificial Pb-contaminated soil samples were prepared by mixing lead nitrate, as the source of lead (Pb), to produce a soil of 4000 mg/kg lead concentration in the natural soil. As a reminder, 300ppm in soil is the maximum acceptable Pb concentration in EU countries [25].

3- Different percentages of stabilizers (0%, 3%, 6%, and 9%) by soil weight were added directly to a 2 kg of the lead contaminated soil and mixed by hand until the mixture seems to be homogeneous. The samples were then packed in special plastic (PVC) mold and were compacted using the Proctor test to be ready for the "mini" jet erosion tests, as described by Al-Madhhachi *et al*. [24] and Mutter *et al*. [26]. It should be noted that all the JET erodibility tests were conducted after 7 days of curing time.

4.2 Soil Suspension Testing Methods

4.2.1 Chemistry of Soil

All tests on soil sample solutions were carried out at the sanitary laboratory of the Environment Department, Engineering College, Al-Mustansiriyah University. The soil solution chemical properties, namely pH, EC, soluble Pb, and SAR, were measured in the filtered 1:2 soil solution prepared for this purpose. The pH was measured by a pH-meter, EC by an Electrical Bridge, soluble Pb (ppm), Na, Ca and Mg in (meq/l) by the Atomic absorption Spectrophotometry. The sodium adsorption ratio was calculated by the following formula [27]:

$$SAR = \frac{Na}{\dfrac{\sqrt{Ca+Mg}}{2}} \qquad (1)$$

; Where sodium, calcium and magnesium concentrations are in meq/liter.

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in irrigation to prevent soils from the sodium hazard. In general, the higher the sodium adsorption ratio, the less suitable the water is for irrigation. It is also an index of the soil sodicity and can be determined from the chemical analysis of the soil solution.

4.2.2 Dispersion Ratio (DR, %)

The dispersion ratio in this study was measured according to Middleton (1930) principles and by a quick method modified from CMG [28]. In this study, 25g of lead contaminated soil were mixed in 250ml conical flask with 50ml water to get a 1:2 soil water mixture. The mixture was shaken by hand for 1minute and then left for 2 hours. After 2 hours the soil particles greater than the clay (>0.002mm) may settle down. A10 ml of the suspension was transferred to a weighed beaker and put in the oven to determine the dispersed soil materials in suspension by the gravimetric method. For the clay content in the untreated original soil sample, the same above procedure is followed to determine the clay existing in the original soil sample. The gravimetric (DR, %) was calculated by the following equation:

$$DR\%\,(Gravimetric) = \frac{g\ Clay\ in\ suspension}{g\ Clay\ in\ untreated\ soil\ suspension} \times 100 \qquad (2)$$

Field Portable Turbidity Meter (Micro-TPW, Scientific Inc. Ft. Myers, Florida, U.S.A) was used to estimate the suspended soil materials in (NTU units) of both treated and the untreated soil sample. The turbid metric DR (%) was calculated by the following equation:

$$DR\%\,(Turbidity) = \frac{NTU\ Clay\ in\ suspension}{NTU\ Clay\ in\ untreated\ soil\ suspension} \times 100 \qquad (3)$$

5. Results and Discussion

Due to the results obtained from this work and the findings of another related detailed studies published by the same author [26-29-30], the three stabilizers used in this study have markedly improved both soil mechanical and chemical properties related to soil stabilization and erodibility. According to [29], cement and lime stabilizers had noticeably increased pH and reduced both EC and SAR in soil solution. Bitumen had less effect on chemical properties and hence was less efficient than both cement and lime in soil stabilization [30]. It should be noted, however, that a 9% of bitumen was needed for the best stabilization; compared with only 6% for both lime and cement. Table 2 shows the bitumen impact on the erodibility parameters of lead contaminated soil. A 9% of bitumen was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), bitumen has a significant impact on shear stress (τ_c, pa) and to some extent on the degree of hardness (DH). Hence the scouring depth (SD) was reduced from 24.5 to 0.38 mm and the erodibility coefficient (k_d) from 1090 to 0.1cm^3/kN.s. On the chemical properties, bitumen seems to have a positive impact on soil properties related to soil stability; by reducing the suspended solids and both the gravimetric dispersion ratio from (7.03 to 2.93%) and turbidity dispersion ratio from (7.06 to 2.25%). The bitumen improvement of soil stability may be due to the increase in cohesive and load bearing capacity of soil particles which increases the resistance to the action of water. The soil particles may be covered and voids blocked with bitumen that prevent or slow the penetration of water [31]. In soil stabilizing with bitumen, two basic processes are active: water proofing and adhesion. Soil particles are coated with bitumen that stops or reduces the penetration of water, which could result in decreasing soil strength. The soil aggregates adhere to the bitumen and it behaves as a binder and thus the cohesion forces and shear strength increase [32]. Droplets in contact with clay minerals spread on the surface eventually displace the water film on the aggregate surface [33-34]. When a contact happened between the bitumen emulsion and soil aggregates, adsorption of free emulsifier and soil particles may occur and the pH rises. This rise in pH leads to the flocculation of soil particles. In addition, bitumen may sometimes behave as a positively charged cation and this may neutralize the acid in the cationic emulsion causing the pH to rise and this may enhance the clay flocculation [35].

Table 2 Erodibility parameters of lead contaminated soil in relation to bitumen percentages

	Bitumen,%				
Erodibility Parameter	0	3	6	9	Corr., R*
DH	76.5	92.3	93.35	97.75	0.90
SD, mm	24.5	3.35	2.25	0.38	-0.84
(τ_c, pa)	0.05	4.13	5.09	7.74	0.97
(k_d, cm^3/kN.s)	1090	170	165	0.1	-0.85
SS, mg/l (Gravimetric)	10550	7760	7100	6725	-0.91
Turbidity, NTU	592.4	356.3	265.6	188.7	-0.96
DR, % (Gravimetric)	7.03	4.07	3.83	2.93	-0.91
DR, % (Turbidity)	7.06	4.25	3.17	2.25	-0.96

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 levels, respectively.

The most commonly-applied pozzolanic stabilizers are Portland cement, lime and/or fly ash [36-37]. Table 3 shows the lime impact on the erodibility parameters of lead contaminated soil. Only 6% of lime was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), lime has a clear impact on shear stress (τ_c, pa) and on the degree of hardness (DH). Hence the scouring depth (SD) was reduced from (24.5 to 1.4 mm), and the erodibility coefficient (k_d) from (1090 to 170 cm^3/kN.s). On the chemical properties, lime seems to have a positive impact on soil properties related to soil stability; by increasing divalent cations (Ca and Mg) required for clay flocculation and hence granulation [9]. Emersion [10] suggests that at least 0.6-2.0 meq/l divalent cation concentration is required in solution to inhibit clay dispersion. Hence, lime succeeded in reducing suspended solids and both the gravimetric dispersion ratio from (7.03 to 1.96%) and turbidity dispersion ratio from (7.06 to 1.25%). The decreasing in k_d values with lime was due to the cementing products that strengthen soil layers [38]. Note that the chemical reaction with lime required more time when compared with cement [39].

Table 3 Erodibility parameters of lead contaminated soil in relation to Lime percentages

	Lime, %				
Erodibility Parameter	0	3	6	9	Corr., R*
DH	76.5	89.1	93.5	94	0.90
SD, mm	24.5	2.93	1.45	1.40	-0.80
(τ_c, pa)	0.05	4.6	6.2	5.9	0.89
(k_d, cm^3/kN.s)	1090	180	150	170	-0.78
SS, mg/l (Gravimetric)	10550	3895	3135	2995	-0.83
Turbidity, NTU	592.4	343.4	194.0	104.9	-0.98
DR, % (Gravimetric)	7.03	2.95	2.09	1.96	-0.83
DR, % (Turbidity)	7.06	4.09	2.31	1.25	-0.98

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 levels, respectively.

Table 4 shows the cement impact on the erodibility parameters of lead contaminated soil. A 6% of cement was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), cement has a big impact on shear stress (τ_c, pa) and on the degree of hardness (DH). Hence, the scouring depth (SD) was reduced from (24.5 to 0.38) mm and the erodibility coefficient (k_d) from (1090 to 0.0) cm^3/kN.s. On the chemical properties, cement seems to have a significant impact on soil properties related to soil stability; by reducing the suspended solids and both the gravimetric dispersion ratio (from 7.03 to 1.33%) and turbidity dispersion ratio (from 7.06 to 1.16%). According to the k_d values, cement was the best stabilizer followed by bitumen and then lime. While from DR values, cement once again was the best stabilizer, followed by lime and then bitumen this time. The greater decreasing in k_d with cement was due to the cement chemical composition, especially in the existence of divalent and trivalent oxides, and the adhesive and cohesive property that make it capable of flocculating clay and binding fragments of mineral [31]. When Portland cement is mixed with water, it will hydrated forming strong cementing compounds of calcium-silicate-hydrate, calcium-aluminum-hydrate as well as calcium hydroxide [40].

Table 4 Erodibility parameters of lead contaminated soil in relation to cement percentages

	Cement, %				
Erodibility Parameter	0	3	6	9	Corre., R*
DH	76.5	92.5	96	98.2	0.90
SD, mm	24.5	3.35	2.25	0.38	-0.84
(τ_c, pa)	0.05	4.49	7.37	7.74	0.94
(k_d, cm^3/kN.s)	1090	170	0.1	0.0	-0.85
SS, mg/l (Gravimetric)	10550	6275	2740	1995	-0.96
Turbidity, NTU	592.4	213.4	121.8	97.3	-0.87
DR, % (Gravimetric)	7.03	4.18	1.83	1.33	-0.96
DR, % (Turbidity)	7.06	2.54	1.45	1.16	-0.87

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 levels, respectively.

Fig. 1 shows that there is a high and good relationship between turbidity and suspended solids of soil solution and stabilizers percentage (0%, 3%, 6%, and 9%). The figure indicates that whenever the stabilizers percentage increase in the soil, the turbidity and dispersed solids of soil solution decreased which means that soils are under better stabilization conditions. Once again, cement appears as the best stabilizer in reducing both suspended solids and turbidity of soil solution, followed by lime and then bitumen, due to the same reasons mentioned above in the discussions of the tables. These results agree with the results of Sivapalan [40].

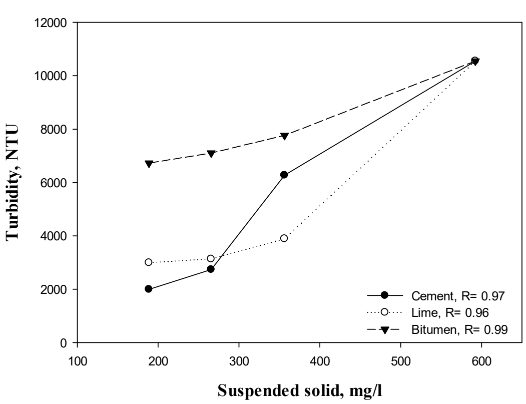

Fig. 1: Relationships between suspended solids in (1:2 soil:water) soil suspension (mg/l) and Turbidity (NTU) of different soil stabilizers

Sivapalan [40] found that the application of small quantities of such soil stabilizers may improve the soil aggregate stability, enhance the infiltration, reduce runoff and overcome the water turbidity problem in water resources.

Hannouche *et al*. [41] confirmed the possible successes of using turbidity in assessing TSS within a combined sewer system; because the turbidity-TSS relationships show linearity regardless of weather conditions and most of them tend to pass close to the origin.

Figs. 2 to 4 show a clear relationships between the dispersion ratios of the lead contaminated soil and the stabilizers percentage (0%, 3%, 6%, and 9%).

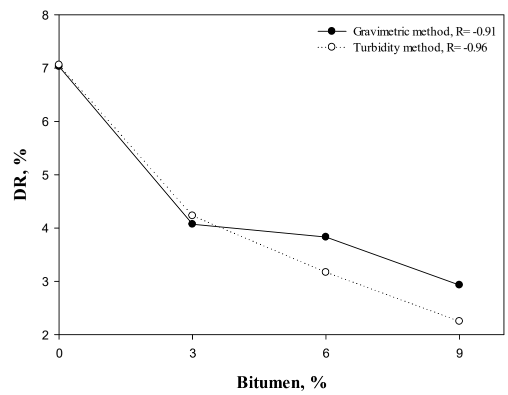

Fig. 2: Relationships between DR (%) in (1:2 soil:water) soil suspension and the Bitumen percentages

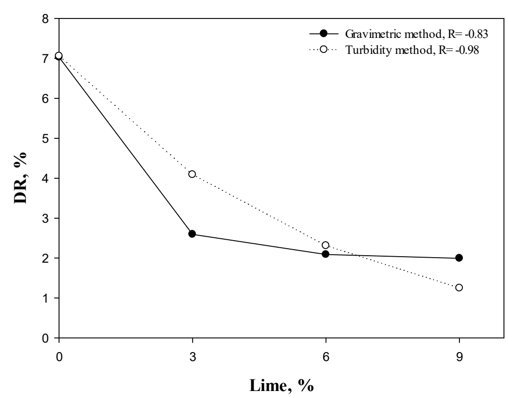

Fig. 3: Relationships between DR (%) in (1:2 soil:water) soil suspension and the Lime percentage

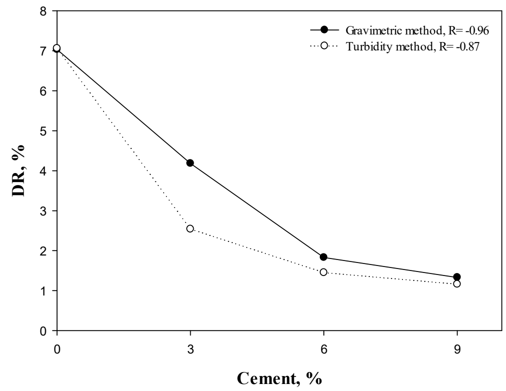

Fig. 4: Relationships between DR (%) in (1:2 soil: water) soil suspension and Cement percentage

The figures indicate that there is a high correlation between the DR and the amounts of stabilizers, and whenever the stabilizers percentage increase in soil, the dispersion ratio (DR, %) in soil solution decrease. From these figures, gravimetric DR values appeared to be slightly greater than those turbid metric ones. This may because the heating of soil suspension samples in an oven at 103 to 105° C may evaporate or burn some of the materials vulnerable in soil and stabilizers. However, the turbidity DR (%) appears to have a high correlation with both lime (R= -0.98) and bitumen (R= -0.98) amounts and in lesser extent with cement (R= -0.87). This is in fact not because cement is not a good stabilizer, but because a smaller amount (3%) of it has sharply reduced the DR of soil from (7.03 to 2.54%), compared with lime and bitumen (4.09 and 4.25%) respectively at the same percentage. In the gravimetric methods; although it may be difficult to obtain a representative sample and it is time consuming and may take two or four hours or more to complete [18], and as far as that DR is well known to give a reliable estimation of soil erodibility [4], and the micro-aggregation or dispersion technique developed by Middleton [5] has since been used as index of aggregate stability, these results may suggest and recommend the use of the turbidity DR in assessing the stability of artificially stabilized soils.

Fig. 5 relates the Turbidity DR (%) of the three stabilizers with the erodibility coefficients (k_d). The turbidity DR seems to have a high and good correlation with k_d. The turbidity DR of cement, bitumen and to some extent lime had significantly correlated with the k_d values of the stabilized soils (R= 0.99, 0.96 and 0.90) respectively. This can prove that the Turbidity DR (%) can be successfully used as a reliable index of the soil stabilization status. However, this fact is in agreement with Sadar and Engelhardt [42] who found that turbidity measurements often can be correlated and used as a substitute for gravimetric solids measurement in the monitoring and controlling of industrial processes. They suggested that this correlation study must be done in a timely manner; because the longer it takes to perform the study, the more chance exists for the sample, instrument, or environmental changes to occur. A turbidity meter can be used as an alternative measure of suspended solids if sample and instrumental variables are properly controlled [19]. Thus, Hach [20] suggests:

1. The sample must be a true representative of the sample stream from which it came. A well-mixed sample and dilutions of the original sample must be used in all sample manipulation. All dilutions must be treated the same throughout the study,
2. Consistent technique and environmental conditions must be used throughout the test to reduce variability in the instruments and samples.

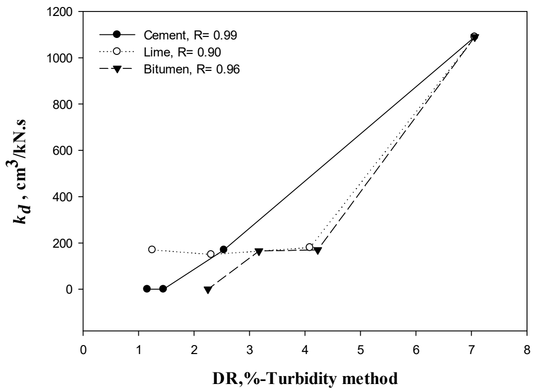

Fig. 5: Relationships between DR (%), measured by the Turbidity method, in (1:2 soil: water) soil suspension and the erodibility coefficient (k_d)

6. Conclusion

From the results of this study (and others obtained earlier by the same author about the mechanical [26] and the chemical [29-30] effects of these stabilizers on soil), it could be concluded that all stabilizers can markedly improve the stability of the lead contaminated soil; as measured by the "Mini" JET device (as SD, k_d and τ_c) or by the turbidity meter and the gravimetric dispersion ratio methods (as DR, %) and cement was the best stabilizer. Chemically [29-30], the three stabilizers have increased pH but decreased the EC (Electrical Conductivity) and SAR (Sodium Adsorption Ratio) and hence DR (%) in soil solution. Noticeably, a very significant correlation was found between the turbidity readings (NTU) and the suspended solids (mg/l) of the treated soils (R= 0.99, 0.96 and 0.97) for bitumen, lime and cement, respectively. There is a good and high correlation between the DR (%), as measured by a turbid meter or a gravimetric method, and the amount of stabilizers. However, the turbidity method appears to have a higher correlation with both lime and bitumen amounts and in lesser extent with cement. This is in fact not because cement is not a good stabilizer, but because a smaller amount (only 3%) of cement has sharply reduced the DR (%) of treated soil. Moreover, the turbidity DR (%) seems to be highly correlated with the k_d of all stabilized soils (R= 0.99, 0.96 and 0.90) for cement, bitumen and lime, respectively, and cement was the best in the erodibility reductions (k_d). However, it could be concluded that the turbidity DR (%) method can be easily utilized as a successful index of soil stability. Because this method is quick and has a significant correlation with the erodibility coefficient (k_d), this may encourage and recommend the use of the turbidity meter devices in measuring DR (%) and estimating the stability of artificially stabilized soils and other similar soils.

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