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Stabilization of Baiji Sand Dunes by Petroleum Residues

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Abstract. This research is concerned with the use of petroleum residues to stabilize Baiji sand dunes. The purpose of this research is to study the stabilizing effect of these residues irrespective of their possible toxicity to plant and environment. Two petroleum mixtures were prepared in different mulching rates to test their efficiency in stabilizing sand dunes. Those mixtures were added to the dune samples with variable mulching rates, mixtures temperatures and initial water contents. Mechanical stability was estimated from percent of dry aggregates greater than 0.84 mm and percent of aggregates less than 0.42 mm. The mixtures of petroleum residues used in this study were found to be effective in forming large amounts of nonerodible aggregates greater than 0.84 mm and reducing the erodible aggregates less than 0.42 mm. treated samples also showed a good stability against breakdown under repeated sieving and the effect of cyclic freezing and thawing on the mean weight diameter factor MWD. The results of repeated sieving test RST showed that petroleum mixtures create a stable crust preventing the bare sand dunes from erosion.

1. Introduction

Sand dunes occupy large areas all over the world. It became a great threat to the arable lands that enforce the civilization to withdraw to limited areas. The sorting action of the wind tends to wash away the sand, depositing it wherever the movement of winds ceases. Besides deposition, amount of drifting sand often causes great damages in roads, drainage ditches, channels, environment and agriculture, reducing their efficiency and making costly removal necessary.

Most of the Iraqi's land is affected by wind erosion which tends to wash away the sand, depositing it wherever the movement of the wind ceases. Dune forests should be treated so as to provide a permanent protection against wind erosion. This can be achieved through the establishment of vegetation. This the most durable and effective approach to control sand dunes migration but it is the longest way. Therefor it is important to find a quick treatment that would make the dune at least, temporarily non-erosive.

This research is based on the use of petroleum residues for treatment. The reasons behind choosing these materials are:

- Low cost.
- Plenty of surpluses with less usage.
- Closeness of the sand dunes region to Baiji refinery.

Several published studies were interested in finding effective treatment for this problem. Asl et al. (2017) investigate the effect of different mixtures of micro silica-lime-clay as a mulch on stabilizing the drifting sand. They found that the mixture was effective in soil losses decrease at high wind speeds. The composite of 200 g clay + 10 g lime + 20 g micro silica was recommended for the stabilization of drifting sands.

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Fattah et al. (2016) used silica fume (SF) and lime-silica fume (L-SF) mixture for stabilizing sand dunes. Four percentages of lime (0, 3, 6, and 9) % and four percentages of silica fume (3, 6, 9, and 12) % were used. They found that the percentage of (6% L+3% SF) achieved the maximum dry density which is directly related to the angle of internal friction. Moreover, higher cohesion was reached (10 kPa) with percentage of mixture (6% L+ 12% SF).

Al-Taie et al. (2013) investigated the geotechnical properties of Baiji sand dunes on soaked and unsoaked samples. It is found that the density of dunes of this region is more affected by vibration rather than by standard proctor compaction. The dune has no swell potential and exhibit low values of axial strain under different soaking pressure.

Al- Aghbari et.al. (2009) used different amount of ordinary portland cement (OPC) and cement bypass dust (CBPD) (2%, 4%, 8%, 10%, and 12%) to stabilize desert sand for possible use as a foundation bearing soil. They found that the unconfined compressive strength for sand stabilized with 12% OPC is about 2.5 MPa while for the corresponding value of CBPD is about 1.2 MPa.

Fadhil (2002) studied the effect of using different petroleum products (fuel oil and bitumen) at different rates of mulching (0.5, 1.0, and 2.0 l/m^2) on stabilizing Baiji sand dunes. Fuel oil was more effective in increasing mean weight diameter factor, percentage of dry aggregates greater than 0.84 mm, and time of dry sieving required to complete de-aggregation.

Khadhair's (1997) used a cement dust in stabilizing sand dune. Three suspensions of cement dust diluted in water with different concentrations and applied to the dune samples with different rates. Treated samples were subjected to the wind tunnel test, wet sieving and dry sieving. The results clearly indicated that the least erodible samples by wind were those containing the greatest proportion of aggregate > 0.84 mm.

The aim of this study is to investigate some of the factors that affect aggregates stability and consequently affect soil erosion. These factors are:

- Effect of mixture's temperature on percent of dry aggregates greater than 0.84 mm and less than 0.42 under repeated sieving.
- Effect of water content on percent of dry aggregates greater than 0.84 mm and less than 0.42 under repeated sieving.
- Effect of mixture's temperature on the mean weight diameter MWD of water-stable aggregates under cyclic freezing and thawing.
- Effect of water content on the mean weight diameter MWD of water-stable aggregates under cyclic freezing and thawing.

2. Wind erosion

The word erosion is of Latin origin, it is derived from the verb "erodere" to eat away, to excavate. This term generally means the destruction of soil by the action of water and wind.

The importance of wind erosion with respect to the soil is similar to water erosion. It occurs mainly in those areas where there is a lack of precipitation together with predominantly high temperature. The main factor in wind erosion is the movement and circulation of wind. The wind affects the soil by desiccating the surface layer, drying up and removing soil particles by deflation. The stronger the wind, the greater is its influence on the soil.

Particles with diameter ranging from 0.2 - 0.5 mm are classed as sand. Particles having diameter smaller than 0.05 mm can be called dust. Sand – sized particles, after transported of sand by wind, accumulated as dunes of different shapes and sizes.

The manner of the transport of sand by wind was studied and understood by many researchers but fundamental principles of wind erosion were established by Bagnold (1941), who restricted this movement in three types according to the size grains; saltation, suspension, and creep. He asserted that sand dunes are carried by wind mainly in saltation.

Saltation is the bouncing, jumping motion of sand grains driven by action of direct wind to form the initial stage of movement. They gain considerable forward momentum from the pressure of the

wind upon them, and acceleration of horizontal velocity continue from grains begin to rise to the time they strike the ground.

On striking the surface they either rebound and continue their movement in saltation or loose most of their energy by striking other grains, causing them to rise upward and themselves sinking into the surface or forming part of the movement in surface creep.

Soil that is moved by saltation consist mainly of fine grains 0.1 to 0.5 mm in diameter, this range of size is predominant in most types of sand dunes. Measurements indicated that most of the soil movement in saltation was carried below the height of 600 to 900 mm.

Surface creep is the slow movement of the soil surface which is caused primarily by the direct impact of saltating grains on particles that are too heavy to be dislodged and bounced into the air. Such particles vary in diameter from 0.5 to 1.0 mm. Roughly; the amount of surface creep depends on the quantity of erosive grains greater than 0.5 mm in diameter for cultivated soils and over 0.25 mm for dune sand.

Suspension is the transporting by wind of small particles less than 0.1 mm in diameter. Particles of this size have a lower falling velocity than upward velocity of the turbulent winds, and after having been dislodged from the surface by saltating grains or by mechanical disturbance, are governed by the characteristic movement of the wind which carries them to great heights and over long distances from the original location.

These aspects were mentioned in many works which deal with wind erosion. Some or all of these forms of movement may be operating at the same time, but none of these exist without saltation. So the elimination of saltation will eliminate wind erosion.

Mineral soils can be classified on the basis of particle sizes with varying responses to wind action, see table (1).

Table 1. Classification by Chepil (1950)					
Fraction	Particle diameter, mm Wind susceptibility				
Α	< 0.42	Highly erodible			
В	0.42 to 0.84	Difficulty erodible			
С	0.84 to 6.4	Usually nonerodible			
D	> 6.4	Nonerodible			

3. Materials and Method

Baiji was chosen as the field of study. It lies on the longitude 43.5° and the latitude 350, and surrounded by series of Makhul-Hamrin Mountains from the north and north-east direction, Tigris river from the east direction, wadi Al-Tharthar from the west, Jazira area from the north west and the western desert from the west.

The area that was chosen to take the samples from lies behind the stabilized sand dunes zone in Baiji. Samples were taken within a layer 50 mm below the ground surface.

The sand samples have a specific gravity $G_s=2.67$. The grain size distribution curve is shown in Figure (1). This figure shows that the coefficient of uniformity (C_u) of Baiji sand dunes is 2.66 and the coefficient of curvature (C_z) is 1.58. The soil is classified as uniform fine sand according to ASTM D-2487.

Two petroleum mixtures, having the specifications shown in table (2), were prepared for the treatment:

- First mixture consists of vacuum residue/crude oil of 1/1 in volume.
- Second mixture consists of blend fuel oil/crude oil of 2/1 in volume.

Each mixture is to be heated to a temperature of 70° C and added to a 50 mm layer of an oven dry sand layer with three mulching rates, 4 l/m^2 , 6 l/m^2 , and 8 l/m^2 . The water content is to be changed to 2% and 4% in weight with preparation of the same mulching rates in accordance with water content.

To study the influence of the reduction in the mixture's temperature on the amount and stability of aggregates, the whole steps were repeated for other mixtures heated to a temperature of 50° C. The samples were left in air for a month after treatment.



Figure 1. Grain size distribution curve of Baiji sand dunes

Specification	Vacuum residue	Blend fuel oil	Crude oil	Mixture No.1	Mixture No.2
Specific Gravity at 15.6°C	1.0073	0.9728	0.8572	0.9413	0.9383
Viscosity at 50° C/CST	5000	728	4.6	141	82
Sulpher content	5.1	4.3	2.0	3.84	3.5

Table 2. Specifications of the petroleum derivatives

3.1 Aggregate stability and size distribution test

Chepil (1953) mentioned that water-stable particles, as conventionally determined by sedimentation or sieving of soil in water, are the building blocks of field structure of soil. He made a comparison between different kinds of soils tested in three ways (i) wet sieving (ii) dry sieving (iii) wind tunnel. The results illustrated that the water-stable particles less than 0.02 mm and greater than 0.84 mm in diameter, greatly influence the dry aggregate structure and erodibility of soil by wind.

Van Bavel (1949) proposed that aggregates should be assigned an importance or weighting factor that is proportional to their size. The parameter that he called the mean weight diameter MWD is equal to the sum of products of (i) the mean diameter (X_i) of each size fraction and (ii) the proportion of the total sample weight (wi) occurring in the corresponding size fraction, where the summation of is carried out over all (n) size fractions, including the one that passes through the finest sieve

To estimate the stability of aggregates formed after the preceding treatment, two procedures were adopted:

3.1.1 Dry sieving

Air dried samples passed through sieve 9.0 mm were taken to test the grain size distribution under repeated dry sieving. Samples were sieved for a minute in an electrical shaker of sieves (1.0, 0.84, 0.5, 0.42, 0.25, 0.21, 0.149, and 0.053 mm) respectively. Dry sieving was repeated three times to find out the stability of aggregates presented in the percentage of non-erodible aggregates greater than 0.84 mm and erodible aggregates less than 0.42 mm retained on the sieves.

3.1.2 Wet sieving

For the purpose of studying the effect of cyclic freezing and thawing on the mean weight diameter MWD of the water stable aggregates, samples were taken after treatment and subjected to 0, 2, 5, and 8 cycles of freezing and thawing. The time required for freezing was about 6 hours at a temperature 0° C and then the samples were allowed to thaw at room temperature to finish the first cycle.

When the desired number of cycles has been completed, the samples were air dried preparing them for the water stable aggregates test in the Yoder's machine.

This test was explained by Kemper and Rosenau (1986). The Yoder's setup consists of a nest of sieves (4.85, 2.36, 1.0, 0.5, and 0.25 mm) respectively which are placed in a holder and suspended in a container of water. For each test, 25 grams were taken from these samples and placed on the top sieve of the nest. The nest was lowered to the point where the soil sample on the top was just covered with water. A motor and mechanical arrangement lowered and raised the nest of sieves through a distance of 3.18 mm at a rate of 30 cycles/min for 6 minutes. The amount of soil retained on each sieve was determined by oven drying and weighing.

4. Results and Discussion

Repeated sieving test is considered as an indication to the mechanical stability which tends to prevent wind erosion by resisting the breakdown of nonerodible fractions into smaller erodible fractions. In order to get sensible results and to be closer to the evaluation of dune treatment, the following factors are used:

Nonerodibility ratio (N) =
$$\frac{\text{Percent aggregates} > 0.84 \text{ mm of treated sand dunes}}{\text{Percent aggregates} > 0.84 \text{ mm of untreated sand dunes}}$$
(2)

$$Erodibility ratio (E) = \frac{Percent aggregates < 0.42 \text{ mm of treated sand dunes}}{Percent aggregates < 0.42 \text{ mm of untreated sand dunes}}$$
(3)

4.1 Percent of nonerodible aggregates greater than 0.84 mm

Dry aggregates of diameters greater than 0.84 mm were obtained from treated dune samples broken down to different size under subsequent repeated sieving. The nonerodibility ratio plotted against number of sieving as shown in Fig. 2.

This figure shows the influence of type of mixture on the aggregate's formation and aggregate's stability for different rates of mulching. Samples were treated with mixtures No.1 and No.2. This treatment leads to increase the (N) ratio during repeated sieving. The reason of this increment is due to the slow breakdown of treated sample as compared to the rapid breakdown of the untreated samples. The (N) ratio achieved a higher value at every sieving which reflects the strong bonding among sand particles due to the mixtures as compared to the untreated sand on its cohesionless structure.

Fig. 2 reveals that the (N) ratios of mixture No.2 are higher than those of mixture No.1. Rising up the (N) ratio under repeated sieving were due to low viscosity of mixture No.1 which made it more capable of penetrating dry sand and forming greater percent of nonerodible aggregates. It can be also seen that the behavior of treated samples at a temperature of 50° C is similar to those treated at a temperature of 700 C except that the (N) ratios are greater at the later than that at the former. This is because the mixture's viscosity is decreased with increasing its temperature which increased the penetration through the sand and formed large amounts of nonerodible aggregates.

Fig. 2 reveals also that the existence of some water content in the sand at the moment of treatment tends to increase aggregates formation and aggregates stability during repeated sieving test. This is obvious from the continuous increase in the values of the (N) ratio with increasing the water content. The prewetting process enables the mixture micelles to migrate through the sand, linking their particles together after drying.



Figure 2. Relation between number of sieving and (N) ratio for samples treated with mixtures at different temperatures; a) $T = 50^{\circ} C$, b) $T = 70^{\circ} C$.

4.2 Percent of highly erodible aggregates less than 0.42 mm

It was necessary to determine the mechanical stability at the highly erodible fractions that pass through 0.42 mm sieve. This particle sized diameter is considered as an approximate dividing line between erodible and nonerodible fractions.

Fig.3 shows the relation between number of sieving and the (E) ratio for the treated samples. One can notice the small difference in (E) throughout repeated sieving test that made the relationships, approximately, a horizontal line. This is due to the concentration of most of the untreated dune particles within the erodible fraction (0.1-0.42) mm, hence these small differences could not be avoided by comparing the percent of aggregates less than 0.42 mm of treated samples with the corresponding percent of untreated samples.

This increase in the amount of highly erodible fractions is always associated with the decrease in nonerodible fractions, thus the factor that contributes in increasing one of them will lead to decrease the other. Mixture's type, temperature, and water content have a positive effect on the (N) ratios as shown in Fig.2. On the contrary, Fig.3 illustrates that these variables have an inverse effect on the values of the (E) ratios. These results confirm with Chepil (1954) and Gabriels and De Boodt (1976).



Figure 3. Relation between number of sieving and (E) ratio for samples treated with mixtures at different temperatures; a) $T = 50^{\circ} C$, b) $T = 70^{\circ} C$

4.3 Effects of Cyclic Freezing and Thawing on the MWD of Water-Stable Aggregates

A study was made for the effect of climatic conditions on the MWD of water-stable aggregates. Treated samples were subjected to several freezing and thawing cycles, and the MWD values were plotted against the number of these cycles, as shown in Fig.4.

The values of the MWD on the axis of ordinate reflect the considerable improvement in dune structure to resist water erosion. The minimum value of MWD was 6.04 mm and the maximum value was 6.81 mm, while it was for untreated samples 0.182 mm.

Chepil (1954) stated that the breakdown of wet coarse aggregates during winter is apparently due to expansion of ice crystals within aggregates. If aggregates were dry, no crystals are formed and no breakdown.



Figure 4. Relation between cyclic freezing and thawing for samples treated with mixtures at different temperatures; a) $T=50^{\circ}$ C , b) $T=70^{\circ}$ C

Fig.4 shows that the effect of cyclic freezing and thawing on the MWD was very small when dune samples were treated in their dry state. The small variation in the MWD during these cycles is likely due to the existence of some moisture content within the mixtures. The action of frost on the water-stable aggregates took place whenever the dune samples were previously moistened. This action tends to destroy the nonerodible water-stable aggregates greater than 0.84 mm into smaller erodible aggregates less than 0.42 mm and consequently, as shown in Fig.4, the MWD begins to decrease with the repeated cycles of freezing and thawing. This decrease is continued with increasing the water content from 2% to 4%. Fig. 4 reveals also that the effect of cyclic freezing and thawing on the MWD varies directly with the mixture's viscosity, by the progression of mixture No.2, and inversely with mixture's temperature.

4.4 Effect of mixture's temperature

Figure (5) shows the effect of dry sample with mixtures No.1 and No.2 using under repeated sieving test. It can be seen that the behavior of treated samples at both temperatures are the same except that the (N) ratios of Mix.2 are higher than Mix.2. Rising up the (N) ratio under repeated sieving were due to low viscosity of Mix.2 compared to Mix.1 that made it more capable of penetrating the dry sand and forming greater percent of nonerodible aggregates. Similar results were noticed by Fadhil (2002).

Chepil (1955) stated that the finer the spray and the more dilute the solution or suspension, the more uniform and stable was the film. The depth of penetrating and stability of the film increased with the increase in dilution. On the other hand the dilution would have been unnecessary if the asphalt material had been heated.



Figure 5. Effect of mixture's temperature on the dry aggregates greater than 0.84 mm for W.C= 0% and M= 4 $1/m^2$.

4.5 Effect of water content

Dry samples were moistened before treatment to determine the effect of water content on the stability of aggregates against breakdown by sieving. Figure (6) shows the effect of water content on the (N) ratios when the samples treated with mixtures No.1 and No.2 at the same mulching rate. It is obvious that the prewetting process causes a considerable increase in (N) ratio during the repeated sieving.

These results are in good agreement with Gabriels and De Boot (1976) who stated that as the water drop with a chemical micelle (as bitumen) hits the water film around the particles, the equilibrium of moisture distribution is disturbed. The capillary suction due to the meniscus tends to decrease the thickness of the water film and hence there is a migration of water with micelles from the water film towards the meniscus. The result is an accumulation of soil conditioner under the meniscus

at the points of contact between the particles. After drying of the soil, the meniscus water evaporates and the sticky soil conditioner binds the particles together.



Figure 6. Effect of water content on the (N) ratio of samples treated with mixtures at: a) $T = M = 4 l/m^2 \& 50^{\circ} C$, b) $M = 4 l/m^2 \& T = 70^{\circ} C$

5. Conclusions

The mixtures of petroleum residues used in this study are found to be effective in increasing aggregates resistance against erosion. The treated samples shows good stability against breakdown under repeated sieving and the effect of cyclic freezing and thawing on the water-stable aggregates.

The results of repeated sieving test indicate that the petroleum mixtures succeeded in creating a stable crust, preventing the sand dunes from erosion. The larger percentages of dry aggregates are lying within the nonerodible fraction greater than 0.84 mm the smaller percentages passed the 0.42 mm mesh to lie within the erodible fraction during subsequent repeated sieving.

The treated sample showed a good stability against the disintegrating forces of water. The mixtures are sufficient to increase the water-stable aggregates greater than 0.84 mm and decrease the water-stable aggregates less than 0.42 mm which leads to decrease soil erosion.

Frost action tends to breakdown the large aggregates into smaller erodible aggregates and changes the fine particles into intermediate erodible aggregates. These petroleum residues succeeded, to a great extent, in reducing the highly erodible fraction of water-stable aggregates less than 0.42 mm which are formed under frost action depending on the reasonable high values of the MWD and its little decrements during cyclic freezing and thawing.

Temperature of petroleum residues played an important role during the stabilization process. Rising up the temperature reduces the mixture's viscosity and made it flow easily and rapidly within the dune particles forming larger amounts of nonerodible aggregates.

Besides temperature, water content for the dune samples has a profound influence on the stability of aggregates. Prewetting process leads the mixture micelles to migrate deeply under the dune surface, sticking the particles after drying.

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