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Wind erosion control of soils using polymeric materials

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Abstract

Wind erosion of soils is one of the most important problems in environment and agriculture which could affects several fields. Agricultural lands, water reservoires, irrigation canals, drains and etc. may be affected by wind erosion and suspended particles. As a result wind erosion control needs attention in arid and semi-arid regions. In recent years, some polymeric materials have been used for improvement of structural stability, increasing aggregate stability and soil stabilization, though kind of polymer, quantity of polymer, field efficiency and durability and environmental impacts are some important parameters which should be taken into consideration. In this study, a Polyvinil Acetate-based polymer was used to treat different soils. Then polymer-added soil samples were investigated experimentally in a wind tunnel to verify the effecte of polymer on wind erosion control of the soils and the results were compared with water treated soil samples. The results of wind tunnel experiments with a maximum 26 m/s wind velocity showed that there was a significat difference between the erosion of polymer treated and water treated soil samples. Application of 25g/m^2 polymer to Aeolian sands reduced the erosion of Aeolian sands samples to zero related to water treated samples. For silty and calyey soils treated by polymer, the wind erosion reduced minimum 90% in relation to water treated samples.

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Introduction

Wind erosion is one of the main factors in soil and environment degradations, air pollution, suspended particles transports, etc. So there must be many studies to get a better understanding of the process of this phenomenon (Refahi, 2004). On the other hand, with regard to climate changes, wind erosion is one of the important issues in arid and semiarid areas. Wind erosion damages depend on wind characteristics such as velocity and duration of the wind as well as the amounts and types of transported particles and also surface layer properties. Wind erosion causes many damages to agricultural productions, buildings and structures (Lian-You et al., 2003). There are different methods to control wind erosion; biological methods (using plants as windbreak), mechanical methods (trench excavation and building windbreak), and surface layer reinforcement using soil stabilizers such as petroleum mulches and polymeric materials. Applications of mechanical and biological combinations are better especially to reduce the execution time and costs of the surface stabilization.

One of the common methods in dust control is water sprinkling on soil surface which prevents dust production and wind erosion and it can be also very expensive depending on climate condition, site position and labor wage (Hoover, 1987). Some methods as petroleum mulch and artificial polymers application have

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been considered to increase soil and aggregates stability in order to control of wind erosion and soil stabilization. Many factors such as defining effective polymer in wind erosion control, resistance to erosive factors, effeciency in water erosion control, optimum concentration, durability in natural condition (low and high temperatures, UV rays, chemical solutions and etc.) must be considered in selection of a polymer as soil stabilizer. Application of these types of materials is under development due to its numerous advantages.

Many attempts in laboratories and fields have been done to find the simple index of soil erosivity against wind and water. Investigation of wind erosion by wind tunnel showed that soil erosion depends on dry aggregates size distribution (Chepil and Milne, 1941). Other studies also revealed that aggregates' stability is one of the main factors in erosion control. Bryan (1968) represented the aggregate's stability in water as the best index. However, soil resistance to erosion depends on dry aggregates' stability. Soil moisture percentage also is one of the effective factors to wind erosion, so wet soils are more resistant than dry ones. Chepil and Woodruff (1963) by investigating different soils, listed their mechanical consistency from the high to the low: water stable aggregates, secondary aggregates, surface layer and small particles between secondary aggregates. As water stable aggregates are smaller than 1 mm in diameter, only the other particles can provide a stable surface layer. However, the stability of aggregate with diameter less than 1 mm is also important as they could be eroded and source of suspended soil (Hagen and Lyles, 1985). Estimations of region soil losses are assessed by experimental methods such as I.R.I.F.R or similar methods (based on effective factors in wind erosion) or indirect measuring by Wind Erosion Meter with analyzing of regional analysis of wind duration and velocity (Ekhtesasi and Ahmadi, 1996).

Application of chemical polymers to control of wind erosion and to increase water holding capacity of soil is one of the other methods in dust and erosion control which depends on polymer characteristics. Moore and Siddiqi (1981) investigated water and wind erosion of sandy soils which revealed that Butadiene-Styrene has good performance in wind and water erosion control and treated soil permeability is not significantly different. Wellace et al. (1986) showed that contrary to anionic polymer, cationic polymer has better aggregation in calcic soil rather than acidic one. These results show that salts make the clay particle close to each other, so some of them can adhere together by one poly anion. Telyscheva and Shulga (1995) revealed that application of water solution polymer (Si-Ad) which contains 0.5-0.8 % silicone with application doses of 375 gr/m^2, causes the sand particle adheres and makes one 4-14 mm layer with 0.49-2.9 MPa penetration resistance. So polymeric materials reduced the evaporation from soil surface and wind erosion (wind erosion is less than 0.09-0.11 kg/m^2) and it didn't affect the germination and seed growth. Kennth and Nwankwo (2001) represented that polymer effects on soil appears with large aggregates formations by adhering the smaller ones. The study about application of 30-50 gr Acetate polymers on fly ash showed that it makes a protective layer to 20m/s wind velocity and it stays stable for 6-8 months (Hadjiv and Hadjiv, 2003). Research about poly Acryl Amid also revealed that 4 gr/m^2 application of this material increases the soil resistance to wind erosion (He et al. 2008). Therefore, application of polymers for increasing of soil particles diameter and agregates is one of the control methode to prevent surface layer erosion. But in polymers applications in wind erosion control some factors must be considered. The aim of this study is experimentally investigation of the efficiency of Poly Vinyl Acetate (PVA) in wind erosion control of different soils.

Material and Methods

First, the appropriate soil samples were provided. To this end and define polymer efficiency in wind erosion control, three types of soil textures including wind-blown sand, silty and heavy clay soils were selected. Clayey and silty soils were provided from Alborz province and wind-blown sand was supplied from Aran and Bidgol and were transported to laboratory. Physical properties of the soils including natural soil moisture, sieve analysis and hydrometery test, Atterberg limits and soil density were determined by standard tests. In this study applied chemical material for soil stabilizing was a chemical co-polymer based on Poly Vinyl Acetate (($C_4H_6O_2$) n) which used as a water emulsion. The emulsion was white in color and had 1.05 g/cm3 specific gravity and concentration of 25 g/lit. The type and rate of applied polymer for wind erosion experiments were defined based on last researches results. Therefore, D_{25} or 25 gr polymeric material in 1 liter of water was used for treatment of the soils. The rate of 25 gr/m^2 of added polymer and water without polymer in 25 gr/m^2 were considered as treatments. To investigate the wind erosion rate, an open-circuit wind tunnel was designed, fabricated and applied (Figure 1). This tunnel was similar to low-speed wind tunnel (Pope and Harper, 1966) designed and constructed by Ekhtesasi (1991). Wind tunnel was fabricated by 2 mm galvanized iron sheets with dimensions of 0.3×0.3×2.25 m and it has four windows. These windows were designed to install anemometer, samples and observation of the wind erosion process (Figure 1). Samples were prepared in 0.02×0.3×0.4 m trays and initialled in the tunnel's floor in centre of tunnel. Also central part of tunnel had a 4 cm metallic frame to allow the installation of the samples. Wind was produced by a fan with 56 cm propeller diameter and 16000 m3/hr air capacity. Fan was set on a platform; tunnel and fan were concentric. A white iron diffuser in 1.8 m length was applied to connect the fan and tunnel.

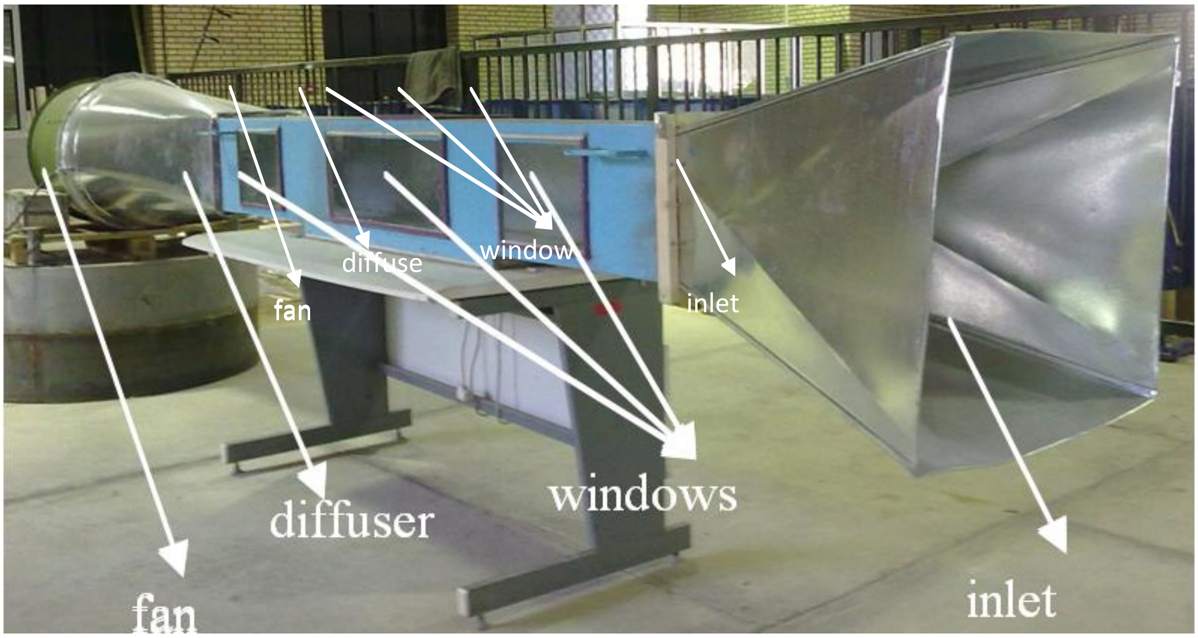

Fig. 1- Fabricated wind tunnel including, inlet, tunnel and windows, diffuser and fan

To facilitate air entrance in the tunnel an inlet was applied by the proportion of inlet to outlet as 4 to 1 (Rathakrishnan, 2007). Wind velocity was measured by two anemometers; propeller velocimeter and hot film anemometer. Logarithmic wind velocity in the center of tunnel was investigated and confirmed. Experimental samples were preapared in 0.3×0.4×0.02 m metallic trays. After filling sieved soil, water or polymer emulsion (25 gr/m^2) was sprayed on the samples by weighted method. So the samples were put on an automatic balance, then the emulsion or water was added up to the defined weight. The samples were put in an air conditioned place to make dry naturally. Then the samples were set in specified place in wind tunnel to investigate the wind erosion. To study the polymeric treatments in wind erosion the maximum velocity in tunnel center (26 m/s) was considered which was more than wind erosion threshold in the region and it was appropriate for investigating polymeric samples. Experiment duration was determined considering maximium wind velocity and size of the samples and was fixed to 5 minutes. After this time, the samples were weighted again and compared with its primary weights to find out wind erosion rate. Treatments comprising three soil different soils (wind-blown, silty and clayey soils), two types of materials; water (D_0) and polymer emulsion with 25 gr concentration (D_{25}) were selected. So, three types of soils with two materials in three replications or 18 samples were considered. Table 1 shows the treatment's characteristics.

Table 1- Treatment properties

Soil type	Experiment	Tretment	
Sand	Wind (26 m/s)	by water	D_0
	Wind (26 m/s)	Polymeric	D_{25}
Silty	Wind (26 m/s)	by water	D_0
	Wind (26 m/s)	Polymeric	D_{25}
Clayey	Wind (26 m/s)	by water	D_0
	Wind (26 m/s)	Polymeric	D_{25}

D_0: 1 lit/m^2 water added to soil
D_{25}: 1 lit/m^2 polymeric emulsion added to soil

Results and Discussion

Soil texture, compaction characteristics and Atterberg limits were presented in Table 2. Wind-Blown sand, silty and clayey soils were classified based on USDA as sand, silty loam and clay silty loam, respectively (Table 2).

Table 2. Physical properties of soils

Sample	Soil texture (%)			Compaction (Standard Proctor test)		Atterberg limits		Unified Classification
	Clay	Silt	Sand	Optimum water content (%)	Maximum dry density (g/cm^3)	LL (%)	PL (%)	
Sand-blown	0	0.4	99.6	12.5	1.73	NP[1]	NP[1]	SP[2]
Silty loam	15	75	10	19.5	1.58	38	28	ML[3]
Silty Clay Loam	30	65	5	21	1.60	42	28	CL[4]

1: Non-Plastic; 2: Poorly graded Sand; 3: Low plasticity Silt; 4: Low plasticity Clay

The volumetric water content of wind-blown sand, silty and clayey soils were 0.65, 3.38 and 4.06% respectively which shows that soil moistures are very low. Atterberg limits; i.e. Liquid Limit (LL), Plastic Limit (PL) and Shrinkage Limit (SL) of samples were determined based on Unified System. Based on Table 2 the sand sample (wind-blown) is completely non-plastic (NP) with uniform particle size and two other soils are a little plastic (liquid limit is less than 50). To identify the soils compaction characteristics (optimum water content and maximum dry density) were determined by Proctor method. Investigation of the samples before putting in tunnel showed that surface layers in both water and polymer treatment samples of silty loam and silty clay loam soils included multiple cracks. Meanwhile in sandy soil, an integrated surface layer without any cracks was established. Studying wind velocity profile in wind tunnel center shows the maximum velocity (26 m/s) in tunnel center (Fig. 2). In addition, Fig. 2 represents the high-speed velocity gradient in tunnel bed. The wind velocity difference between the beginning and the end of tunnel was less than 5%. Table 3. Represents the results of wind erosion of different soils.

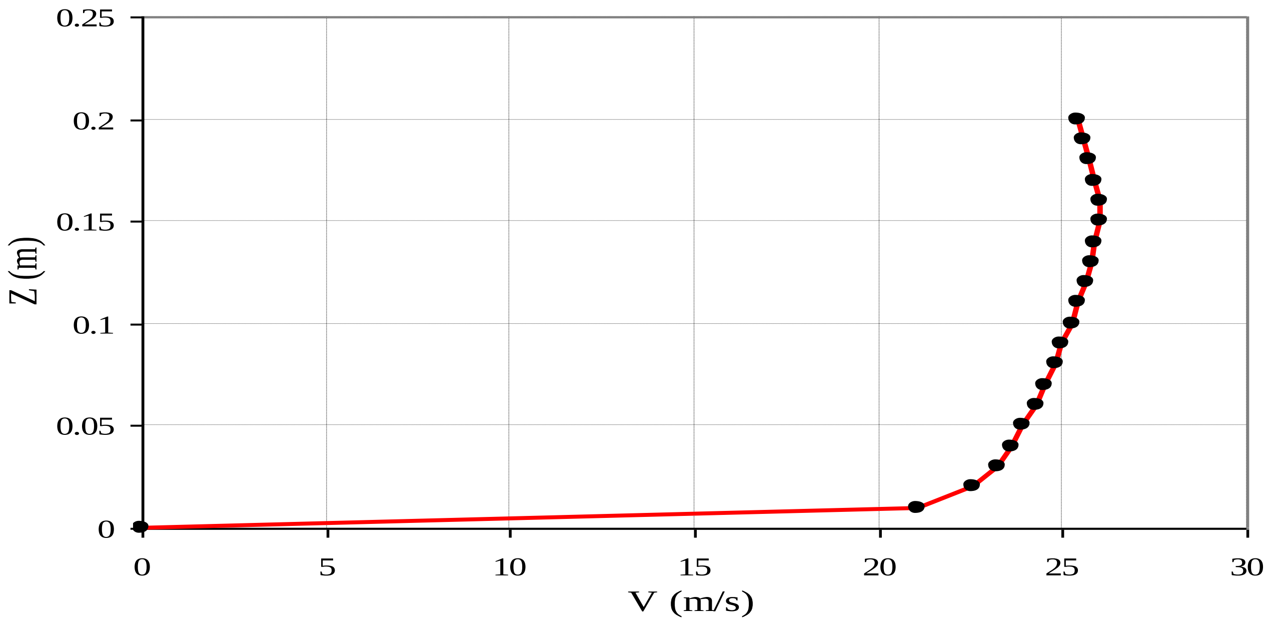

Fig. 2- Wind velocity distribution in centre line of wind tunnel
(Z and V are distance from the bed and wind velocity, respectively)

Table 3- Soil losses of samples by wind velocity of 26 m/s

Test No.	Soil	Treatment	Mean erosion[1] (gr)	Mean erosion ($kg/m^2/hr$)	Mean erosion ($kg/m^2/hr$)		
					Soils	D_0	D_{25}
1	Sand-blown	D_0	2126	212.6	106.3	55.2	0.2
2		D_{25}	0	0			
3	Silty loam	D_0	35	3.5	1.95		
4		D_{25}	4	0.4			
5	Silty clay loam	D_0	23	2.3	1.25		
6		D_{25}	2	0.2			

1: Mean of three replications

The effect of polymer on wind erosion was statistically analyzed by completely randomized block as factorial experiment design using SPSS ver. 16 (Table 4).

Table 4- Results of variance analysis of effects of soil and stabilizer on wind erosion

Sources of variation	Degree of Freedom	Mean square of soil erosion
Replication	2	220.5^{ns}
Soil	2	21924.8^{**}
Stabilizer	1	23718.4^{**}
Soil X Stabilizer	2	22050.4^{**}
Total error	10	196.4
Total mean ($kg/m^2/hr$)	17	36.5
Coefficient of Variation (%)		38.4

**: significant at a significance level of 1 % (0.01)   ns Non-significance

Considered factors were stabilizer (in two levels; D_0 and D_{25}), types of soil (in three levels; wind-blown sand, silty loam, and silty clayey loam) and in three replications (Table 4). The statistical analysis (Table 4) reveals that there is no significant difference between all replications at a significance level of 0.01 or with a probability level of 99%. But there is significant difference between soil erosion of treatments containing different levels of polymer and soil types. Also, the table shows that various parameters; i.e. soil type and kind of stabilizer, affect the erosion, significantly, meanwhile there exist interactions between these parameters. Assessment of the effect of polymer application on soil erosion control of soils by mean values comparison using Duncan method showed that there is no significant difference between wind erosion of silty loam and silty clayey loam (with 1.95 and 1.25 $kg/m^2/hr$ soil losses, respectively; Table 3). But there is significant difference between these soils and sand-blown sand (with 103.6 $kg/m^2/hr$ soil loss; Table 3). Table 3 shows also that the erosivity of polymer treated samples is less than water treated samples (0.2 and 55.2 $kg/m^2/hr$, respectively). On the other hand, wind erosion averages in different soils (using Duncan method) are different significantly. Based on Table 3, clayey soil with 1.25 $kg/m^2/hr$ and wind-blown sand with 106.3 $kg/m^2/hr$ are the lowest and highest erosion respectively. Silty soil erosion is limited to 1.95 $kg/m^2/hr$. As in Table 3, wind erosion of wind-blown sand treated by polymer is zero. In addition, wind erosion of polymer treated silty soil is 90% less than water treatment silty soil and in clayey soil this reduction is 91%. Therefore, wind erosion rates in polymer treatment soil is reduced more than 90% which proves the polymer efficiency in wind erosion control.

In fact, added polymer chains produce a layer on the soil surface that contains the aggregates and particles. Although the surface layer's nature is different in soils but polymer material increases the soil resistance to wind, by producing this thin layer. The surface layer of polymeric samples of sandy soil, is completely homogenous, relatively hard and without any crack after drying. Surface layer in silty loam and silty clayey loam treated by polymer, includes also a layer but with cracks. The crack patterns in water and polymer treated samples are not different. However, polymer emulsion is efficient in erosion reduction of these soils (Table 3). Therefore, the surface layer in wind-blown sand treated by polymer is sufficiently resistant against wind erosion and is different from water treated samples. The surface layer of polymeric samples in silty and clayey soils includes random cracks with lower efficiency against wind erosion.

Conclusion

In order to study of the effect of Poly Vinyl Acetate based polymer emulsion on resistance to wind erosion, three types of soils were treated by polymer emulsion in three replications. Wind-tunnel was designed and fabricated for experiments. The results showed that 25 gr/m^2 of this polymer (added as water emulsion of 25 gr/lit) by forming a resistant layer on soil surface, which is completely different from water layer formation, controls the wind erosion against 26 m/s wind velocity. Based on results, polymer erosion rate in 26 m/s velocity is very low. Polymer treatment erosion is reduced at least 90% in comparison to water treatment and it represents the polymer emulsion efficiency in wind erosion control. In fact the mechanisms of erosion control by polymer are increasing dry aggregates stability and their connections and creating a surface layer which is resistant to erosion. To optimize performance condition it is recommended to determine the optimum polymer in natural condition, considering important parameters such as temperature, humidity, durability, wind velocity, vegetation and etc.

References

Bryan, R.B., 1968, The development, use and efficiency of indices of soil erodibility, *Geoderma* 2, 5-26.

Chepil, W.S., Woodruff, N.P. 1963. The physics of wind erosion and its control. *Advances in Agronomy* 15, 211-302.

Ekhtessasi, M.R., 1991. Design and fabrication of wind erosion meter. Iranian Res. Organization for Sci. and Tech. Report, 15p. (In Persian)

Ekhtesasi, M.R., Ahmdi, H., 1996. Introducing of new methods for wind erosion estimation: IRTIFR and indirect measurement using Wind Erosion Meter and regional analysis of wind velocity and duration. 2nd National Conference on Desertification and Desertification Control Methods, 23-24 Aug., Kerman, Iran.

Hadjiev, A., Hadjiev, P. ,2003. On some methods for surface erosion control on tailings ponds and waste fly-ash piles. 50 years Uni. of Mining and Geology “St. Ivan Rilski”, Annual, vol. 46, part 22, Mining and Mineral Processing, Sofia.185-187.

Hagen, L.J., Lyles, L., 1985. Amount and nutrient content of particles produced by soil aggregate abrasion. In: Proc. of the National Symposium on Erosion and Soil Productivity 8-(85): 1 17- 129.

He, J.J., Cai, O.G., Tang, Z.J., 2008. Wind tunnel experimental study on the effect of PAM on soil wind erosion control, *Environmental Monitoring and Assessment* 145, 185–193.

Hoover, J.M., 1987. Dust control on construction sites, Arizona Department of Transportation, Report No. FHWA-AZ,86-807. 65p.

Kenneth, N., Nwankwo, P.E., 2001. Polyacrylamide as a soil stabilizer for erosion control. Wisconsin department of transportation. Report No. W1, 06-98.

Lian-You, L., Shang-Yu G., Pei- Jun S., Xiao-Yan L., and Zhi-Bao, D., 2003. Wind tunnel measurements of adobe abrasion by blown sand: profile characteristics in relation to wind velocity and sand flux, J*ournal of Arid Environments* 53(3), 351-363.

Pope, A., Harper, J, J., 1966. Low speed wind tunnel testing, John Wiley & Sons, New York.

Rathakrishnan, E., 2007. Measurement, instrumentation, and experiments in fluids. CRC Press. 492p.

Refahi, H., 2004, Wind erosion and its control. Tehran University, Iran, 320p.

Siddiqi, R.A., Moore, J.C., 1981, Polymer stabilization of sandy soils for erosion control, Transportation Research Record No. 827, General Soils Problems. 30-34.

SPSS, Release 16.0, SPSS Inc., Chicago, Illinois, USA.

Telysheva, G., Shulga, G., 1995. Silicon-containing polycomplexes for protection against wind erosion of sandy soil. Journal of Agricultural Engineering Research, 62(4), 221-227.

Wallace, A., Wallace, G.A., Abouzamzam, A.M., 1986. Amelioration of sodic soils with polymers . Soil Science Society America Journal 141, 359-362