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LIGNIN-BASED DUST SUPPRESSANT AND ITS EFFECT ON THE PROPERTIES OF LIGHT SOIL

Galia Shulga[1], Talrits Betkers[2]

[1]*Latvian State Institute of Wood Chemistry, 27 Dzerbenes St, LV-1006 Riga, Latvia. E-mail: shulga@junik.lv*
[2]*Riga Technical University, 22 Azenes St, LV 1048 Riga, Latvia. E-mail: betkers@rtu.lv*

Abstract. Road dust negatively impacts the environment. For diminishing this effect, chemical suppressants are often used. Among the known suppressants, the lignin-based ones are of great scientific and practical interest, because they are low-cost, environmentally friendly and biodegradable products. In this work, a lignin-based binder, representing an interpolymer complex, in the liquid concentrated form was developed for structuring and gluing the surface of light-textured soil. The study of the mechanical properties, water and wind resistance of the created soil structure and soil glued layers as well as changing these properties as a result of the action of the climatic conditions in a climatic chamber demonstrated the effectiveness of the developed binder as a dust suppressant. The technological method of the binder application does not require any special machinery, because its water solutions at the applied concentrations are not viscous, and are easy to apply to the soil surface.

Keywords: dust suppressant, polyelectrolyte complex, lignin-based binder, penetration resistance, soil aggregates, soil glued layers, wind resistance.

1. Introduction

Road dust negatively impacts the environment. Forest roads are a major contributor to dust production from forested lands. It is known that dust particles less than 1 mm in size are considered a health hazard. To prevent the erosion of unpaved forest roads, to prolong their maintenance and to diminish the negative impact on the environment, control of soil losses is required. The use of the principles of structural mechanics makes it possible to improve the physico-mechanical properties of the soil surface, to protect it against erosion, to reinforce the ground and to prevent soil blowing off. One of the rational solutions based on the structural mechanics approaches for soil properties regulation is the application of gluing substances affecting the inter-particle interactions in soil. It is a known application of dust suppressing chemicals for this purpose (Sanders *et al.* 1997; Sanders and Addo 2000; Woods 1960). The mechanism of dust suppression involves aggregation, binding, increasing soil surface cohesion and density, hydroscopic action and surface stabilization (Ingles and Metcalf 1992). The use of dust suppressants has big benefits, because it allows an effective control of the dust amount at a relatively low cost. Chemical suppressants may have organic and inorganic nature, but the most popular and widespread ones are chloride salts, synthetic adhesives and lignin derivatives. In today's market, many of synthetic suppressants are expensive and have major complications in application. Among the known suppressants, the lignin-based chemicals such as DC-22, DUSTEX, DUSTAC, CALBINDER, POLYBINDER, RB ULTRA PLUS, etc. are of great scientific and practical interest, because they are environmentally friendly and biodegradable products due to lignin, which is a natural wood polymer. During wood sulphite pulping, lignin is sulphonated and releases in the cooking liquid in the form of lignosulphonates (LS). LS are a wide scale low cost commercial technical lignin.

The aim of the work was to study the effect of the composition of the developed lignin-based binder on soil aggregation and the formation of upper glued soil layers as well as on the water and wind resistance of the formed soil aggregates and reinforced surface layers.

2. Experimental

Objects

A water concentrate of sodium LS, a by-product of wood delignification, was used to create a lignin-based dust suppressant (LDS) in the form of a polyelectrolyte complex with different composition via the chemical modification of LS with an eco-friendly water-soluble acrylic polymer with the molecular mass equal to $1.88 \cdot 10^5$ in water medium under defined conditions. The composition (Z) of the lignin-based interpolymer complex varied from 0.02 to 1.00, where Z corresponded to the modifier/lignin mass ratio. The LDS batches, obtained under laboratory conditions, represented homogenous liquids with a dark brown colour and without a specific odour. The characteristics of the laboratory batches of LDS are given in Table 1. Their values of dynamic viscosity were determined by Hoppler viscometry.

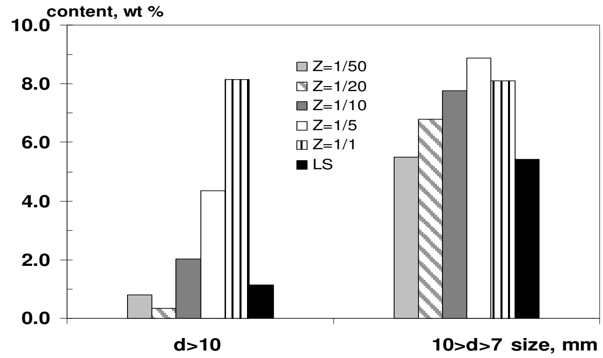
Table 1. The characteristics of the laboratory batches of the lignin-based binder

Z	Dry substances, %	Content of lignin, %	pH of 20% solution	Maximal Newton viscosity, mPa s
LS	50.3	100	4.25	25
0.02	49.5	97.9	3.90	45
0.05	48.7	94.8	3.75	98
0.1	47.5	90.2	3.70	450
0.2	45.6	81.5	3.49	1620
1.0	38.3	51.4	3.25	14590

The artificial aggregates (> 0.25 mm) were obtained by mixing the soil and LDS dilute water solutions. The fractional composition and water resistance of the structured soil were determined by dry and wet sieving, respectively (Plusnin and Vernikovskaya 1974). The structuring coefficients K_1 and K_2 were found as the mass ratios of the sum of artificial aggregates > 0.25 mm to the initial sandy soil (K_1) and of the sum of aggregates > 3.0 mm to the sum of all aggregates formed in the structured soil after the treatment (K_2). Water resistance (WR) was characterized by the content of the soil aggregates > 0.25 mm (wt %) in the structured soil after its wet sieving. For obtaining a glued soil surface layer, the slightly moistened sandy soil was placed into aluminium containers and treated by spraying the water solutions of LDS with a defined concentration of 50-200 g l^{-1} at an application rate of 1.0-2.5 l m^{-2} at its surface. The treated soil samples were dried at room temperature. The penetration resistance and thickness of the glued soil layers were measured using a manual laboratory coner penetrometer (angle 30 ^{o}) of original construction and a calliper square, described in detail earlier (Shulga *et al.* 2001). For the wetting-drying testing, the soil aggregates and glued layers were moistened with distilled water until a saturated state, and then dried at room temperature. The time for one wetting-drying cycle was 72 h. The amount of the applied cycles varied from 1 to 7. The wind stability of the soil aggregates and glued soil layers was tested, using a wind tunnel of original construction at a wind velocity of 5-25 m s^{-1}. The climatic conditions (temperature, moisture, day and UV radiation) were simulated using a climatic chamber "Binder".

3. Results

The artificial soil aggregates were obtained by structuring sandy soil particles (< 0.25 mm) with the water solutions of LDS with a concentration of 5-20 wt %. The content of LDS in soil varied from 0.5 to 3.0 wt %. According to Fig. 1, the obtained soil samples are different in terms of the content of large and small aggregates, depending on Z. With growing LDS composition, the content of large soil aggregates increases, reaching 12.8 wt % and 16.2 wt % for Z = 0.2 and 1, respectively, but the amount of the small soil particles remarkably decreases. At all the applied LDS rates, the increase in Z causes the enhancement of the values of K_1 and K_2 (Fig. 2).



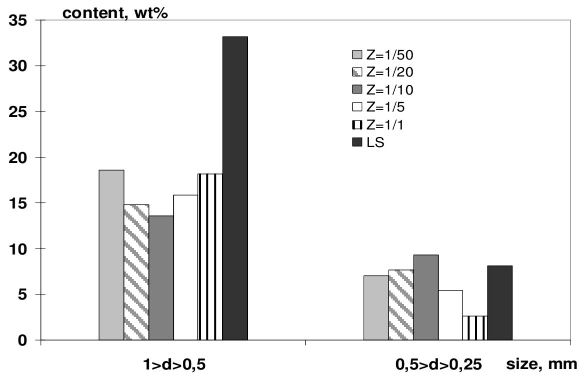


Fig 1. Amount of large and small soil aggregates depending on LDS composition; content - 1.5 %

The different character of the dependence of the structuring coefficients on the composition of the soil binder should be noted. The K_1 values linearly increase with the growth in the composition of LDS, which may reflect the growth in the flocculating ability of the lignin-based polyelectrolyte complex with increasing content of the polymer modifier.

Table 2. Effective content of LDS and water resistance of the aggregates (< 0.25 mm)

Z	0.02	0.05	0.1	0.2	1.0	LS
$C_{eff,}$ %	2.0	1.9	1.7	1.1	0.75	2.2
WR, %	25	29	50	72	21	0

Fig. 2 shows that the pronounced change in the K_1 value is observed with increasing Z from 0.1 to 0.2. It has been noted that the more is the LDS composition, i.e. the higher is the maximum Newtonian viscosity, the less is the content of the binder in sandy soil, which may be called as the effective content (C_{eff}), required for the transition of soil from the unstructured state to the fully structured one (Table 2). At the same time, the dependence of K_2 on the composition of LDS has an extreme character with the maximum at Z = 0.2 (Fig. 2). The obtained result may be explained from the viewpoint of the complex mechanism of soil particles aggregation under the action of water solutions of polymers, combining simultaneously the flocculation of soil particles and the stabilization of the formed aggregates (La Mer and Healy 1963) according to the coagulation-condensation mechanism of the soil structure formation.

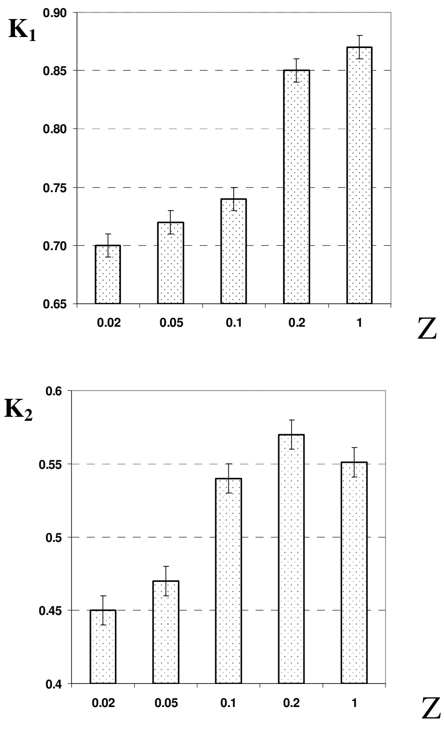


Fig 2. Dependence of K_1 and K_2 on LDS composition at its effective content in soil

It has been found that the artificial soil aggregates formed by the separated application of the solutions of the initial lignosulphonate and acrylic polymer are fully disaggregated under the action of water. At the same time, the maximal value of water resistance of the formed soil structure close to 70% (aggregates > 0.25 mm) is observed at Z = 0.2 (Table 2), which is the stoichiometric composition for the lignin-based polyelectrolyte complex (Shulga *et al*. 2005).

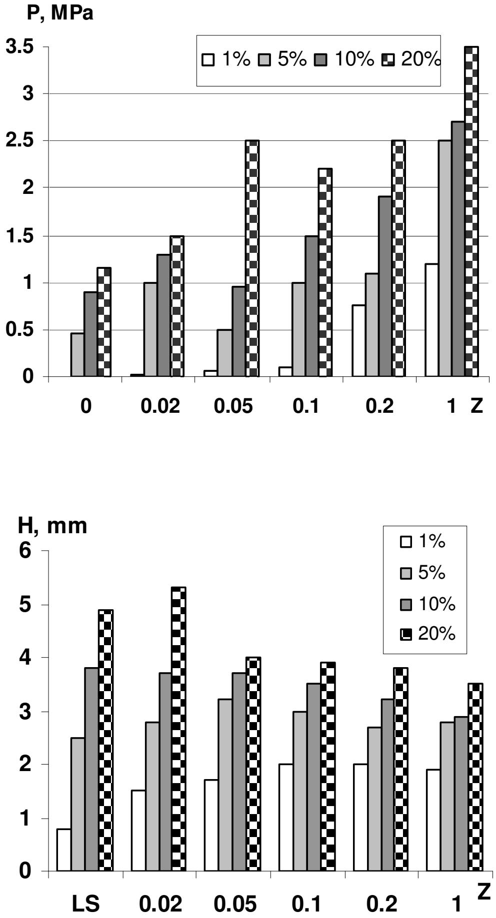


Fig 3. Dependence of the penetration resistance and thickness of the glued soil layers on the LDS composition at different concentrations of its water solutions

The penetration resistance (P) and thickness (H) of the upper glued sandy layers were measured using a manual laboratory coner penetrometer and a calliper square, respectively. According to our findings, the penetration resistance and thickness of the glued sandy layers formed depend on the concentration of the applied water solutions, their application rate and the LDS composition. The penetration resistance and thickness of the formed glued soil layers increase from 0.05 to 3.50 MPa and from 0.5 to 6.1 mm, respectively, with increasing application rate of the LSC solutions from 1.0 to 2.5 l m^{-2}, the concentration from 10 to 200 g l^{-1} and Z from 0.02 to 0.2. Figure 3 demonstrates the dependences of the penetration strength and thickness of the glued soil layers for different concentrations of the applied solutions on Z at an application rate of 1.5 l m^{-2}. With increasing LDS composition from 0.05 to 1.00 and its solution concentration from 50 g l^{-1} to 200 g l^{-1} at the same application rate, the penetration strength of the layers increases 1.8-2.5 times. The observed gain in the mechanical properties may confirm the increase of the LDS flocculation ability relative to the soil particles as a result of the enhancement of the molecular weight of the polyelectrolyte complex. This may be testified by an increase in the maximum dynamic viscosity of the concentrated solutions of LDS with an increase in Z (Table 1). At the same time, the thickness of the glued sandy layers tends to decrease with growing Z and the concentration of the applied solutions. The higher values of thickness for the glued soil layers are provided by the application of the solutions with Z = 0.02-0.05, having lower values of dynamic viscosity (Fig. 3).

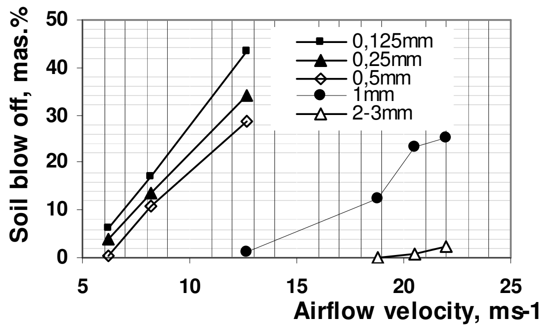


Fig 4. Dependence of soil loss on airflow velocity in a wind tunnel for soil aggregates of different sizes

The soil loss from the structured soil surface as a result of the action of the airflow in the wind tunnel shows its dependence on the sizes of the soil particles and the speed of the airflow (Fig. 5). The aggregates with d ≥ 1 mm start blowing off from the soil surface at a speed of 12-13 ms^{-1}; at the same time, the increase in the sizes of the structured soil aggregates to 2-3 mm leads to the pronounced enhancement of the wind erosion resistance of the soil surface. A crucial value of the airflow speed, at which the fully structured soil surface can be eroded, is 19-20 ms^{-1}.

The quality of the artificial soil aggregates and the reinforced layers was studied under cyclic wetting-drying and testing in a climatic chamber "Binder". The resistance to destruction under these conditions was evaluated by changing the wind resistance of the glued soil layers and the fraction compositions of the structured soil. It has been shown that the action of the wetting-drying cycles decreases both the penetration and wind resistance of the layers, and the content of the large soil aggregates obtained with both LS and LDS, but at a different rate. A decrease in the penetration resistance and the soil loss for a 10% solution of LDS with Z = 0.02 and at an application rate of 1.5 lm^{-2} is 26% and 35%, respectively, after the 7 wetting-drying cycles. For the solution of LDS with Z = 0.2, which is a stoichiometric composition of the polyelectrolyte complex, these alterations are only 10-12%. It has been found that the increase in the content of acrylic polymer more than 19-20% (Z > 0.2) in the polymer complex causes a decrease in the mechanical properties and wind stability of the reinforced soil layers. The layers glued with the unmodified LS water solutions at the same application rate and concentration after the 7 cycles are characterized by essential decrease in the penetration resistance and increase in the soil loss (by 64% and 83%, respectively).

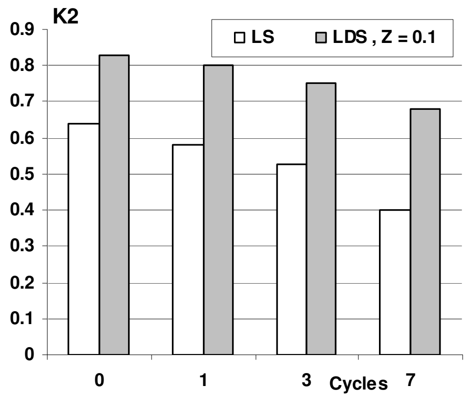


Fig 5. Dependence of K_2 on the number of wetting-drying cycles for soil aggregates structured with LS and LDS solutions; concentration - 10 %; content - 1.0 %

The conducted study has shown that the wetting-drying cycles dramatically reduce the content of large soil aggregates (≥ 3 mm), which are characterized by K_2. After 7 cycles, K_2 values for the soil structured with the LDS solutions decrease by 12-25% depending on Z, the solution concentration and application rate. According to Fig. 5, after 7 wetting-drying cycles, the decrease in the content of large aggregates in the soil sample treated with a 10% solution of LDS with Z = 0.05 at the application rate 1.5 lm^{-2} is 16%. Under the same conditions, the decreasing K_2 for the soil structured with the LS solutions is 40%.

Table 3. Wind resistance of glued soil layers after a 30-day testing in a climatic chamber

Composition	Soil mass loss, kg m^2 h^{-1}	
	Time, days	
	0	30
LS	0.39 - 0.48	erosion
Z = 0.02	0.35 - 0.38	0.41 - 0.44
Z = 0.1	0.25 -0.27	0.28 – 0.32
Z = 0.2	0.23 - 0.25	0.25 – 0.27
Z = 1.0	0.19 - 0. 22	0.30 - 0.35

A climatic testing of the reinforced soil layers was performed in a climatic chamber "Binder" under the following conditions: 85% moisture, 20°C, day radiation - 4000 lx, UV radiation - 1.7 Wm^{-2} in a range of 320-400 nm, during 30 days. Table 3 shows the soil loss as a result of the wind action upon the soil glued surfaces, obtained with 5% solutions of LDS, having different composition, at the application rate 1.5 lm^{-2}, in the climatic chamber. It can be seen that the soil loss values depend on the composition of LDS, vary from 0.25 to 0.44 kg m^{-2} h^{-1} and exceed the wind soil loss of the initial soil samples (before placing them in the chamber) by 8-18%. After testing in the climatic chamber, the samples treated with LDS with the stoichiometric composition (Z = 0.2) are characterized by minimal changes in wind stability. At the same time, the soil surfaces glued only with the LS solutions were destroyed during the exposure to the complex action of moisture and radiation in the chamber, and, therefore, were not wind resistant.

4. Conclusions

The obtained results have shown that the developed binder based on lignosulphonates, a low-cost wide-scale by-product of pulp and paper mills, is able to aggregate unstructured soil and to glue its surface, with the formation of low-dusting reinforced layers. The effectiveness of the impact of the binder on the dusty soil properties non-linearly depends on its composition. Minimal soil loss and disaggregation under laboratory testing are observed for the soil samples treated with the binder having stoichiometric composition. The obtaining of the binder is not complicated and does not require enhanced temperatures and pressures as well as special equipment. This opens up new possibilities for its commercial production and application as a dust suppressant.

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