The article presents the results of experimental study for types of loose soils are easily subject to dusting. In connection with this problem, the task is the study and study of the causes and structure of the formation of dustiness in the roadside zone of roads with common types of coatings or without coatings. The experimental study aims to determine the drying time of chemical dust prevention solutions under the influence of solar radiation and the norm of their distribution.

The object of the research is dust generated on roads with low transport and operational performance (temporary roads in places of road repair work, roads to quarries, etc.), and materials used for dedusting road surfaces.

The problem to be solved is to reduce the emission of a large amount of dust on roads without pavements or with inferior types of pavements, which adversely affects the human body.

The results obtained are the identification of a way to combat dust on road surfaces, ensuring a decrease in wear when vehicles move on roads without pavements.

At the same time, the classification of dust according to their sources of formation is expected at the output result.

Due to their features and characteristics, these results allowed the author to solve this problem - effective ways to combat dust on road surfaces are: treating them with dust-removing materials that reduce wear; maintaining the original evenness; reduction of air pollution; improvement of traffic conditions for cars and the sanitary and hygienic condition of roads near settlements.

For experimental tests, traditional salt solutions of various concentrations (NaCl, $MgCl_2$, $CaCl_2$, $MgCl_2 \cdot 6H_2O$, etc.) and solutions of foreign-made stabilizing additives Durasoil and Soiltac from SOILWORKS were taken

Keywords: hygroscopic materials, dust prevention, dustiness, roadside zone, roads, sources of pollution, dust exposure

UDC 691–405.5: 69.052: 629

DOI: 10.15587/1729-4061.2022.263573

SUBSTANTIATION OF APPLICATION TECHNOLOGY OF HYGROSCOPIC MATERIALS FOR DUST PREVENTION OF ROADS WITH THE LOWEST TYPE OF SURFACES

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Received date 14.06.2022
Accepted date 10.08.2022
Published date 31.08.2022

***How to Cite**: Kiyalbay, S., Sagybekova, A., Kiyalbaev, A., Nauruzbayev, K., Espayeva, G., Bektursunova, G. (2022). Substantiation of application technology of hygroscopic materials for dust prevention of roads with the lowest type of surfaces. Eastern-European Journal of Enterprise Technologies, 4 (6 (118)), 67–77. doi: https://doi.org/10.15587/1729-4061.2022.263573*

1. Introduction

Atmospheric particulate pollutants are the most serious urban air pollution worldwide, as it is possible to see, exceeding the standard of atmospheric particulate matter concentration in many cities has been a very common phenomenon both at home and abroad. In this article, dust generated on roads with low transport and operational performance (inte-village roads, remote settlements, temporary roads in places of road repair work, roads to quarries, etc.) is studied as an object of study.

The relevance of this topic is to address the issues of dust control, which is one of the main sources of air pollution. Such studies are necessary for certain areas where soil conditions, according to their classification (dusty, clayey, etc.), do not allow the construction of roads due to a large filtration coefficient, or high atmospheric air temperature. And also, for remote areas where road construction is impossible (lack of quarries, distance from the settlement, etc.).

The territory of the Republic of Republic of Kazakhstan is characterized by natural processes, which include: the rise in the level of the Caspian Sea, earthquakes, and natural hydrometeorological phenomena. Thus, raising the Caspian Sea level, which began in 1978, continues with an average intensity of 0.14 m per year. So far, the sea level has risen by almost 3 m.

A theoretical study considers the distance of dust distribution in the roadside zone, considering the mechanics of their formation and structural indicators. The experimental substantiation of the technology gives a practical study of the problem of using hygroscopic materials in the dust prevention of roads with the lowest type of coatings.

Dust is one of the varieties of aerosols, i. e., dispersed systems consisting of solid and liquid particles (dispersed phase) suspended in an air (dispersed) medium, namely: an aerosol with solid particles of dispersed origin. Such particles are formed when solids change, such as during the crushing of stone, mechanical processing of metals, wind erosion, and the dynamic impact of a wheel of a moving vehicle on a coating (soil, stone materials, asphalt concrete), etc. In hot, dry weather on unpaved roads, aerosol dust plumes form from the wheel of a moving car (Fig. 1).

a

b

Fig. 1. General view of roads with the lowest type of surfaces: *a* – unpaved roads; *b* – dusty trail

The nature and efficiency of the action of dust when it enters the body depends on its charge. It is known that charged particles stay longer in the lungs than neutral ones. Therefore, the ceteris paribus is more dangerous to the body.

The harmfulness of dust exposure is also associated with solubility, hardness, and the shape of dust particles. In terms of harmfulness, dust can be inert and aggressive. Inert dust (soot, cement dust, etc.) consists of substances that do not have a toxic effect on the human body. Aggressive dust (lead dust, residues of anti-icing materials) has toxic properties. Dust particles are held back by electricity. The chemical composition of the substance determines the magnitude of its charge. Non-metallic dust is positively charged, and metallic dust is negatively charged.

Therefore, the study of solving problems with dust on dirt roads and roads of the lowest category is relevant.

2. Literature review and problem statement

In this study attempts were made for the purpose of the prevention of caking and the reduction of dust formation of ammonium nitrate fertilizer during storage. This was achieved by coating the surface of the granules with urea lignosulfonate mixtures, which renders the surface of the granules hydrophobic. Reduction of dust formation of ammonium nitrate during storage was achieved by coating the surface of the granules with urea-lignosulfonate mixtures, which makes the surface of the granules hydrophobic. This was achieved by coating the surface of the granules with urea lignosulfonate mixtures, which renders the surface of the granules hydrophobic. The best results were obtained: a mixture of urea lignosulfonate containing 80 % solids, a mixing ratio between urea and lignosulfonate not more than 1:2 and a % coverage of not more than 0.3 % [1].

To solve the problem of road dust pollution, an environmental road dust suppressor was developed using monomeric, orthogonal and optimization experiments and based on the dust lifting mechanism. Humectant, hygroscopic agent, coagulant and surfactant, as well as their concentration ranges, were determined in experiments with monomers [2].

According to the performance characterization of the ecological dust suppressant, the ecological and environmentally friendly dust suppressant demonstrates fine moisture absorption and retention performance, good wind and rain erosion resistance, and no toxicity.

Of course, this study has some limitations. The ecological dust suppressor is only applicable to urban road dust, and not to coal dust or other types of dust. Therefore, let's continue to develop eco-road dust suppressants for different types of dust in the future.

The cost of developing dust suppressant will be lower, and the effect of controlling dust on urban road surfaces will be better. Therefore, let's also receive collection of eco-road dust suppressors for various types of dust in the future.

The development cost of the dust suppressor will be lower, the effect of dust control on the urban road surface will be better.

In this study attempts were made for the purpose of the prevention of caking and the reduction of dust formation of ammonium nitrate fertilizer during storage. This was achieved by coating the surface of the granules with urea lignosulfonate mixtures, which renders the surface of the granules hydrophobic. Metal casting industry including is an industry which produce high dust pollution (fly ash). Improvements in the form of ergonomic interventions have been carried out by many companies, but do not guarantee all parameters run well. The total indoor suspended dust (TSP) measurement results are not enough to guarantee healthy working conditions. Additional assessment of workers' inhaled dust is needed to change pollution control and work improvement to ergonomics. The design of this study is Cross Sectional Study. Research subjects numbered 84 people. All samples met the inclusion criteria. Measurement results of Characteristic of research subject, Working Environment Conditions, Exposition of dust inhaled by workers, Total Indoor Suspended Dust of the Company ($p>0.05$). Found critical hours of workers exposed to dust (fly ash), starting from 4 h after working (Department of Process Cement, Department of Black Sand) and 2 h after working for the Department of Loam. Critical hours exposed to dust (fly ash) used as the basis for company management and regulators to take new policies in controlling fly ash pollution and ergonomic interventions. Ergonomic interventions can be carried out by activating the dust collector at critical hours, applying active resting hours at critical hours and conditioning workers to breathe fresh air. The impact of this ergonomic intervention is a decrease in musculoskeletal complaints by 25.27 %, reduction in boredom 25.01 %, and an increase in job satisfaction 38.46 % [3].

This study investigated the mechanical performance in the field of treated and stabilized granular materials used on unpaved roads. The results show an increase in performance, while showing a reduction in the rise of dust into the air. This article proposes a methodology to evaluate the mechanical performance of several stabilization agents and dust suppressants. It also shows results of tests conducted in field conditions to evaluate the influence of the products in terms of bearing capacity and road deterioration. Treated road sections are compared with untreated road sections. The tests took place in two different sites with lighter and heavier traffic. The influence of traffic on the mechanical performance has also been taken into account.

Studies about the performance of stabilization agents and dust suppressants are usually made for a specific context. This article allowed the comparison of stabilization agents and dust suppressants in two different sites.

The results show that polymer emulsion increases bearing capacity of unpaved roads. This type of stabilization agent can thus be used all over the road or only in strategic locations such as beside bridges where the road deterioration is often more important. Also, all the products show potential for dust reduction.

Moreover, heavier traffic increases road deterioration. Finally, the results show that granitic gneiss is a granular material that performs well with polymer emulsion and dust suppressants.

The results from this article were taken into account and are reflected in a guide for the maintenance of unpaved roads that has recently been written. This guide is innovative and allows managers of unpaved road networks to choose effective stabilization agents and dust suppressants depending, among other factors, on the mechanical performance (bearing capacity and road deterioration) of these products [4].

The components were initially selected from moisture agent, coagulation agent and surfactant. The components of dust-suppressant were determined based on the analysis on characteristics and mechanisms of road dust raising in open-pit mines. The components were initially selected from moisture agent, coagulation agent and surfactant. The optimal formulation was determined based on orthogonal test and using the water loss rate as the evaluation index. The performances of moisture releasing and adsorption, wind resistance of optimal formulation in the natural environment were tested. The results show that the formula obtained in experiments provide a good performance of moisture absorption and water retention, and it also had a good dust preventing and controlling performance due to its high surface strength and consolidation under dry conditions. It has good application prospects considering the wide variety of sources for materials and the simple preparation process [5].

Used the Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER) method to monitor different types of roads in Baoding city. A portable online vehicular laser sensor measurement system based on the TRAKER method was used to evaluate the effectiveness of water-sprinkling in controlling urban FRD while the test vehicle was in motion. Vehicle speed is an important factor in the accurate estimation of FRD emissions, so it is necessary to implement parameter localization when using the TRAKER method in different cities. In the speed response test, both T10 and T2.5 increased as a power function of the speed of the vehicle.

The changes inηa and ηPM with time all show a quadratic curve-fitting relationship. According to the measured average value, the ηa (68–100 %) of the three types of roads are over all higher than ηPM (37–70 %). The ηa of the three types of roads ranked: branch road (87 %-100 %) > major arterial (80–83 %)>minor arterial (68–77 %). The order of ηPM was: minor arterial (70 %)>branch road (46–58 %)>major arterial (37–53 %), which may be related to the meteorological conditions (temperature and relative humidity), road conditions (material and smoothness) and traffic volume during the experiment.

According to the prediction of the regression models, the average effective control time (ηa>0) was 62 min on the major and minor arterial roads, and that of the branch roads was much longer than 1 hr. For all three types of roads, the ηPM values resulting from street cleaning diminished completely in 72 min from the end of the sprinkling on average. The time for this to occur is determined to a great extent by the meteorological conditions, in particular wind speed. The results show that water-sprinkling can temporarily remove PM deposited on a road surface and reduce the PM concentration in the road environment, but it cannot fundamentally solve the problem, and the effect lasts for a limited time.

Water-sprinkling can remove PM10 particles from the road surface of the three types of roads (77–100 %) more thoroughly than PM2.5 (68–87 %); and has a better reduction effect on road environment PM10 (53–70 %) than on PM2.5 (37–70 %), which may be due to the fact that water droplets have stronger entrapment and scouring capabilities for large particles than small particles [6].

In this study, concentrations of Cr, Mn, Ni, Cu, Zn, Cd and Pb were determined in road dusts collected from different locations in Dhaka to assess source, contamination status and health risk. Energy-dispersive X-ray fluorescence spectroscopy and energy-dispersive X-ray spectroscopy were used to determine Cr, Mn, Ni, Cu, Zn, Cd and Pb. Among the heavy metals, highest concentrations of Cu, Zn and Pb were found at urban sites-7 (municipal waste dumping) and 8 (medical waste incineration). Highest concentration of Cr followed by Cu and Zn was found at site-5 (Tejgaon, urban). Principal component analysis revealed that anthropogenic activities are the potential sources for Cr, Ni, Cu, Zn and Pb while earth crust for Mn. Pollution index and pollution load index results suggested that all the sites were contaminated and/or degraded by Cr, Cu, Zn and Pb except sites-9 (urban), 10 (sub-urban), 11 (rural) while sites-7 and 8 (urban) were extremely degraded. For non-carcinogenic health risk, hazard quotient values for dermal were higher compared to that of inhalation/ingestion. Though hazard index values were less than 1 at all the sites, these were at least one order of magnitude higher for children group than that of adult group, thus the children group may face more non-carcinogenic health risk at sites-7 and 8. Values of incremental lifetime cancer risk were from 10^{-9} to 10^{-11} showed no carcinogenic health risk by road dusts contaminated with the heavy metals. In this study, concentrations of Cr, Mn, Ni, Cu, Zn, Cd and Pb were determined in road dusts collected from different locations in Dhaka to assess source, contamination status and health risk [7]. The movement of vehicles on roads without pavement or on roads with lower types of pavements, construction and repair work on sections of roads, as well as the production of road construction materials are accompanied by the release of a large amount of dust that adversely affects the human body and mainly on its respiratory organs. Dust adversely affects the human body and sometimes worsens the production environment within the working area, leading to the destruction of the rubbing parts of machine mechanisms and reducing visibility when driving. The degree of impact of dust on the human body depends on its physical and chemical properties, toxicity, dispersion, and concentration. Dust is divided into organic, inorganic, and mixed.

Exhaust and non-exhaust particulate matter (PM) is regarded as the most significant airborne during driving. Among the source of non-exhaust PM, the tire-wear particles (TWP) can be quantified using pyrolysis-gas chromatography/mass spectrometry (Py-GC-MS). TWPs are fragmented by continuous weathering once exposed to the road. Approximately 5 wt % of carbon black (CB) bound in the rubber matrix of TWPs tends to detach from it, and thus some portion of free-bound CB could be co-existed in the road dust. Although there are existing methods for analyzing pure CB and TWPs, only few analysis techniques on the amount of free-bound CB in contaminant samples have been discovered. Herein, let's propose a method for quantifying the total and free-bound CB in road dust using a combination of four analytical tools: a semi-continuous carbon analyzer, element analyzer, thermogravimetric analyzer, and Py-GC-MS. This study is the first attempt in quantifying the concentration of nano-CB derived from TWPs in road dust. The proposed methodology was applied to the samples collected from five open sites, three closed sites, and four types of air conditioner (AC) filters in passenger vehicles. Compared to the samples obtained in open sites, the road dust in the closed sites exhibited 21.5 times higher TWP content (59,747 mg/kg) and 5.1 times higher free-bound CB content (14,632 mg/kg). In addition, unintentional driver respiratory exposure to PM fixed in the vehicle filters was discovered owing to the increase in CB and TWP contents in aged AC filters [8]. The main objective of this article is to propose a methodology to evaluate and to study the mechanical performance of various hygroscopic, organic and synthetic dust suppressants and stabilization agents through field tests. Different road sections were treated for several years and many tests have been conducted. The impact on the mechanical performance of the treated granular material has been studied under field conditions by evaluating the deterioration of the road following the spreading of the product on the road. Field tests were conducted over three years in summers 2007, 2008, and 2009. The deterioration of the road is evaluated in terms of improper cross section, inadequate roadside drainage, corrugations, dust, potholes, ruts, and loose aggregates. To evaluate the influence of stabilization agents on the bearing capacity of the granular material on the road, falling weight deflectometer (FWD) tests have also been performed [9].

As results methods develop and improve and their use on low–grade roads will require updating components and improving the quality of materials, which can lead to an increase in the required parameters. It is necessary to develop the quality and increase the quantity of used laboratory tests with chemical components, which requires time and more extensive research and exploitation of the results of experiments on the roads.

The study determines the level of dust distribution in the urban environment, depending on the daily accumulation of inert materials (estimates) on the tributary part of urban roads. It was found that the spread of dust in the air is significantly affected by the moisture content of the estimate and its fine fractions. The mobility of potentially toxic elements (PTEs) is of paramount concern in urban settings, particularly those who affected by industrial activities. Here, contaminated soils and road dusts of the medium-size, industrialized city of Volos, Central Greece, were subjected to single-step extractions and the modified BCR sequential extraction procedure. This approach will allow for a better understanding of the geochemical phase partitioning of PTEs and associated risks in urban environmental matrices. Based on single extraction procedures, Pb and Zn exhibited the highest remobilization potential. Of the non-residual phases, the reducible was the most important for Pb, and the oxidizable for Cu and Zn in both media. On the other hand, mobility of Ni, Cr, and Fe was low, as inferred by their dominance into the residual fraction. Interestingly, let's found a significant increase of the residual fraction in the road dust samples compared to soils. Carbonate content and organic matter controlled the extractabilities of PTEs in the soil samples. By contrast, for the road dust, magnetic susceptibility exerted the main control on the geochemical partitioning of PTEs. Autors suggest that anthropogenic particles emitted by heavy industries reside in the residual fraction of the SEP, raising concerns about the assessment of this fraction in terms of origin of PTEs and potential environmental risks. Conclusively, the application of sequential extraction procedures should be complemented with source identification of PTEs with the aim to better estimate [10].

Treatment with large amounts of water to protect access roads from dust emissions caused by large trucks has been investigated through many tests. The components of the dust suppressor are determined based on an analysis of the characteristics and mechanisms of raising road dust in quarries. The indicators of moisture release and adsorption, wind resistance of the optimal formulation in the natural environment were tested [11, 12].

Significantly influenced the climatic and soil conditions can make its formation of deposits of natural stone materials, the type of coverage of access roads to quarries, the type of vehicles used in quarries, their traffic conditions, and other factors. The most effective way to combat dust on road surfaces is treating them with dust preventing materials that reduce wear, maintaining the original evenness, reducing air pollution, improving the conditions for the movement of cars, and the sanitary and hygienic conditions of roads in settlements.

All studied materials considered the problem of dust control in various directions as each author researched.

From the analysis of the studies discussed above, it follows that the topic of solving the problem of the occurrence and rise of dust on the roads requires further research.

As results methods develop and improve and their use on low-grade roads will require updating components and improving the quality of materials, which can lead to an increase in the required parameters. It is necessary to develop the quality and increase the quantity of used laboratory tests with chemical components, which requires time and more extensive research and exploitation of the results of experiments on the roads.

3. The aim and objectives of the study

The aim of the study is the purpose of the experimental study is to determine the drying time of chemical dedusting solutions under the influence of solar radiation and their distribution norms.

To achieve this aim, the following objectives are accomplished:

– to develop a method for determining the loss of soil moisture;

– to develop a sequence of technology for dust protection of a section of a road consists of several stages.

4. Materials and methods-

The object of the research is dust generated on roads with low transport and operational performance (temporary roads in places of road repair work, roads to quarries, etc.), and materials used for dedusting road surfaces.

Research subject is to reduce the emission of a large amount of dust on roads without pavements or with inferior types of pavements, which adversely affects the human body.

The main hypothesis of the study. These results of the study make it possible to solve the problem of dust on roads for certain areas where soil conditions do not allow building roads due to the high filtration coefficient and for areas where road construction is impossible (lack of quarries, remoteness from the settlement, etc.), excluding transportation. The destruction of the road surface is excluded as much as possible, since the use of salt solutions of various concentrations contribute to the compaction of surface soil particles. When choosing the right composition and ratio of components, dust may not rise into the atmosphere for up to several months, regardless of the type of soil and atmospheric temperature.

To solve the problem of road dust pollution, an environmental road dust suppressor was developed using monomeric, orthogonal and optimization experiments and based on the dust lifting mechanism. Humectant, hygroscopic agent, coagulant and surfactant, as well as their concentration ranges, were determined in experiments with monomers [10, 13].

The classification nomogram shown in Fig. 2 is a probabilistic-logarithmic grid, on which the boundaries of five dust classification groups are marked with dash-dotted lines [11–13]: I – very coarse dust; II – coarse dust; III – fine dust; IV – medium–dispersed dust; V – very fine dust.

When studying the level of dust content in the urban environment, the following climatological factors were analyzed:

– wind speed at different time intervals;
– average air temperature at different time intervals;
– relative humidity;
– atmosphere pressure.

One of the main factors affecting the concentration of dust in the air is the wind speed at which particles can rise into the air. Calms and weak winds, inversion layers in the atmosphere, and fog increase the concentration of impurities, creating significant atmospheric pollution over individual regions. Moderate and strong winds disperse impurities and carry them over long distances. It should be noted that the concentration of fine dust increases with increasing wind speed.

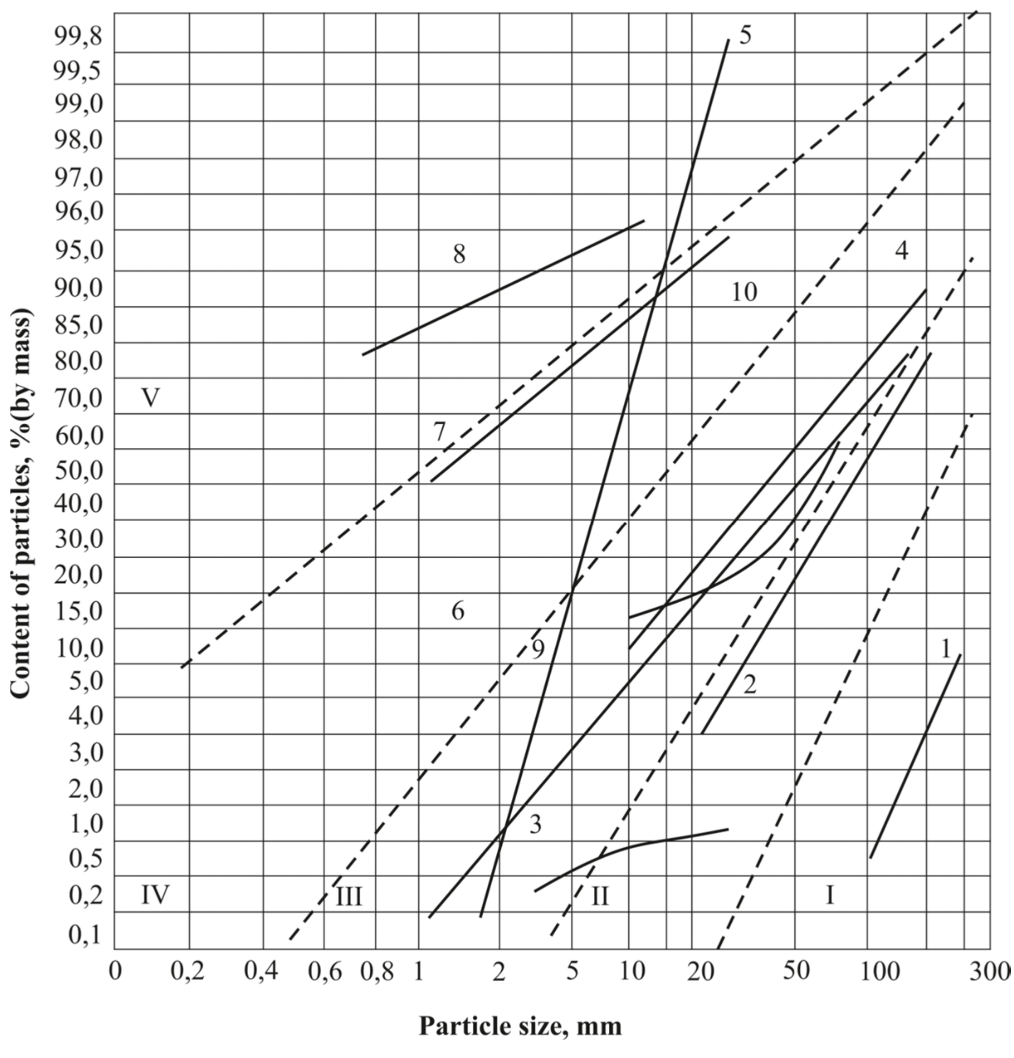

Fig. 2. Classification nomogram of dust according to its dispersion: 1 — coal crushed in a ball mill; 2 — fine quartz sand; 3 — dusty quartz; 4 — cement; 5, 6 — dust arising from laboratory tests; 7 — the smoke of open—hearth furnaces; 8 — atmospheric dust; 9, 10 — standard dust

Thus, the dependence of the concentration of dust and PM10 on the wind speed was obtained (Fig. 3), which are described by equations (1), (2):

$$C=0.2651\ln V_w+0.2236, \quad (1)$$

$$\text{PM10}=0.0999\ln+0.1174, \quad (2)$$

where C is the concentration of dust in the atmospheric air, mg/m^3; PM10 is the concentration of particles less than 10 μm, mg/m^3; V_w – wind speed, m/s.

At the same time, the approximation accuracy is A=0.7051 and A=0.9653 for dust PM10, which indicates a fairly high degree of tightness of the bonds.

The relative humidity of the air has the greatest influence on dust content. It contributes to the coagulation of small particles, their weighting, and subsequent rapid settling. Accordingly, in dry weather, the concentration of dust is higher. The dependence of dust concentration on humidity is described by equations (3), (4). In addition, it should be noted that this dependence is determined by the high closeness of the relationship both for the dust concentration in general and specifically for PM10–A2=0.8056 and 0.6883, respectively.

$$C=-0.0072\ln V_w+0.9812, \quad (3)$$

$$\text{PM10}=-0.0012\ln V_w+0.4532. \quad (4)$$

Air sampling technique. In the first stage, transport and operational indicators were determined (intensity and speed of vehicles, operational indicators of road surfaces, etc.) on the studied section of roads, and the width of the carriageway was measured. Transport and operational parameters were visually assessed.

In the second stage, the causes of air dustiness and factors influencing the level of dustiness were assessed. At this stage, the physical and mechanical properties of the soil, the composition and distribution norms of dust–removing materials, and the temperature and humidity of the air were determined.

In the third stage, field tests are carried out to determine the physical and mechanical properties of the soil and the norm of distribution of dust–removing materials [10, 14].

For one-time air sampling, an electric aspirator model 822 (Fig. 3, *a*) with aerosol analytical filters AFA-VP-40 and AFA-VP-20 and filter holders (Fig. 3, *b*) was used. Table 1 presents the widely used AFA analytical filters.

The electric aspirator is a device consisting of two functional units: an airflow stimulator and a flow meter.

Vacuum cleaners, rotary blowers, and vortex fans are used as airflow drivers, and rotameters and gas meters are used as flow meters.

a *b*

Fig. 3. General view: *a* – electric aspirator model 822; *b* – filters, and filter holders

Table 1

Analytical aerosol filters

Trademark	Technical specifications	Purpose
AFA-B	Made in the shape of circles with pressed edges, cut out of perchlorovinyl filter material (fabric FPP-15). The material is hydrophobic, so the mass of the filters remains constant and does not depend on air humidity. Filters are produced in two types of sizes: AFA-V-10, AFA-V-18	To determine the mass concentration of aerosols
AFA-H	Working surface is 18 cm^2. Four types are produced	For microchemical and radiometric analyzes of the dispersed phase of aerosols
AFA-HA-18	They are made of cellulose acetate hydrophobic filter material (fabric FPA-15), unstable in a chemically aggressive environment, and insoluble in organic solvents	To absorb dust and various aerosols from the air
AFA-HP-18	They are made from perchlorovinyl filter material (fabric FPP-15). By properties, they are close to AFA-V type filters	For sampling aerosols in air analysis
AFA-HC-18	Made of polystyrene hydrophobic filter material resistant to acids and alkalis	For microchemical analysis of aerosols, the dispersed phase is soluble in alkalis

The sample volume (l/min) is defined as the product of the aspiration rate and the sampling time if a rotameter is used as a flow meter in the electric aspirator or as the difference between the initial and final readings (m^3) when using a gas meter. Some models of electric aspirators have built-in time relays, with the help of which the time program for the operation of the device is set. Without a time relay, the countdown is carried out using a stopwatch. Sampling and analysis of atmospheric air in the roadside zone are closely related to the following method for determining the desired impurity. Electroporation devices of various designs are used with sufficient power and provide the necessary pulling speed to draw air through the filter materials. To capture fine dust, various filter materials are used: thick paper (ashless), membrane, fiberglass, etc. When taking air samples in the roadside zone of roads, let's use AFA-VP-40 and AFA-VP-20 analytical filters made of ultra-thin fibrous materials – Petryanov's fabrics. Filters in the form of a disc are placed in a metal or plexiglass cartridge. The speed of drawing air through them is practically unlimited and is determined by the power of the aspiration device (Fig. 3) [13, 15].

Before sampling, the filter must be prepared for operation: bring it to constant weight and weigh it. To reduce the weighing error, the filters are first kept in an open place for 2 hours to equalize their humidity with the humidity of the room where the weighing is performed (Fig. 4). For sampling, the air temperature and humidity are preliminarily measured (glass thermometer and hygroscopic psychrometer):

1. The experimental study aims to determine the drying time of chemical dust prevention solutions under the influence of solar radiation and the norm of their distribution.

2. Method for determining the loss of soil moisture. A sampling of soils with different plastic properties was carried out during diagnostic and other studies conducted by KazADI.

5. Results of research of application of hygroscopic materials for dust prevention of roads

5. 1. Results of develop a method for determining the loss of soil moisture

According to the results of the research, the following results were obtained:

1. Soil samples were divided into 3 groups according to the plasticity number: the first group – sandy, loamy soils, the plasticity number is up to 7; the second group – loamy soils, plasticity number – 7–17; the third group is clay soils, the plasticity number is more than 17. The plastic characteristics of soils were determined following [4, 16, 17].

2. Dust prevention solutions of various concentrations were prepared.

3. Soil samples were pre–moistened using prepared solutions, taking into account the norm of their distribution.

4. Moistened soils, after weighing, were dried in the open air (Fig. 4) at intervals of 30 minutes, the mass of samples was measured, and the time of their drying was recorded.

a

b

Fig. 4. Determination of the drying time of soils conditions: *a* – laboratory; *b* – field

For experimental tests, traditional salt solutions of various concentrations (NaCl, $MgCl_2$, $CaCl_2$, $MgCl_2{\cdot}6H_2O$, etc.) and solutions of foreign-made stabilizing additives Durasoil and Soiltac from SOILWORKS were taken.

The laboratory tests show that the most effective material among traditional dust prevention salt solutions was magnesium chloride with six water molecules (bischofite).

The materials used for dust-preventing road surfaces by impregnation, surface treatment, or mixing are divided into the following groups: water, hygroscopic binders, and various chemical materials.

The effective action of dust preventing hygroscopic binders or materials lasts up to 20 days and more. The most common hygroscopic materials are magnesium chloride (bischofite), calcium chloride, ferric chloride, magnesium perchlorate (anhydrous), kainite, sodium chloride, and potassium chloride. Calcium nitrate-nitrite-chloride and waste from the chemical industry can also be used.

According to the results of the research, the following results were obtained:

1. Soil samples were divided into 3 groups according to the plasticity number: the first group – sandy, loamy soils, the plasticity number is up to 7; the second group – loamy soils, plasticity number – 7–17; the third group is clay soils, the plasticity number is more than 17. The plastic characteristics of soils were determined following [4, 16, 17].

This material was the most effective compared to sodium chloride solutions by 11.8 %, calcium chloride by 22.6 %, and industrial water by 171 %. The ability of soils to retain moisture to a certain extent depends on the plastic characteristics of soils (plasticity number). For example, when pouring a solution of bischofite on the surface of a dirt road at a rate of 2.0 l/m^2, the drying time of the solution reaches 285 minutes; at the same rate, when using sodium chloride, the drying time is already 255 minutes, when using calcium chloride – 232.5 minutes and water – 105 min (Fig. 5). If the filling rate of solutions is doubled, their drying time will be extended by 1.4–1.6 hours.

Compared with sandy, loamy, and clayey soils have a greater water–retaining capacity, depending on the dispersed composition and the plasticity number of the soil. For example, soils with a plasticity number of 20 retain moisture almost 1.5–2 times longer than soils with a plasticity number of 5 (Fig. 6).

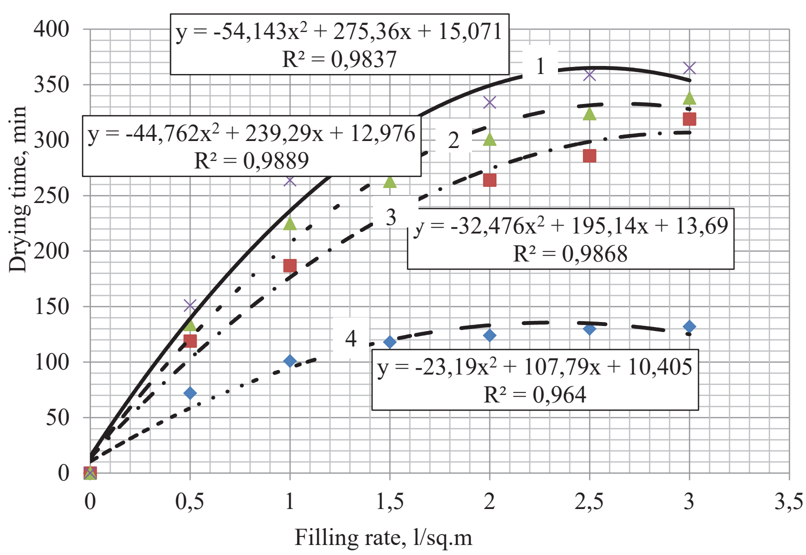

Fig. 5. Drying process of pre-moistened: Loamy soil with a 25 % concentration of various salts: 1 – water; 2 – calcium chloride; 3 – sodium chloride; 4 – magnesium chloride with six water molecules (bischofite)

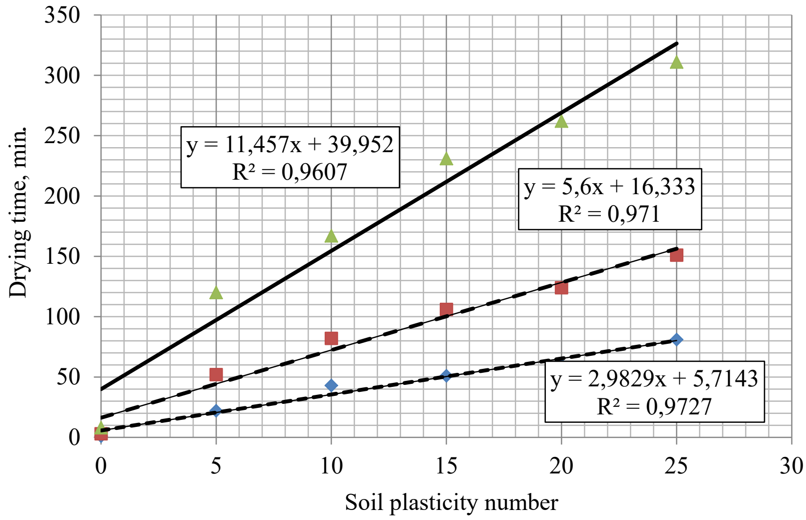

Fig. 6. Drying time for loamy soils, preliminarily moistened with solutions $MgCl_2 \cdot 6H_2O$ (bischofite)

The ability of soils to retain moisture is also largely influenced by the concentration of the applied solutions. The dust prevention effect of a solution of 25 % concentration is 2.5–3.5 times longer compared to a solution of 5 % concentration. Therefore, the use of solutions of increased concentration is the most effective.

As noted above, the formation of dust in the roadside zone of highways and the zone of access or bypass roads are significantly affected by climatic and soil conditions, the type of coverage, the composition of the traffic flow and its speed, wind speed, air humidity, and other factors. The most effective ways to combat dust on road surfaces are: treating them with dust–removing materials that reduce wear; maintaining the original evenness; reducing air pollution; improving traffic conditions for cars and the sanitary and hygienic condition of roads near settlements [13–15].

Dust prevention should be carried out primarily on sections of roads passing through settlements and along fields occupied by crops.

For IV–V climatic zones, solid hygroscopic salts are distributed in the following sequence: water is poured 0.5–2 l/m^2 (with a dry coating), and then solid salts are distributed along the roadway according to the rate given in Table 2.

5. 2. Stages of carrying out technological processes of dust preventing roads from a low category of roads

The required rate of distribution of chloride salts depends on the intensity of traffic and the width of the carriageway, as well as on the proximity of the forest, the direction of the road, the earth base, the road structure, and the quality of the wear layer material. When drawing up guidelines for the distribution of salt on the road surface, it is necessary to consider the influence of all the above factors. However, the required salt rate may be higher when treating open areas or near residential buildings or farms for growing berries and crops. Accordingly, the required rate may be less in wooded areas, in areas with thin structural layers, and with a capillary earthen base.

Table 2

Norms of distribution of dust preventing materials

Material	Unit of measurement	Material consumption rate per 1 m^2 of coverage			
		gravel	crushed stone	soil	validity, day
1. Hygroscopic Calcium chloride technical: Calcined	kg	0.8–0.9	0.6–0.7	0.9–1.0	20–40
fused	kg	1.0–1.1	0.7–1.0	1.1–1.2	20–40
liquid	l	2.0–2.2	1.5–2.0	2.2–2.4	15–25
Calcium chloride inhibited by phosphates (CHCF)	kg	0.9–1.0	0.7–0.8	1.0–1.1	25–40
Sodium chloride (as a solution of 30 % conc.)	l	2.4–3.0	2.0–2.6	3.4–4.0	15–20
Technical salt of sylvinite dumps: solid	kg	1.4–1.8	1.2–1.6	1.6–2.0	15–25
liquid	l	2.7–3.3	2.4–3.0	3.6–4.2	15–20
2. Sea firth water or salt lakes	l	1.5–2.0	1.3–1.8	2.0–2.5	3–5
Technical water	l	1.0–2.0	0.5–1.5	1.5–2.5	0.04–0.12 (1–3 h)
3. Technical lignosulfonates (grade B 50 % concenn tration)	l	1.6–2.0	1.4–1.8	1.8–2.2	20–30
4. Lignodor	l	1.6–2.0	1.4–1.8	1.8–2.2	40–50
5. Sulfite lye (10 % concentration)	l	4.0–6.0	3.5–5.0	4.5–6.5	15–20
6. Liquid bitumen and tar	l	0.8–1.0	0.7–1.0	1.0–1.2	30–90
7. Bituminous emulsions	l	1.2–1.5	1.0–1.3	1.5–2.0	30–90
8. Crude oil	l	0.8–1.0	0.7–1.0	1.0–1.2	30–90

Notes: 1) according to a standard dosimeter, organic binders (tar, crude oils, etc.) are used with a viscosity of not more than 25 s;

2) in the numerator – for I–Sh, in the denominator for IV and V road-climatic zones;

3) fewer consumption rates refer to traffic intensity up to 300 vehicles/day, big – 300 vehicles/day, and above;

4) the duration of the dust prevention action is given after the first treatment of the coating.

During the execution of works, it was decided to scatter 3 tons per km, which is 0.438 kg per 1 m^2. In this case, the consumption rate is lower than required, but according to the experiment results, it turned out to be sufficient for the summer season.

Practical recommendations for the use of hygroscopic dust-preventing materials.

Dust removal should be carried out in the first place on sections of roads passing through settlements and on bypass roads of facilities under construction.

For IV–V climatic zones, solid hygroscopic salts are distributed in the following sequence: water is poured 0.5–2 l/m^2 (with a dry coating), and then solid salts are distributed along the roadway according to the rate given in Table 3.

Lower consumption rates are required on roads with a traffic intensity of up to 300 vehicles/day and over 300 vehicles/day on larger ones.

The duration of the dust-preventing action of the materials is given after the first treatment of the coatings. During repeated treatments, the consumption rate of dust-preventing materials is reduced by 2 times. Processing is carried out at the first signs of dust formation.

Table 3

Norms of distribution of dust preventing materials

Material	Unit of measurement	Material consumption rate per 1 m^2 of coverage			validity, day
		gravel	crushed stone	soil	
Calcium chloride technical: calcined	kg	0.8–0.9	0.6–0.7	0.9–1.0	20–40
Fused	kg	1.0–1.1	0.7–1.0	1.1–1.2	20–40
Liquid	l	2.0–2.2	1.5–2.0	2.2–2.4	15–25
Calcium chloride inhibited by phosphates (CHCF)	kg	0.9–1.0	0.7–0.8	1.0–1.1	25–40
Technical table salt (in the form of a solution of 30 % conc.)	l	2.4–3.0	2.0–2.6	3.4–4.0	15–20
Technical salt of sylvinite dumps: – solid	kg	1.4–1.8	1.2–1.6	1.6–2.0	15–25
– liquid	l	2.7–3.3	2.4–3.0	3.6–4.2	15–20
Sea firth water or salt lakes	l	1.5–2.0	1.3–1.8	2.0–2.5	3–5
Technical water	L	1.0–2.0	0.5–1.5	1.5–2.5	0.04–0.12 (1–3 h)
Technical lignosulfonates (grade B 50 % concentration)	l	1.6–2.0	1.4–1.8	1.8–2.2	20–30
Lignodor	l	1.6–2.0	1.4–1.8	1.8–2.2	40–50
Sulfite lye (10 % concenϑ tration)	l	4.0–6.0	3.5–5.0	4.5–6.5	15–20
Liquid bitumen and tar	l	0.8–1.0	0.7–1.0	1.0–1.2	30–90
Bituminous emulsions	l	1.2–1.5	1.0–1.3	1.5–2.0	30–90
crude oil	l	0.8–1.0	0.7–1.0	1.0–1.2	30–90

Advanced coatings are cleaned with mechanical brushes, watering machines, or sweepers combined with washing. With a large accumulation of dirt on the surface (near crossings, exits, etc.), they resort to combined cleaning, i. e., mechanical brush and watering machine.

Dust preventing coatings of transitional and lower types, arranged without organic binders, is carried out by treating their surface with dust preventing materials. Types of dust preventing materials, approximate rates of their consumption per 1 m^2, and duration of action are given in Table 3. Re-treatment is carried out at the first signs of dust formation. At the same time, the consumption rates of dust preventing materials are reduced by 2 times compared to the rates for the first treatment.

Ready-made solutions and brine water are stored in tanks with 20–100 m^3 or concrete closed storage. Organic dust preventing binders supplied in tanks are stored in closed storage facilities equipped with a heating system.

For the distribution of dust-preventing materials, along with road machines (KDM-130, PM-8, DS-39, PR-130, UR-53, etc.), agricultural distributors of liquid and solid mineral fertilizers are used (RZhT, RUM-3, KSA-3, etc.).

Gravel coatings are dust prevented in two ways: by impregnation or mixing the mineral coating material with the dust preventing material on the road.

6. Discussion of the results of the study to substantiation of application technology of hygroscopic materials

The studies proposed in the article help to solve the problem of the time of evaporation and raising of dust into the atmosphere. An alternative to dust reduction on mountain roads is the use of magnesium chloride hexahydrate ($6H_2O\ MgCl_2$), which is a by-product of local lithium production. So far, there is no scientific evidence that combines laboratory and field studies to evaluate the effectiveness of an industrial by-product used to control dust on haul roads in the mining industry. When choosing the right composition and ratio of components, dust may not rise into the atmosphere for up to several months, regardless of the type of soil and atmospheric temperature.

The results of the study are explained by the experiment on the use of the distribution of chloride salts depending for traffic intensity and the width of the carriageway, as well as the proximity of the forest, the direction of the road, the earth base, the road structure and the quality of the wear layer material. During the execution of works, it was decided to scatter 3 tons to km, which is 0.438 kg to 1 m^2. In this case, the consumption rate is lower than required, but according to the results of the experiment, it turned out to be sufficient for the summer season.

At the present stage of life, an important problem is the factor of lack of water, which affects the use of water in the fight against dust on the road. Several factors affect the availability of water, such as the growth of the world's population and the increase in industrial activity. In the maintenance of low-grade roads in rural areas, access roads to industrial areas, etc. are traditionally treated with large amounts of water to reduce dust emissions caused by transport, which produce up to 97 % of dust, which reduces the safety and productivity of mining operations (Fig. 1). An alternative to dust reduction on mountain roads is the use of magnesium chloride hexahydrate ($6H_2O{\cdot}MgCl_2$), which is a locally produced product. So far, there is no scientific data that combines laboratory and field studies to evaluate the effectiveness of an industrial by–product used to control dust on haul roads.

In addition, the results showed that soils exposed to higher relative air humidity increase water uptake from the air, confirming the hygroscopic properties of $6H_2O{\cdot}MgCl_2$.

The use of ordinary water when moistening soils for dust control leads to high costs and labor intensity. An alternative to reducing the dustiness of mountain roads is the use of magnesium chloride hexahydrate ($6H_2O$ $MgCl_2$) (Fig. 5, 6). When choosing the right composition and ratio of components, dust may not rise into the atmosphere for up to several months, regardless of the type of soil and atmospheric temperature.

A technology for dust protection of a section of a highway has also been developed, which consists of several stages:

– 1 stage. Water irrigation. In order to prevent salt from being carried away from the road section, it is necessary to wet the coating before scattering calcium chloride. The number of passes of the technique depends on the degree of wetting of the coating. During the experiment, on the section from 226 to 227 km, watering was carried out in two passes along each lane since it had rained, so the coating was already sufficiently moistened. In the case of dry weather, the number of passes should be increased to achieve the best result;

– 2 stage. Calcium chloride distribution. Salt distribution was carried out using a conventional distributor machine. When distributing the material, it should be taken into account that its consumption is quite large, so it is necessary to open the dampers as much as possible; otherwise, the number of passes will increase. With proper distribution, two passes are needed for each lane. During the distribution of material, one should not forget about safety precautions. At the end of the work, the equipment must be washed from the chemical so that corrosion does not appear;

– 3 stage. Calcium chloride hydration. The road surface should be sprayed with water to improve the solubility of the salt in the wear layer and for better adhesion of the material and its mixing with the coating after it has been spread. After watering, the granules dissolve and further contact better with water. The recommended number of passes is two, but the number can be reduced or increased depending on the actual conditions;

– 4 stage. Material mixing, grading. After spreading, the wear layer is mixed with salt so that there are no free chloride particles. During grading, calcium chloride particles are mixed with the top layer, forming a homogeneous mass, which, as shown by the experiment, darkens further and visually differs from the untreated areas. During planning, attention must be paid to ensuring that there are no high edges that impede drainage. The number of main passes is two; the remaining passes are necessary to remove the flaws;

– 5 stage. Sealing. The compaction of the wear layer determines how long this wear layer will remain in good condition and how much mineral material will "break off". After sealing the wear layer with optimally calculated moisture content, it withstands road traffic, rain, and long periods without rain. Therefore, the sealing of the wear layer must be carried out carefully. However, using a pneumatic wheeled road roller or a roller with smooth rollers is uneconomical. On the experimental site, dump trucks were used in four passes;

– 6 stage. Additional dust prevention. High-traffic roads or open areas may require additional salting during the summer. The norms of salt distribution with additional dust prevention in the summer period are less than those used in the spring. If potholes and bleeding are observed on the road surface, which requires profiling, additional salt treatment is carried out in salt mixing with the wear layer material. Otherwise, dust prevention is carried out by spreading the salt over the road surface, in which the calcium chloride is not mixed with the mineral material. Additional dust prevention, especially when using dry salt, is carried out immediately after rain to reduce the water needed to moisten the surface. For additional dust prevention, it is also possible to use a brine solution, applied in the same way as in the spring.

The limitations of the use of research results can be a long distance, storage conditions, time for transportation, untimely delivery to the place of processing.

As results methods develop and improve and their use on low-grade roads will require updating components and improving the quality of materials, which can lead to an increase in the required parameters. It is necessary to develop the quality and increase the quantity of used laboratory tests with chemical components, which requires time and more extensive research and exploitation of the results of experiments on the roads.

When impregnated with a solution, it is poured onto a coating whose material has a moisture content equal to or less than optimal. It is poured in two or three doses at a rate of more than 1.5 l/m^3. Each subsequent spill is made after the solution of the previous one is completely absorbed into the coating. Organic dust preventing materials are poured at a temperature that ensures normal absorption. When mixing on the road when processing gravel and similar coatings, the previously exported material for the top layer of the coating is leveled with a motor grader. Pour the solution or distribute the solid dust preventing material in 80 % of the norm and mix thoroughly. If necessary, the coating material is leveled and profiled, adding water, bringing the mixture to the optimum humidity. Self–propelled pneumatic rollers carry out compaction for 8–10 passes along each track. A dust–preventing solution is poured over the finished coating, or the material is distributed in solid form at 20 % of the norm. Within 5–7 days after the dust removal, vehicles' movement is regulated to obtain an evenly rolled surface and ensure better coating formation. Vehicle speed during this period is limited to 40 km/h.

7. Conclusions

1. Dust preventing coatings of transitional and lower types, arranged without organic binders, is carried out by treating their surface with dust preventing materials. Types of dust preventing materials, approximate rates of their consumption per 1 m^2, and duration of action are given in Table 3. Re-treatment is carried out at the first signs of dust formation. At the same time, the consumption rates of dust preventing materials are reduced by 2 times compared to the rates for the first treatment.

The ability of soils to retain moisture is also largely influenced by the concentration of the applied solutions. The duration of the dedusting effect of a solution of 25 % concentration is 2.5–3.5 times longer in comparison with a solution of 5 % concentration. Therefore, the use of solutions of increased concentration is the most effective.

As noted above, the formation of dust in the roadside zone of highways and in the zone of access or bypass roads is significantly affected by climatic and soil conditions, the type of coverage, the composition of the traffic flow and its speed, wind speed, air humidity and other factors. The most effective ways to combat dust on road surfaces are: treating them with dust-removing materials that reduce wear; maintaining the original evenness; reduction of air pollution; improvement of traffic conditions for cars and the anitary and hygienic condition of roads near settlements.

2. Based on the results of the study, a technology for dust protection of a section of a highway was developed, taking into account the sequence of applying the treatment in several stages. Which leads to economical and long-term dust protection of the road section.

Dedusting of coatings of transitional and lower types, arranged without the use of organic binders, is carried out by treating their surface with dedusting materials.

The duration of the dedusting action of the materials is given after the first treatment of the coatings. During repeated treatments, the consumption rate of dedusting materials is reduced by 2 times. Processing is carried out when the first signs of dust formation appear.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Acknowledgments

We express our gratitude to the (Republic of Kazakhstan).

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