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Effects of molasses, polyacrylamide and bentonite on dust control in forest roads

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Abstract: In this study, some environmentally friendly anti-dust agents including sugar cane molasses, polyacrylamide and bentonite were used to control dust emission from the forest road surface within the 3, 9, 27 and 81-day timeframe. A rear-mounted spray system and dust collector devices were used for implementation of treatments and dust emission recording, respectively. The results showed that emitted dust tended to decrease with the increase of anti-dust agent concentrations. Moreover, the emitted dust started to decrease with time, with minimum reduction efficiency at the end of the 81st day. More than half of road surface aggregates had the size smaller than 10 µm that were aggregated by the application of molasses and polyacrylamide. The size of 70% of the road surface fines increased to more than 50 µm. Bentonite affected negatively road surface materials and caused fine aggregates to increase. It is concluded that the amount of fine aggregates in surfacing materials, rainfall occurrence, and type and dosage of anti-dust agents play an important role in the effectiveness and longevity of treatment.

Keywords: anti-dust agent; rear-mounted spray system; road surface material; fine aggregates; dust collector

The major problem of forest roads, especially in summer, is the generation of dust due to vehicle traffic. Dust particles of less than 150 µm in diameter are generated in the form of clouds behind the vehicles and cause disturbance to tourists (Addo, Sanders 1995), reducing the vision distance of drivers and thus reducing road safety (Jones 1999). Other negative effects of dust include damage to human health, plant growth decline (Manoochehri et al. 2016), water and aquatic habitat pollution, pavement destruction (Forman, Alexander 1998) and increased cost of road repairing and maintenance (Gulia et al. 2019). Observations have shown that the dust emission process occurs at a threshold speed of about 25–35 km·h^{-1} (Powers 2007). Anti-dust agents agglomerate fine particles, contribute to adherence of surface particles together and increase road surface density (Bergeson, Brocka

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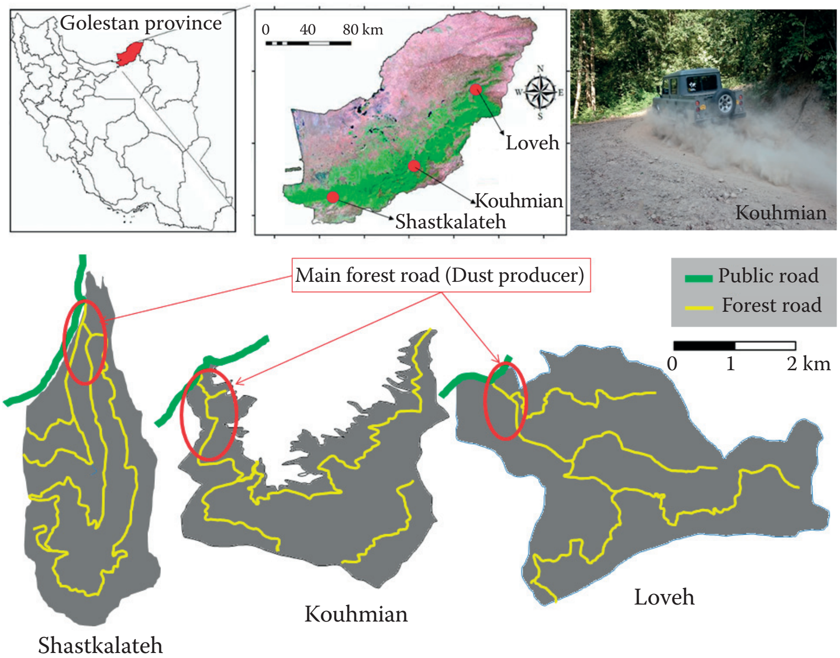

Figure 1. Position of the road segments in the study sites for the implementation of treatments

1996). Generally, dust control treatments cannot act effectively on the soil surface or on roads that contain more than 30% of fine particles in their pavement materials (Bolander, Yamada 1999). The use of these treatments on roads with less than 5% of fine particles in their materials is not efficient either. In addition, dust control treatments in sandy soils have a small efficiency due to low plasticity (Kirchner, Gall 1991). In the case of forest roads, it is necessary to use cost-effective and environmentally friendly approaches to dust control (Bolander, Yamada 1999). Sugar cane molasses is a thick and dark brown juice that is extracted from the sugarcane stem. It acts as a binder of fine particles on the road surface, preventing dust emission in this way (Gotosa et al. 2015). The use of acrylic-based polymer mulch is also expanding because of its environmental friendliness and safety. Polyacrylamides are odourless, colourless and non-polluting in surface and underground waters, plant tissues and soil (Wang et al. 2019). Bentonites are swelling clay in the presence of moisture which has a high level of inflation, good adhesion and moisture absorbing capacity (Pusch 2015). Bentonite is used to control dust through electrostatic bonding and agglomeration (Bergeson, Brocka 1996). More than 87% of the bentonite chemical composition includes SiO_2, Al_2O_3, MgO, CaO, Fe_2O_3, K_2O and Na_2O.

Gotosa et al. (2015) examined the potential of molasses (sugar syrup) and water in mitigating dust emission from gravel roads and compared them with control treatment in Zimbabwe. Each treatment was carried at a rate of 4 litres per square meter. The results showed that the dust suppression capacity of molasses and water was 83–77% and 18–39%, respectively. The climatic and geological features of the region are among the reasons for dust generation in some forest roads. Especially in the east of the Hyrcanian zone, the presence of wind sediments in the form of silt, clay and sand particles in the soil bed causes massive dust and as a result the rapid destruction of forest roads. This issue has led to a high annual cost of the renewal of materials and the restoration of forest roads. The objectives of this research were to investigate the effect of different dosages of sugar cane molasses, polyacrylamide and bentonite treatments on a reduction of dust emission from unpaved forest roads in the Hyrcanian region within the 3, 9, 27 and 81-day timeframe and determine the optimum treatment and dosage in each site with considerations of dust reduction efficiency.

MATERIAL AND METHODS

Study area description. This study was carried out in three sites distributed in forests of the Golestan province, north of Iran. At first, parts of the main forest roads in Loveh (55°41'00" to 55°46'00"E and 37°19'00" to 37°20'00"N), Kouhmian (55°10'30" to 55°14'49"E and 37°00'00" to 37°56'15"N) and Shastkalateh (54°21'26" to 54°24'57"E from 36°48'06"

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Table 1. Characteristics of road segments containing treatments with molasses, bentonite and PAM

Study area	Treatment	Slope (%)	Elevation (m)	Material moisture (%)	Surfacing thickness (cm)	Fine aggregates (%)	Material class (%)	Canopy (%)	Road age (years)	Climate
Loveh	Molasses	4	300–400	5	15	11	GP	60	2007	moist
	PAM	5	300–400	4	16	14	GP	65		
	Bentonite	6	300–400	5	14	12	GP	60		
Kouhmian	Molasses	5	320–420	6	15	9	GP	65	1993	moderately moist to medium moist
	PAM	4	320–420	6	15	6	GP	60		
	Bentonite	5	320–420	5	16	7	GP	60		
Shastkalateh	Molasses	4	250–350	6	15	5	GW	55	1971	moderately moist
	PAM	5	250–350	5	16	4	GW	65		
	Bentonite	7	250–350	6	16	5	GW	60		

PAM – polyacrylamide, GP – poorly graded gravel, GW – well graded gravel

to 36°43'27''N) with serious problems in terms of dust production were selected (Figure 1). Annual temperature in Loveh, Kouhmian and Shastkalateh was 12.20, 16.83 and 18.00 °C, respectively. Annual rainfall in Loveh, Kouhmian and Shastkalateh was 524, 700 and 562 mm·h^{-1}, respectively. The surfacing type and thickness of roads were recorded using the digging of trenches at the beginning, in the middle and at the end of each segment. A sample of 15 kg in weight was collected from each trench and then transferred to the Soil Mechanics Laboratory, where the granulation analysis was carried out according to ASTM-D422. In each site, a 960-meter segment of the main forest road in northern direction was selected and various treatments with sugar cane molasses, polyacrylamide and bentonite were carried out at a distance of 320 m with an interval of 20 m between treatments (Gotosa et al. 2015). The mean traffic in studied roads is 25 vehicle passes per day. Two-axle vehicles with height equal to or less than 2.2 m used these roads. The characteristics of the study area and different treated road segments with anti-dust agents are described in Table 1.

Implementation of treatments and dust measurement. In this study, anti-dust treatments were prepared in different concentrations and then applied using a rear-mounted spray system equipped with a 100 l capacity tank and a motor pump. The proportions of the volume of anti-dust agents to the amount of water that dissolves were 5%, 10% and 20% for sugar cane molasses (Brown, Elton 1994) and 2%, 4% and 6% for polyacrylamide (McLaughlin et al. 2014). The ratios of the weight of bentonite to the weight of the materials added to it were 1%, 2% and 3% (Edwards et al. 2016). The treatment rates were 2–2.5 litres per square meter (Addo et al. 2004). Each concentration was applied to a road segment of 60 meters in length with a 20-meter interval. Traffic was restricted for 24 hours to allow the solution to penetrate in the road. Dust samples were collected by a rear-mounted dust collector device within the 3, 9, 27 and 81-day timeframe (from 28 May to 17 August 2019) to evaluate the efficiency and longevity of the treatments (Figure 2). This timeframe was determined according to a dry season extracted from an ombrothermic diagram of the study sites which was less than three months.

The dust collector used in the present study is a mobile sampler that measures a quantity that is related

Figure 2. Electrical dust collector device used in the present study

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to how much dust is emitted from a road to the air ($g \cdot m^{-3}$) when a vehicle moves (Addo et al. 2004). This device includes a fiberglass box to hold 20×20 cm glass wool fitted to the rear bumper, an electric engine, a high volume collector pump, a flexible plastic tube, one-meter metal boom, head and filter box. The filter box has an input of 25×25 cm and has been covered by a filter with 450-μm apertures. This filter score (450 μm) prevents the entry of non-volatile particles into the filter box. In dust sampling, at first the empty filter was weighed and then the collector's boom was drawn behind a Land Rover (1900 kg) at the height of 40 cm from the road surface. The collector was turned on when the Land Rover began to move at a speed of 40 km h^{-1} (Jones 1984) and after 60 meters it was turned off and the filter was taken for weighing. The difference between the second weight and the initial weight of the filter is the weight of the dust in each sampling. This procedure was repeated 5 times for each treatment. Thus a total of 720 samples were taken. Microscopy analysis of the effect of anti-dust agents on fine aggregates of the road surface was done using a scanning electron microscope (SEM.)

Statistical analysis. The normality of the data was tested using the Kolmogorov-Smirnov test and then subjected to analysis of variance (ANOVA) in SAS software. The comparison of means was performed based on Fisher's least significant difference (LSD). The effect and significance of each of the measured variables and their impacts on the road dust emission were examined using the Pearson correlation.

RESULTS

Comparison of anti-dust agent dosages for dust control in forest roads

Results indicated that emitted dust tended to decrease with the increase of anti-dust agent concentrations. Moreover, the emitted dust started to decrease with time, with minimum reduction efficiency at the end of the 81st day. In Loveh, different concentrations of bentonite could not control the emitted dust from the treated road segments within the 81-day timeframe. In Kouhmian, a minimum amount of emitted dust was detected in dosage of 3% bentonite. In this dosage, emitted dust decreased from 10.4 to 6.1 $g \cdot m^{-3}$ on the 81st day. Only a few studies have measured dust abatement from bentonite. In Loveh and Kouhmian, the longevity of polyacrylamide (PAM) treated road segments with concentration of 4% and 6% is more than 81 days. The optimum dosage of PAM in Loveh and Kouhmian was 6% and 4%, respectively. In Shastkalateh, a dosage of 2% was observed as an optimum PAM concentration for the dust reduction because beyond this dosage, adding higher concentrations had no impact on the dust emission. A dosage of 20% was found as an optimum molasses concentration for the dust reduction in Loveh and Kouhmian, because lower dosage had no impact on the dust reduction within the 81-day timeframe. In this dosage emitted dust decreased from 12.3 to 5.0 $g \cdot m^{-3}$ and from 10.4 to 5.0 $g \cdot m^{-3}$ in Loveh and Kouhmian, respectively (Table 2).

Comparison of the different anti-dust agents in the study sites

In Loveh and Kouhmian, PAM and molasses treated road segments had lower emitted dust than bentonite treated road segments. In Loveh, dust reduction efficiencies were 42.34%, 52.50% and 56.06% and these efficiencies in Kouhmian were 42.99%, 52.39% and 63.14% for bentonite, molasses and PAM, respectively ($P < 0.05$, Figure 3). For PAM treated road segments in Shastkalateh, dust emission rates ranged from 1.3 to 1.8 $g \cdot m^{-3}$ on the 3rd day to 2.9-4.1 $g \cdot m^{-3}$ on the 81st day. In this study site, reduction efficiencies of 56.09%, 59.35% and 70.62% were achieved for bentonite, molasses and PAM, respectively.

Microscopy analysis of the effects of anti-dust agents on road aggregates

As it is observed in Figure 4, more than half of the road surface aggregates have the size smaller than 10 μm. After the application of molasses and PAM the aggregate size increased by aggregating. The size of 70% of the road surface fine aggregates increased to more than 50 μm. Bentonite affected the road fine aggregates negatively and caused the fine aggregates to increase.

DISCUSSION

Results indicated that emitted dust tended to decrease with the increase of anti-dust agent concentrations. Moreover, the emitted dust started to decrease with time, with minimum reduction efficiency at the end of the 81st day. It seems that two rainfall events washed the anti-dust agents from

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Table 2. Interaction of anti-dust agent concentrations and longevity on emitted dust (g·m^{-3}) from the treated road segments

Anti-dust agent	Conc. (%)		Longevity (days)											
			Loveh				Kouhmian				Shastkalateh			
			3	9	27	81	3	9	27	81	3	9	27	81
Bentonite	0	Mean	12.5^{Aa}	11.9^{Aa}	11.4^{Aa}	12.3^{Aa}	10.1^{Aa}	9.7^{Aa}	9.5^{Aa}	10.4^{Aa}	8.7^{Aa}	9.1^{Aa}	7.9^{Aa}	8.0^{Aa}
		SD	0.79	0.79	0.76	0.74	0.82	0.86	0.79	0.76	0.21	0.50	0.43	0.38
	1	Mean	5.3^{Bb}	6.2^{Bb}	10.5^{Aa}	11.7^{Aa}	4.7^{Bb}	5.4^{Bb}	8.6^{Aa}	9.7^{Aa}	3.3^{Bb}	3.5^{Bb}	4.6^{Bb}	7.0^{Aa}
		SD	0.41	0.14	0.91	0.42	0.47	0.32	0.30	0.35	0.37	0.45	0.42	0.29
	2	Mean	3.8^{Bb}	5.4^{Bb}	5.9^{Bb}	11.0^{Aa}	3.1^{Bb}	4.5^{Bb}	5.4^{Bb}	9.2^{Aa}	2.8^{Bb}	3.0^{Bb}	3.7^{Bb}	5.3^{Ba}
		SD	0.57	0.32	0.64	0.96	0.07	0.41	0.40	0.44	0.23	0.28	0.56	0.35
	3	Mean	3.4^{Bb}	4.1^{Bb}	5.0^{Bb}	10.9^{Aa}	3.0^{Bb}	3.9^{Bb}	4.3^{Bb}	6.1^{Ba}	2.1^{Bb}	2.3^{Bb}	2.6^{Bb}	4.2^{Ba}
		SD	0.16	0.22	0.38	0.80	0.35	0.16	0.32	0.37	0.14	0.22	0.29	0.14
PAM	0	Mean	12.5^{Aa}	11.9^{Aa}	11.4^{Aa}	12.3^{Aa}	10.1^{Aa}	9.7^{Aa}	9.5^{Aa}	10.4^{Aa}	8.7^{Aa}	9.1^{Aa}	7.9^{Aa}	8.0^{Aa}
		SD	0.79	0.79	0.76	0.74	0.82	0.86	0.79	0.76	0.21	0.50	0.43	0.38
	2	Mean	4.7^{Bb}	5.1^{Bb}	6.1^{Bb}	11.0^{Aa}	2.9^{Bb}	3.3^{Bb}	3.9^{Bb}	9.0^{Aa}	1.8^{Ba}	2.4^{Ba}	3.0^{Ba}	4.1^{Ba}
		SD	0.54	0.22	0.16	0.72	0. 07	0.22	0.36	0.25	0.29	0.22	0.37	0.60
	4	Mean	3.5^{Bb}	4.2^{Bb}	5.5^{Bb}	7.1^{Ba}	2.4^{Ba}	3.2^{Ba}	3.4^{Ba}	4.0^{Ba}	1.5^{Ba}	2.4^{Ba}	2.6^{Ba}	3.5^{Ba}
		SD	0.29	0.51	0.45	0.36	0.41	0.19	0.42	0.19	0.07	0.19	0.24	0.37
	6	Mean	3.0^{Ba}	3.5^{Ba}	4.1^{Ba}	5.6^{Ba}	2.2^{Ba}	2.8^{Ba}	3.3^{Ba}	3.5^{Ba}	1.5^{Ba}	2.0^{Ba}	2.3^{Ba}	2.9^{Ba}
		SD	0.49	0.45	0.36	0.35	0.32	0.38	0.12	0.50	0.07	0.07	0.28	0.14
Molasses	0	Mean	12.5^{Aa}	11.9^{Aa}	11.4^{Aa}	12.3^{Aa}	10.1^{Aa}	9.7^{Aa}	9.5^{Aa}	10.4^{Aa}	8.7^{Aa}	9.1^{Aa}	7.9^{Aa}	8.0^{Aa}
		SD	0.79	0.79	0.76	0.74	0.82	0.86	0.79	0.76	0.21	0.50	0.43	0.38
	5	Mean	6.0^{Bb}	6.3^{Bb}	8.0^{Bb}	11.1^{Aa}	5.0^{Bb}	5.1^{Bb}	5.8^{Bb}	9.1^{Aa}	3.1^{Bb}	4.4^{Bb}	5.2^{Bb}	7.2^{Aa}
		SD	0.61	0.25	1.0	0.53	0.07	0.07	0.72	0.26	0.57	0.56	0.24	0.81
	10	Mean	3.9^{Cb}	5.0^{Bb}	5.1^{Cb}	7.0^{Ba}	3.1^{Cb}	3.4^{Bb}	4.1^{Bb}	6.4^{Ba}	1.5^{Bb}	2.0^{Cb}	3.6^{Bb}	5.4^{Ba}
		SD	0.14	0.19	0.12	0.71	0.19	0.42	0.14	0.42	0.22	0.35	0.46	0.35
	20	Mean	3.1^{Ca}	4.0^{Ba}	4.1^{Ca}	5.0^{Ca}	3.0^{Ca}	3.1^{Ba}	3.6^{Ba}	5.0^{Ba}	1.1^{Bb}	1.6^{Cb}	2.1^{Bb}	3.9^{Ba}
		SD	0.14	0.67	0.17	0.37	0.21	0.22	0.29	0.12	0.16	0.28	0.12	0.41

Different lowercase letters at each row, different capital letters at each column mean the significant difference at probability level of 95%; PAM – polyacrylamide

the road surface and this may be the reason for an increase in emitted dust at the end of the 81st day. In Loveh, different concentrations of bentonite could not control the emitted dust from the treated road segments within the 81-day timeframe. Indeed, the longevity of this anti-dust agent is less than 81 days. Bentonite is most effective in conditions where low levels of fines are present in the surface materials (Lohnes, Coree 2002), while the surfacing materials of forest roads in Loveh are GP with a high level of fines, so added clay particles could not provide the fines needed to bind surface aggregates. In Kouhmian, a minimum amount of emitted dust was detected in dosage of 3% bentonite. In this dosage, emitted dust decreased from 10.4 to 6.1 g·m^{-3} on the 81st day. Only a few studies have measured dust abatement from bentonite. Bergeson and Brocka (1996) used sodium montmorillonite as a dust palliative on limestone surfaced secondary roads in Texas. Applications tested ranged from 0.5 to 9 percent by weight of aggregate. Dust generation was reduced by about 45% on sites where 3% bentonite was employed and 70% on sites with 9% bentonite. In Loveh and Kouhmian, the longevity of PAM treated road segments with the concentration of 4% and 6% is more than 81 days. The optimum dosage of PAM in Loveh and Kouhmian was 6% and 4%, respectively. This conforms to the research done by Omane et al. (2018). They found the concentration of 5% as an appropriate dosage for the chloride-free solution, polymer and molasses. In Shastkalateh, a dosage of 2% was observed as an optimum PAM

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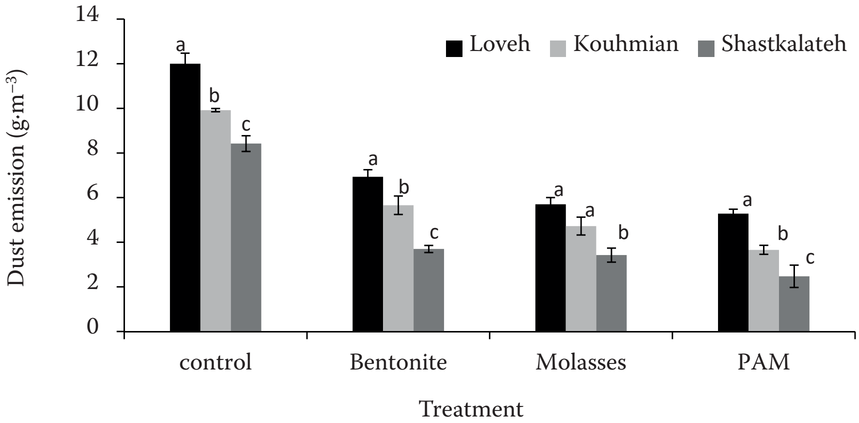

Figure 3. Comparison of dust emission from the treated road segments in different sites (PAM – polyacrylamide)

concentration for the dust reduction because beyond this dosage, the use of higher concentrations had no impact on the dust emission. A dosage of 20% was observed as an optimum molasses concentration for the dust reduction in Loveh and Kouhmian, because the lower dosage had no impact on the dust reduction within the 81-day timeframe. In this dosage emitted dust decreased from 12.3 to 5.0 $g{\cdot}m^{-3}$ and from 10.4 to 5.0 $g{\cdot}m^{-3}$ in Loveh and Kouhmian, respectively. In Shastkalateh forest, at the initial stage of application, molasses was highly efficient, but as time progressed the dust emission increased. This result was in agreement with the findings of Shirsavkar and Koranne (2010). Molasses contains sugars which are hygroscopic and attract moisture from the air (Manyuchi et al. 2018). The hygroscopic nature of the molasses was therefore the reason for reduced dust emission (Gotosa et al. 2015). Gotosa et al. (2015) detected that molasses was a better suppressant than water over the six month study period.

In this study, reduction efficiency of PAM was higher than that of bentonite and molasses. This result is supported by Omane et al. (2018). They reported that the adhesiveness between the molecular structures of the PAM solution was higher and

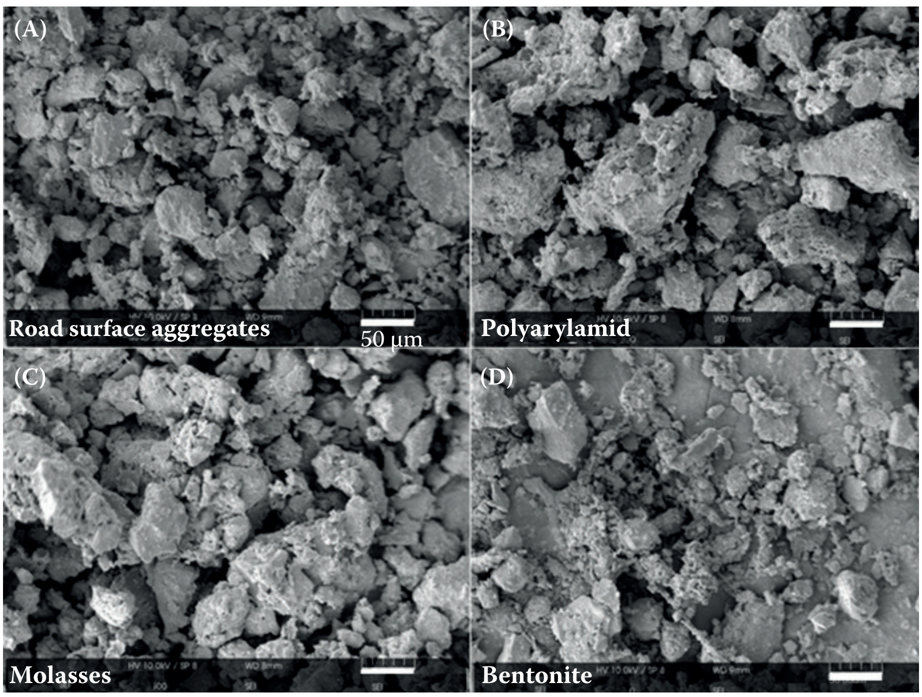

Figure 4. SEM for road fine aggregates treated with different anti-dust agents

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a smaller surface tension led to a decrease in the evaporation rate. Other researchers such as Goma and Mwale (2016) and Thompson and Visser (2007) reported similar findings. They found that the PAM solution was more efficient than water, salt solution and chloride-free solution. PAMs are manufactured in a broad range of molecular weights, charge types, and charge densities. The breakdown of PAM requires several weeks and occurs as a result of mechanical disturbances (Ding et al. 2019). As expected, earlier treated roads exhibit higher dust emission than recently treated roads, and the overall amount of dust emissions in Loveh forest roads is larger than that of Kouhmian and Shastkalateh roads (Figure 4). Surfacing materials in Loveh forest roads are typically dirty (GP) and the poor condition of these materials may contribute to the increased dust emission. The mean amount of fine particles in surfacing materials of Loveh forest roads was 12.3%. Gulia et al. (2019) reported that the emission of road dust significantly varied based on the amount of silt deposited on the road, number and types of vehicles.

CONCLUSION

Effectiveness of different anti-dust agents on forest road dust emissions was examined from 81-day emission data collected in three sites in Hyrcanian forests. It is concluded that molasses was an effective agent for controlling dust emissions from the road surface with high levels of fines and unwashed materials.

In forest roads with lower levels of fine particles in surfacing materials, PAM is the most efficient method of dust emission reduction. Cohesive behaviour of this agent can aggregate the fine particles of the road surface.

The amount of fine aggregates in surfacing materials, rainfall occurrence, and type and dosage of anti-dust agent play an important role in the effectiveness and longevity of treatment.

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