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Characterization of Desert Road Dust Aerosol from Provinces of Afghanistan and Iraq

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ABSTRACT

Resuspended desert dust is an important air pollutant in both local and transboundary levels. Research on the resuspension and properties of desert road dust particulate matter (PM) was performed with dust samples from the provinces of Kandahar, Herat and Ghor in Afghanistan, and the province of Baghdad in Iraq. Measurements of the concentrations of airborne PM in Kandahar province showed that near the military unit PM_{total} ranged from 58.3 µg/m^3 to 85.5 µg/m^3, while in the motorcade the concentrations ranged from 13787.9 µg/m^3 to 18181.8 µg/m^3. The particle size distribution (PSD) of the resuspended dust samples in laboratory conditions revealed that the PSD may have a bi-modal shape with a clearly defined mode (d = 1.98–2.13 µm), and less expressed second mode at ~1 µm. The highest amounts of resuspended PM resulted from the samples taken at Kandahar province. The dust from other regions showed lower amounts of resuspended particles (~75% lower in Ghor, ~85% in Herat, and ~96% in Bagdad). The X-ray diffraction (XRD) analysis of dust showed the presence of calcite, quartzite, albite, muscovite, potassium-feldspar, and nimite in the samples. SO_4^{2-} concentrations in the road dust samples ranged from 71.3 ± 8.5 × 10^3 µg/kg to 221.1 ± 18.3 × 10^3 µg/kg, and the amounts of Cl^- varied from 378.2 ± 81.9 × 10^3 µg/kg to 3876.2 ± 295.2 × 10^3 µg/kg. The results of particle size distribution and composition were discussed with respect to their potential negative influences on road vehicles.

Keywords: Middle east; Desert road dust; Particulate matter; Aerosol; Resuspension.

INTRODUCTION

Resuspended particulate matter (PM) is one of the major air pollution sources in the countries of Middle Asia (Park, 2002). The natural processes (soil erosion caused by wind, sandstorms in deserts) and anthropogenic processes (off-road traffic, agricultural activity) (Meng, 2001; McDonald and Caldwell, 2004; Gillies *et al.*, 2005; Zhang *et al.*, 2008; Zhang *et al.*, 2010) are dominant factors effecting air quality in these countries. During the periods of spring and summer when precipitation is minimal, the relative air humidity is reduced to 10–30% and winds become more intense (wind speed is several times higher compared to the cold period), thus favourable conditions for soil erosion and PM resuspension are created. Due to these reasons, concentration of PM in the ambient air increases. Depending on the geographical, geological, and meteorological conditions, PM concentration in the ambient air may vary from 30 to 150 µg/m^3, and from 1000 to 5000 µg/m^3 during sandstorms (Fu *et al.*, 2008). PM concentration in Yuma desert (State of Arizona, USA) varied in the range of 0.5–10.6 × 10^6 µg/m^3 during sandstorms (Graveris, 1977). Earlier studies in Afghanistan have showed that during the period of June-July, total PM concentration in the height of 2 m can reach 10.4 × 10^6 µg/m^3 (Avduevskij *et al.*, 1990). Sandstorm (dust devil) mechanisms are also studied mathematically (Gu *et al.*, 2008; Gu *et al.*, 2010). Sandstorms take place up to 30 times in a year in the province of Kandahar, ~5–10 in the province of Herat, and ~3–5 in the province of Ghor (NOAA, 1995). During the cold period in December-March, the major part of annual rainfall comes down. In July–August, rainfall barely reaches several centimetres in a month, or it is completely absent. During the cold period, the average relative humidity varies from 50 to 85%, while during the warm period, depending on the amount of rainfall, the average humidity is around 20–40%.

Deserts and farmlands where agricultural or other activities are executed become potential sources of PM.

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Depending on their size, PM can be transported long distances thus affecting air quality not only in the vicinities but also in distant territories (Husar *et al.*, 1997). Desert dust research is quite well developed; there are extensive data on the characteristics of Sahara desert dust (O'Hara *et al.*, 2006; Weinzierl *et al.*, 2009), and China desert dust (Zhuang *et al.*, 2001; Jinyuan *et al.*, 2005; Tiantao *et al.*, 2006), however, far less is known about the characteristics and origins of PM in the air of Afghanistan and Iraq deserts (CAI-Asia, 2006).

Excessive concentrations of airborne PM affect not only human health and environment but also the exploitation properties of civil and military automotive vehicles (Allen *et al.*, 2001; Konrad and Beebe, 2005). The majority of non-paved roads are formed by thickening the existing soil. When vehicles are driven on this kind of road, road dust is raised to the air due to the force of shear and turbulence (Nicholson *et al.*, 1989). PM abrade moving mechanical parts of vehicles, and can damage internal combustion engines if passing inside the engine through the filters and leaky systems (Wenk and Bulakh, 2004; Warren *et al.*, 2005). Such environmental conditions reduce vehicle service time, increase repair costs, fuel and oil consumption, etc. Hardness of some particles was shown to be higher compared to the elements of mechanisms of road machinery; therefore their presence in the moving parts of engine causes abrasive attrition (Wenk and Bulakh, 2004).

In order to evaluate and reduce the impact of PM on vehicle exploitation properties, it is necessary to characterize the road dust, and determine the potential of resuspension. The lack of extensive data on PM with respect to deteriorative effect to road vehicles is regarded as problem for Afghanistan and Iraq regions (Sokolik *et al.*, 2001; Moorthy *et al.*, 2007).

The aim of this research was to examine and characterize the main parameters of desert/road dust in the provinces of Afghanistan and Iraq. Number and mass PM size distributions in the laboratory resuspension system have been researched; in addition mineral composition, water-soluble salt concentrations and pH were investigated. The results have been discussed with the respect to possible impacts on various systems of road vehicles.

MATERIALS AND METHODS

Determining PM Concentrations in Ambient Air

In order to define PM concentrations in the ambient air and in the moving motorcade, PM samples were taken using aerodynamic collector. Samples of two particle sizes – PM_{total} (airborne particles with aerodynamic diameter up to approx. 100 μm) and PM_4 (particles with aerodynamic diameter less than 4 μm) – were collected. The polypropylene cassettes (SKC Inc. USA) were used to collect PM_{total} samples; PM_4 samples were taken using PM_4 cyclones (SKC Inc. USA). Air was pumped at 2.2 L/min using personal air pumps (Model 224-PCXR4, SKC Inc, USA) for six hours in stationary locations and 20 minutes in moving motorcade. PM samples were taken on the mixed cellulose ester filters (MCE, SKC Inc. USA); filter diameter - 25 mm, pore size - 0.8 μm.

PM concentrations in ambient air were measured in the height of 1 m above the ground at three different locations: near the territory of military unit, at the automotive vehicle repair workshop, and in the motorcade (at the front and in the middle). The motorcade of vehicles consisted of 3 heavy duty vehicles and 14 light duty vehicles; the average speed of the motorcade was 15–20 km/h. During the period of measurement, the average daily temperature was 2.8°C, wind speed - 1.6 m/s, relative air humidity - 31%.

Determining of Particle Size Distribution in Resuspended Dust

Samples of desert dust were collected from near-road environments in the provinces of Kandahar, Herat, and Ghor in Afghanistan, as well as in the province of Baghdad in Iraq. Some of characteristic meteorological parameters of the sampling locations are represented in Table 1.

Samples were collected by taking ~200 g of dust, putting it into hermetic polyethylene bags, and transporting them to Lithuania, where samples were examined in the laboratories of the Department of Environmental Engineering at Kaunas University of Technology. In addition, on 12–14 of November 2009, concentrations of airborne PM were measured at Ghor province in Afghanistan.

For the resuspension of desert/road dust and subsequent measurement of particle size distribution (PSD), a special laboratory system was designed (see Fig. 1). The laboratory setup consisted of a 0.063 m^3 volume chamber. Dust was

Table 1. Typical meteorological conditions in the provinces of Afghanistan and Iraq (NOAA, 1995).

No.	Name of the Meteorological station	Coordinates of the location			Temperature (°C)					Atmosphere pressure, hPa
		Latitude	Longitude	Height above sea level	Absolute minimum	Absolute maximum	Average T in January	Average T in July	Amplitude of annual variation of air T	
		Northern	Eastern	Meters						
1	Kandahar (Afghanistan)	31°30′	65°51′	1005	–12.1	46.5	5.5	32.2	26.7	904
2	Ghor (Afghanistan)	34°34′	65°17′	2240	–46.1	41.1	–6.6	20.6	27.2	777
3	Herat (Afghanistan)	34°13′	62°13′	964	–26.0	44.0	3.3	30.5	27.2	911
4	Baghdad (Iraq)	33°14′	44°14′	34	–3.9	50.0	15.2	34.4	22.2	1013

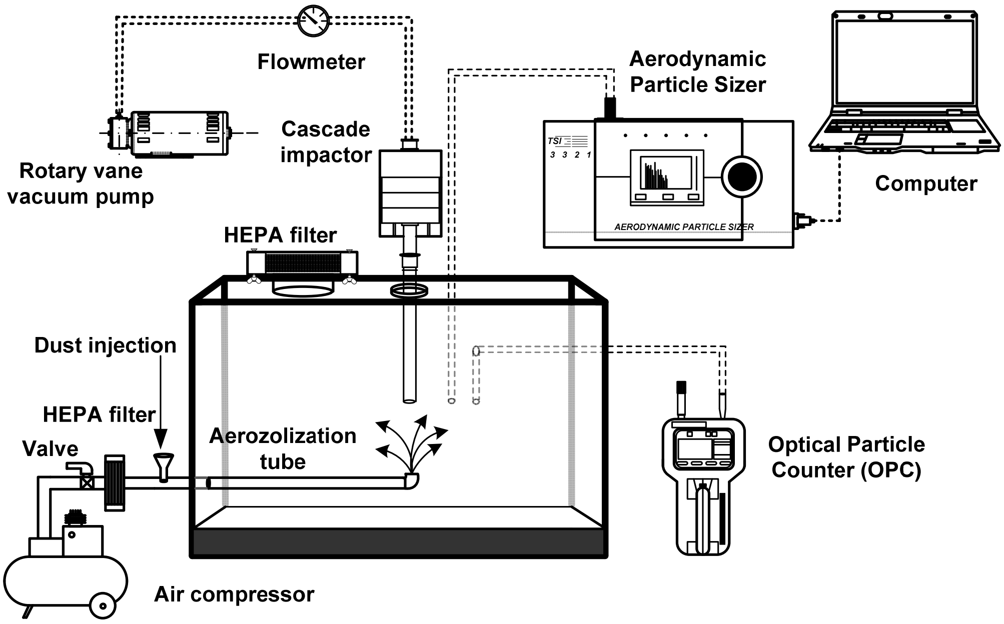

Fig. 1. Scheme of laboratory set-up for dust resuspension modelling.

resuspended and dispersed in the chamber by placing a fixed amount of dust into a pipe and blowing it into the chamber using a stream of compressed air. The flow rate of the compressed air was 0.05 m^3/s, duration - 2 s. The air supplied for resuspension was purified using high efficiency particulate filter (HEPA, class 12). The mass of resuspended dust sample was 0.1 g. In order to prevent the particles from adhering due to electrostatic forces, the inner surfaces of the chamber were covered with grounded aluminium foil. This type of resuspension chamber is attributable to the powdery and dusting materials' fluidization chambers in which dust is resuspended by direct entrainment into airflow in a tube (Gill *et al.*, 2006).

PM samples were taken from resuspension chamber using Tygon sampling tubes. Particle size distribution based on number concentration was examined using aerodynamic particle spectrometer (APS, model 3321, TSI Inc., USA) and optical particle counter (OPC, Handheld 3016, Lighthouse Worldwide Solutions Inc., USA). The measurement range of APS was from 0.5 to 20 µm in 56 size channels, with the sampling flow rate of 1 L/min. The OPC measured particle concentration in 6 channels: 0.3–0.5 µm; 0.5–1 µm; 1–2.5 µm; 2.5–5 µm; 5–10 µm; > 10 µm, with the flow rate of 2.88 L/min. Additionally, the PSD based on mass concentrations was determined using 4-stage cascade impactor (PM_{10} Impactor, Dekati Ltd., Finland). Concentrations were determined in the fractions > 10 µm; 10–2,5 µm; 2,5–1 µm; < 1 µm, with the flow rate of 10 L/min. PM samples were collected on aluminium foil plates, the surfaces of which were covered with thin layer of vacuum silicon paste (Dow Corning 732, Dow Corning Corp., USA) to prevent particle bounce-off. Before starting a new measurement, inner surface of the chamber was covered by a fresh aluminium foil. The chamber was sealed and flushed by pumping out the air until the concentration of PM was reduced up to the predetermined background value, i.e., < 200 #/m^3 for the particles of the diameter of 0.3 µm. The duration of the resuspended PM collection was 180 s.

Gravimetric Analysis

PM concentration was determined on the basis of the difference of substrate mass before and after PM exposition. Before weighing, quartz filters were conditioned for 24 hours in a thermostat (Memmert GmbH, Germany) where a constant temperature of 20 ± 1°C and the relative humidity of 30–40% were maintained in order to equalize measurement conditions. The filters were weighed using microbalance (Radwag MXA 5, Poland), with the resolution of 1 µg. During the process of weighting environmental conditions were controlled. In order to ensure the quality of analysis performed, the gravimetric analysis was performed following the principles of a good laboratory practice.

XRD Qualitative Analysis

The X-ray diffraction (XRD) analysis of road dust samples was performed using a diffractometer (DRON–6, Bourevestnik Inc., Russia). The following XRD parameters were used: CuK_α beam, Ni filter, detector movement step - 0.02°, duration of intensity measurement in a step - 0.5 s, anodic voltage U_a = 30 kV, current intensity I = 20 mA.

After performing the XRD analysis, the inter-plane distance was calculated on the basis of diffraction angles *2θ*. Having calculated the inter-plane distances, the mineral coumpounds comprising the material under examination were identified using search - match databases.

Determining Concentrations of Water-Soluble Sulphates, Chlorides and pH

The concentration of chlorides in desert/road dust was determined in accordance to the standard ISO 9297:1998. The concentration of sulphates was determined using the turbidimetric method in accordance to the standard ISO

11048:1995. The pH values of mixture of dust in water were determined in accordance to the standard ISO 10390:2003.

Mathematical-Statistical Data Processing

The obtained data were processed using Microsoft Office Excel 2003. The measured PM concentrations were normalized to the particle size and expressed as dC/dlog D_p. PM mass and numeric distribution was normalized by equating the highest concentration of resuspended particles to the unity; all the values were changed respectively in the range from 0 to 1. The PSDs were recalculated taking into account gravitational losses in the chamber depending on the particle size.

RESULTS AND DISCUSSION

PM Concentration in the Ambient Air

The authors were seeking to register the PM concentrations during sandstorms as the most extreme environment; however this episode was not registered due to short researchers' visit in the study areas. Individual measurements of PM concentrations in the province of Ghor were performed in the military unit and in a moving motorcade of automotive vehicles. The results of measurements are presented in the Table 2. The PM_{total} values measured varied in the range from 58.3 μg/m^3 to 18181.8 μg/m^3 (in the environment of motorcade). The respective PM_4 concentration values were varying in the range from 33.4 μg/m^3 to 6818.2 μg/m^3. The registered values of PM concentrations in ambient air without any soil disturbance were low, compared to other data reported from the sandstorm occasions (Avduevskij *et al.*, 1990; Fu *et al.*, 2008). This may have been expected, since the sampling took place in November, where the occurrence of sand storms is rather sparse, and the meteorological conditions are not favourable for soil resuspension. At the same time in the moving motorcade, PM concentration increased several hundreds of times compared to PM concentrations when there were no vehicles moving on the road. PM_{total} concentration in the middle of motorcade was 1.3 times higher than in the front of it, and PM_4 concentration in the middle of the motorcade was 3 times higher compared to the concentration in the front of motorcade. The movement of the vehicles caused the resuspension of larger particles, as demonstrated by the relatively low ratios of PM_4/PM_{total}. The relatively high values of PM_4/PM_{total} in other investigated locations showed that there was a substantial portion of fine particles (< 4 μm) in ambient air.

PM Size Distribution

The dust samples collected in the three provinces of Afghanistan and in the province of Baghdad in Iraq were examined with respect to resuspended PSD and the overall resuspension potential. The PSD (especially aerodynamic one) is a key parameter not only in particle behaviour control and estimation of possible health effects, but also in the filter media development process, especially for vehicle air intake systems. The PSD of airborne particles may be measured as sediment PSD (airborne particles close to the surface), minimally-disturbed PSD (the disturbance is so weak that the breakup of aggregates does not occur) and fully-disturbed PSD (aggregates are as much broken up by mechanical forces) (Shao, 2008). The PSD determined in our experiments may be attributed to the fully-disturbed particle-size distribution, which in this case is of the highest relevance and may represent desert road dust systems during strong wind or moving motor vehicles machinery events.

The PSD expressed by the relative concentration of particles is presented in the Fig. 2, while the main numeric parameters of PSDs are presented in Table 3. The PSD based on aerodynamic classification and number concentration (as measured by APS) is presented in Fig. 2(A). Samples from the provinces of Kandahar and Ghor demonstrated a clearly defined mode ($d_{Kandahar}$ = 1.98 μm; d_{Ghor} = 2.13 μm), and formation of a second mode at 1 μm. The PSD of PM in the samples taken from the provinces of Herat and Baghdad can be attributed to a bimodal one, the most pronounced mode was observed at 1.84 μm and less expressed one - at 0.90 μm. Measurements by optical classification technique (as measured by OPC) have revealed bimodal distributions in the samples from all the provinces (Fig. 2(B)). Clearly defined modes were observed in the ranges 0.5–1 μm and 2.5–5 μm. The highest concentration of resuspended particles in the samples from the provinces of Kandahar and Ghor was in the range of 2.5–5 μm; at the same time, the highest concentrations in the samples taken from the provinces of Herat and Baghdad was in the range of 0.5–1 μm.

PM mass size distribution calculated from both the APS and OPC measurements (Fig. 2(C) and 2(D)), was monomodal in the samples taken from all the provinces; the highest value was observed at > 10 μm.

The comparison of obtained PSDs with cumulative PSDs of standard particles characterized in ISO 12103-1 "Arizona test dust contaminants" revealed a shape similar to ultrafine particles PSD (A1) (Fig. 3). On the other hand,

Table 2. PM concentrations in the ambient air of various environments of the province of Kandahar.

Date of measurement	PM_{total} concentration (μg/m^3)	PM_4 concentration (μg/m^3)	PM_4/PM_{total}	Measurement characterization
2009-11-12	58.3	33.4	0.57	Near military unit
2009-11-13	85.5	42.7	0.50	Near military unit
2009-11-13	13787.9	2424.2	0.18	In the motorcade (in the front)
2009-11-13	18181.8	6818.2	0.37	In the motorcade (in the middle)
2009-11-13	1620.4	831.0	0.51	Automotive workshop (business hours)
2009-11-14	226.1	94.6	0.42	Automotive workshop (non-business hours)

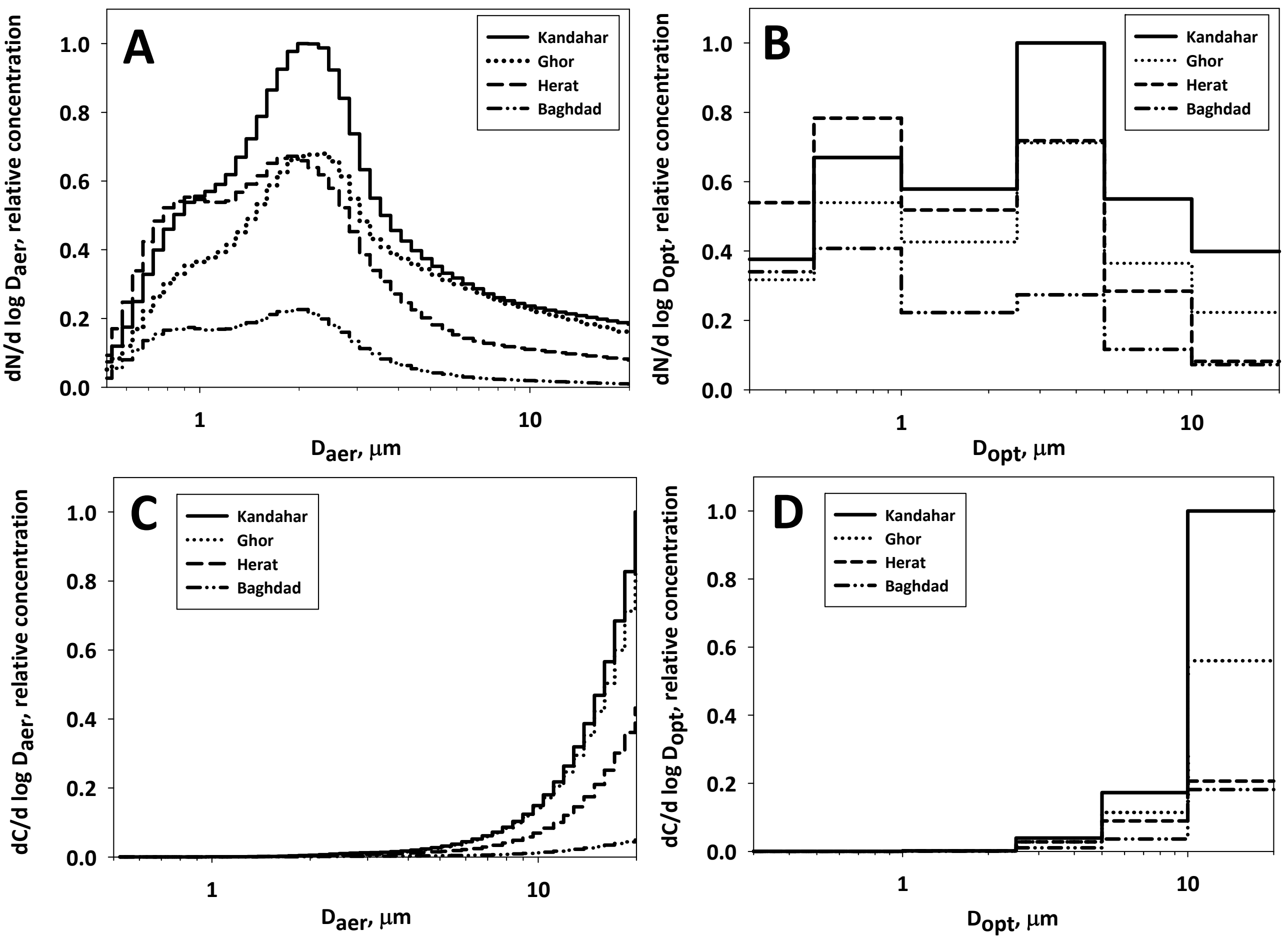

Fig. 2. Particle size distributions in samples collected in different provinces: number concentration measured using APS; B: number concentration, measured using OPC; C: mass concentration, calculated from APS measurements; D: mass concentration, calculated from OPC measurements.

Table 3. Characteristics of PSD of resuspended PM samples from researched provinces (based on measurements by APS).

Sampling location	Main mode (µm)	Median (µm)	Mean (µm)	Geometric mean (µm)	Geometric standard deviation
Kandahar	1.981	1.852	1.959	1.792	1.815
Ghor	2.128	1.915	2.012	1.843	1.839
Herat	1.843	1.734	1.806	1.694	1.752
Baghdad	1.843	1.686	1.779	1.663	1.784

the PSD curve of tested particles is shifted to left, showing a higher content of smaller particles (d_{50} = 3 µm vs. d_{50} = 4 µm). Thus, the desert/road dust from Middle East regions may have higher penetration efficiency through the automotive air filters that are tested against standard dust.

In addition to real-time instrumentation, the PSD based on aerodynamic classification and mass distribution was also measured using 4-stage cascade impactor (see Fig. 4). As expected, the PSD in the samples from all the provinces was monomodal. The largest mass of resuspended particles in the samples from Kandahar was in particles fraction > 10 µm. The largest mass of resuspended particles in Ghor, Herat and Baghdad provinces was in the range of 2.5–10 µm. The latter finding suggests that even based on mass measurements, the aerosol contained substantial portion of very fine particles, thus indicating higher potential of penetration to automotive systems.

The above presented data on particle size distributions allows assessing and comparing the potential of road dust resuspension. Shao (2008) suggested that the fully-disturbed particle-size distribution may be utilized as a measure of the potential of soil/road dust resuspension. The resuspension potential has been calculated as mass amount of emitted particles per unit of soil/road dust (× 10^3 µg/kg). The highest amount of PM was resuspended from the samples collected in the province of Kandahar - 795 × 10^3 µg/kg. The samples taken from the province of Ghor demonstrated lower resuspension potential - 560 × 10^3 µg/kg, from the province of Herat and Baghdad - 435 × 10^3 µg/kg and 160 × 10^3 µg/kg, respectively.

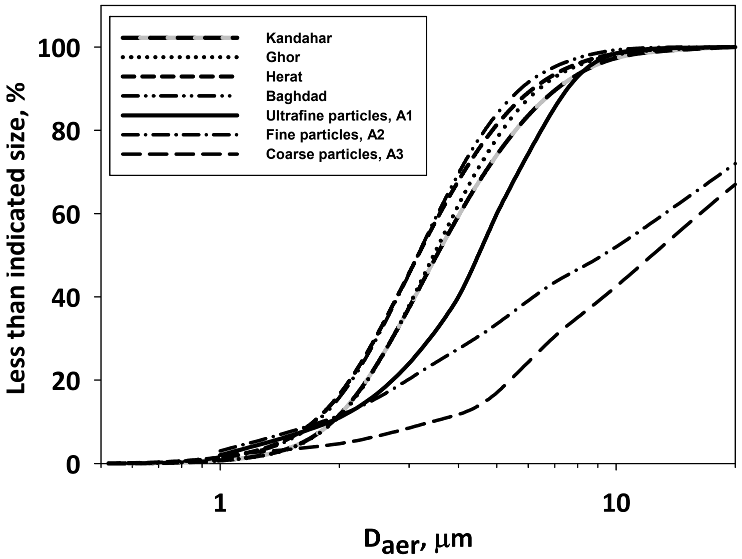

Fig. 3. PSD of dust from the provinces of Kandahar, Ghor, Herat, and Baghdad comparison with "ISO 12103-1 Arizona test dust contaminants" ultrafine (A1), fine (A2) and course (A3) particles grades.

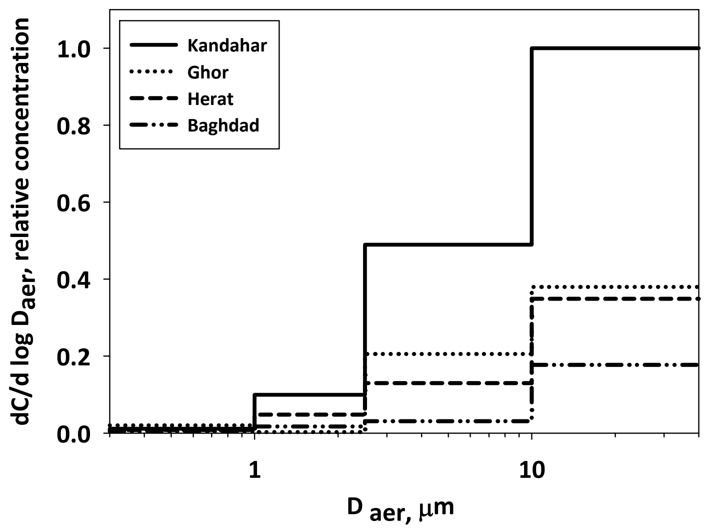

Fig. 4. PM mass size distribution in various provinces measured using cascade impactor.

Mineral Composition of Road Dust and the Potential to the Wear of Machine Elements

In order to explore the mineral composition of desert/road dust, a qualitative XRD analysis was performed. It was determined that the dust samples taken from the provinces of Afghanistan and Iraq contained the following minerals: quartz (predominant one), calcite, albite, muscovite, potassium-feldspar, nimite. The hardness of quartz, according to the Mohs scale of mineral hardness equals to 7; the hardness of albite and potassium-feldspar is 5 and 6, respectively (Wenk and Bulakh, 2004). The presence of these minerals in the moving mechanisms and engine components shows the potential to the abrasive attrition and impedes engine exploitation. For example silica particles are harder than the engine structural materials (Al-Rousan, 2006). The behaviour of hard particles in elastohydrodynamic contacts is generally different from that of ductile, soft particles because hard particles have higher resistance to deformation (Nikas, 2010). Particles of hardness near or above the contact counter-surface hardness are usually responsible for abrasive wear on a surface, which occurs as the particle dig in, slide, and plough out grooves of the material.

Concentrations of Water-Soluble Sulphates, Chlorides and pH

In order to estimate the concentrations of salines in road dust samples which can potentially cause corrosion of metals, the analysis of concentrations and pH values of water-soluble sulphates and chlorides was conducted (Table 4). The highest concentrations of water-soluble sulphates were found in the dust samples from Kandahar, while the lowest concentrations were observed in the samples from the province of Herat. The highest concentration of water-

Table 4. Concentrations of water soluble sulphates and chlorides, pH values in dust samples.

Sampling site	Sulphate concentration (× 10^3 μg/kg)	Chloride concentration (× 10^3 μg/kg)	pH
Kandahar	221.1 ± 18.3	3876.2 ± 295.2	9.3 ± 0.1
Ghor	142.0 ± 12.8	992.7 ± 141.8	9.2 ± 0.1
Herat	71.3 ± 8.5	567.2 ± 141.8	9.6 ± 0.1
Baghdad	182.7 ± 14.0	378.2 ± 81.9	9.2 ± 0.1

soluble chlorides was also found in the samples from Kandahar, while the lowest - of Baghdad. pH values varied in the range from 9.3 to 9.6, showing that road dust samples are dominated by alkaline medium.

Nishikawa *et al.* (2000) have analyzed dust from Taklamakan desert (China) and found the SO_4^{2-} concentration in the surface layer of 157 × 10^3 μg/kg, and the concentration of SO_4^{2-} in the resuspended PM of 120 μg/m^3. Cl^- concentration was 883 × 10^3 μg/kg in the surface layer and 49 μg/m^3 in the resuspended PM. The concentrations of water-soluble SO_4^{2-} and Cl^- in the road dust measured by the authors of this article are similar to that found in the samples from the Chinese desert, therefore it may be assumed that the concentrations of these salines in the ambient air may be similar. During the examinations of Iraq dust and surface layer samples, McDonald and Coldwell (2004) have found that the concentration of water-soluble SO_4^{2-} varied in the range from 600 to 40800 × 10^3 μg/kg, whereas the concentrations of Cl^- varied in the range from 61.8 to 37600 × 10^3 μg/kg; respectively, pH values varied from 6.9 to 8.9. During the research performed by the authors of this article, the values of sulphate concentrations in the samples from the provinces of Baghdad were significantly lower than that found by McDonald and Coldwell. This can be explained by the fact that McDonald and Coldwell were taking samples from different kinds of soils and different surface layers.

The survey of the research results showed substantial concentrations of water-soluble SO_4^{2-} and Cl^- in the samples taken from the provinces of Afghanistan and Iraq, therefore, road dust containing these salines can significantly speed up the processes of corrosion if making their way into an internal combustion engine. Murakami (1995) has pointed out that diesel engines may be subjected to corrosive wear of piston rings and cylinder bores caused by sulphuric acid formed from SO_4^{2-} ions. This type of corrosive wear is known to increase during low-temperature engine operation and when exhaust gas recirculation is used. Lyyränen *et al.* (2004) have suggested that main corrosive/erosive elements are mainly chlorine, sulphur compounds and alkalis. The authors pointed out that chlorine is mostly a problem in marine environments originating from intake air. In this study, we have found that substantial amounts of chlorine are present in the desert dust and could penetrate into the engine elements of vehicles.

CONCLUSIONS

Desert dusts collected from three provinces in Afghanistan and one location in Iraq were tested as potential factors for the deterioration of engine elements of road motor vehicles machinery.

In situ PM_4 and PM_{total} concentrations measured in a moving motorcade have reached 18.1 × 10^3 μg/m^3 of PM_{total} and 6.8 × 10^3 μg/m^3 of PM_4. In an environment without major soil disturbances the PM_4/PM_{total} ratio equaled to ~0.5, whereas the concentration of large-sized particles in a moving motorcade increased (PM_4/PM_{total} ratio ranged between 0.18 and 0.37).

The PM resuspension factor was highest in the samples from the province of Kandahar - 795 × 10^3 μg/kg; the resuspended PM mass in the provinces of Ghor, Herat and Baghdad were 560 × 10^3 μg/kg, 435 × 10^3 μg/kg and 160 × 10^3 μg/kg, respectively. The PM main mode of differential PSD from the samples taken at the province of Kandahar peaked at 1.98 μm, Herat and Baghdad - 1.84 μm, and Ghor - 2.13 μm.

The comparison of measured PSDs with PSDs of standard particles (ISO 12103-1) revealed a similar shape of distribution to ultrafine standard dust, but the tested desert dusts from all regions showed higher content of smaller particles (d_{50} ~3 μm vs. d_{50} ~4 μm). Thus, the desert/road dust from Middle East regions may have higher penetration efficiency through the automotive air filters that are tested against standard dust.

The analysis of XRD of road dust sample revealed that the mineral composition of road dust in different provinces of Afghanistan and Iraq were very similar, containing quartz (predominant one), calcite, albite, muscovite, potassium-feldspar, nimite. This suggests the fine dust particles have potential to cause the abrasive attrition and impede engine exploitation.

The analysis of water-soluble sulfates and chlorides has showed substantial concentrations of these salines in the samples from the provinces of Afghanistan and Iraq, indicating that the fraction of desert dust passing through the air filter may activate the processes of corrosion in the internal combustion engine.

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