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Supplemental Material

Review of Respirable Coal Mine Dust Characterization for Mass Concentration, Size Distribution and Chemical Composition

Behrooz Abbasi [1,*], Xiaoliang Wang [2,*], Judith C. Chow [2], John G. Watson [2], Bijan Peik [3], Vahid Nasiri [4], Kyle B. Riemenschnitter [5] and Mohammadreza Elahifard [1]

1 Department of Mining and Metallurgical Engineering, University of Nevada, Reno, NV 89557, USA; Melahifard@unr.edu
2 Division of Atmospheric Sciences, Desert Research Institute, Reno, NV 89512, USA; Judy.Chow@dri.edu (J.C.C.); John.Watson@dri.edu (J.G.W.)
3 Golder Associates Inc., Toronto, ON M5H 3R3, Canada; Bpeik@golder.com
4 College of Business, University of Nevada, Reno, Reno, NV 89557, USA; Vnasiri@unr.edu
5 Department of Mechanical Engineering, University of Nevada, Reno, Reno, NV 89557, USA; Kriemenschnitter@unr.edu
* Correspondence: Abbasi@unr.edu (B.A.); Xiaoliang.Wang@dri.edu (X.W.); Tel.: +775-784-6907 (B.A.); +775-674-7177 (X.W.)

Table S1. Summary of Respirable Coal Mine Dust (RCMD) characterization studies.

Study	Method	Observables	Results
Samples from underground coal mines in three Appalachian regions [1–3].	Computer controlled scanning electron microscopy with energy dispersive X-ray (CCSEM-EDX)	Number-based projected size distributions and shape	Compared to manual analysis, CCSEM-EDX detection of filter deposits increased the data acquisition rate and provided reproducible, representative results. Computer controlled analysis revealed that samples collected near production activities or in return airways have higher percentages of small particles with higher aspect ratios than samples collected near the feeder or in intake airways. Large particles dominated mass concentrations while the smaller particles dominated particle numbers.
Samples from eight mines in central and northern Appalachia [4].	Scanning electron microscopy (SEM)	Number-based projected size distributions and shape	Subsamples from each sample set were re-analyzed by manual SEM to characterize submicron particles. Of the four defined particle types (coal dust particles, mineral dust particles, dust particles associated with rock dusting products, and particles associated with emissions from diesel engines), diesel particulates should be primarily limited to the submicron range, whereas all other particle types can occur in both the sub- and supermicron ranges.

Coal dust and diesel exhaust size distributions in underground mines [5–7]	Cascade impactors (Microorifice Uniform Deposit Impactor [MOUDI])	Mass-based aerodynamic size distributions	RCMD size distributions were measured in three dieselized coal mines and two all-electric mines. Chemical mass balance (CMB) modeling was used to apportion RCMD to diesel exhaust and mineral dust sources. Diesel emissions contribute 75-90% of the submicron mode, while coal dusts contribute 92% of the coarse mode.
Thoracic dust exposure on longwall and continuous mining sections [8]	Personal cascade impactors	Mass-based aerodynamic size distributions	Particle size distributions were measured in in different mining areas. Even though respirable dust level is within limit, the thoracic dust level can be as high as five times. This paper suggests that respirable dust exposure might not be the best health predictor and recommends monitoring thoracic/respirable ratios and studying its correlation with health outcomes.
RCMD from four bituminous mines in Western Pennsylvania, Kentucky, and Maryland that used conventional and modern mining technologies [9].	Personal cascade impactors	Mass-based aerodynamic size distributions	It's not possible to distinguish the particle size distributions between specific occupations or group of occupations, and it appears that the variability in distributions may be greater between mines than between occupations.
RCMD size distribution and elemental carbon (EC) in coal mines [10]	Cascade and single stage impactors for sizes and TOT for OC/EC	Mass-based aerodynamic size distributions and EC concentration	Dieselized mines show high concentrations of submicron particles, in addition to a supermicron peak that is also seen in non-dieselized mines. EC concentration in submicron RCMD from non-dieselized coal mines was low but much higher in dieselized mines.
Characterization of aerosols in an underground mine during a longwall move [11]	ELPI, PDM3600, and filter cassettes	Number- and mass-based aerodynamic size distributions, OC and EC	During a longwall move operation, diesel engine emissions and entrainment of road dust were the primary sources of submicron and coarse aerosols, respectively.
Diesel and welding aerosols in an underground mine [12]	ELPI and FMPS	Number-based aerodynamic and mobility size distributions	Diesel exhaust particles were mostly distributed in a nucleation mode (15 nm) and an accumulation mode (70 nm). Welding fume particles were also found in an accumulation mode with a mobility diameter of 140 nm and aerodynamic diameter of 480 nm. Neither diesel exhaust nor welding produced supermicron particles.
Particle size distribution and chemical composition in an underground chrome mine [13]	Two SMPS, APS, MOUDI, and time-of-flight aerosol chemical	Number-based aerodynamic and mobility	Most submicron particles (peak between 30 and 200 nm) originated from diesel engine emissions and combustion of explosives, while supermicron particles originated from dust particles. Submicron particles

	speciation monitor	size distributions, chemical composition	were composed of 62%, 30%, and 8% of organic matter, black carbon, and major inorganic species, respectively.
Particle sources and characteristics in different areas of an underground chrome mine [14]	SMPS, OPC, ELPI, and soot particle aerosol mass spectrometer	Number-based aerodynamic and mobility size distributions, chemical composition	Number size distributions were similar at all sites, with a model 30-60 nm. Mass size distributions had one mode at 100 nm – 1 μm and the second mode at 2-5 μm. Vehicle emissions (dominated by organic matter and black carbon) accounted for 35–84% of submicron particle mass, and blasting (dominated by organic matter, sulfate, nitrate, ammonium, and black carbon) produced 7–60% of submicron particles mass in an underground chrome mine.
Ambient PM sampling was conducted at three rural residential areas in WV; The two mountaintop coal mining (MTM) sampling sites were located in valleys surrounded active MTM and other coal mining activities. A comparison site in eastern WV (Green Bank, Pocahontas County) did not have any mining activity [15].	APS and SMPS	Number-based aerodynamic and mobility size distributions	Particle size distributions were measured by an SMPS and an APS and converted to number- and mass-based lung deposition doses. Particle concentrations and lung deposition were much greater around mining areas than non-mining areas. Significant differences in the number concentration and deposited number concentration between the /MTM and non-mining areas are correlated with previously documented differences in population health outcomes including mortality, cardiovascular disease, birth defects, and cancer.

Table 2. Summary of Respirable Coal Mine Dust (RCMD) chemical characterization studies.

Study/Sample	Method	Observables	Results
Rock dust product, and pulverized shale pieces were collected from a large run-of-coal mine in central Appalachia (Peerless seam) [16].	Thermal Gravimetric Analysis (TGA)	Coal and non-coal dust mass fractions	TGA can distinguish between carbonate and non-carbonate minerals. Using this information, the influence of carbonates (i.e., rock dust used to coat mine surfaces) on the respirable fraction of dust can be evaluated. Average mass fractions of samples were: 49% coal, 47% non-carbonate, and 4% carbonate.
Sample was prepared by dissolving 0.05 g of gas coal powder in 100 ml of fluid and then 5 min mechanical stirring [17].	Differential Scanning Calorimetry (DSC)	Evaluate a new type of dust suppressant	Based on the intensity, shape and location of the endothermic and exothermic peaks, DSC provides characteristics of a multifunctional dust suppressant with agglomeration and wettability performance used in coal mine.
Samples from 12 different coals: Kaixi, Sangei, Kaipin, Jinjin, Datong (China); Loy Yang, Newlands, Blair Athol (Australia); Kangra (South Africa); Hongay (Vietnam); and IBC-106, IBC-109 (American) [18]	Differential Thermal Analysis (DTA)	Estimate combustibility	As volatile matter content of coal decreases, ignition temperature increases. Three ranks of coals (i.e., anthracite, bituminous, and lignite) were found to have different ignition characteristics, suggesting the potential of using TG/DTA to rank coal.
Pulverized Japanese brown coal (Taiheiyo coal), a mixture with 72-62% for daytime and 48-33% for night time [19].	Energy Dispersive X-ray (EDX), Inductively Coupled Plasma (ICP), and X-Ray Diffraction (XRD)	Elemental analysis	Elemental characterization of particle size-density for coal fly ash was carried out by spectrophotometry methods including ICP, XRD, and EDX. Coal fly ash mainly consists of Si, Al, Fe, Ca, and Mg. These elemental concentrations varied by density but not by particle size.
A total of RCMD 210 samples from 8 underground coal mines in three Appalachian regions [2].	Scanning Electron Microscopy with EDX (SEM-EDX)	Carbonaceous, alumino-silicate, quartz, carbonate, and heavy mineral	SEM-EDX provides general relationships between mineralogy categories and particle size/aspect ratio. Samples from the two central Appalachian mine regions had higher percentages of quartz and alumino-silicate particles than those in northern Appalachia, whereas samples from northern Appalachian mines had higher percentages of carbonate (presumably due to heavy rock dusting in many cases), and heavy mineral particles.

Airborne particulate matter (PM) from opencast coal mines, during 01–07 October 2014 for the Sonepur Bazari Opencast Project in India [20].	EDX	Surface elemental analysis and OC, EC	Surface elemental composition analysis and average organic carbon (OC) to elemental carbon (EC) ratio were estimated by EDX method. Surface elemental analysis indicates that Fe (~45–70%) and C (~30–50%) are the dominant elements $PM_{2.5}$. An OC/EC ratio for diesel vehicle and coal smoke of 3.5 was reported (typical source for opencast coal mining).
A total of 47 of RCMD samples from eight mines in central and northern Appalachia [4].	Inductively Coupled Plasma with Mass Spectrometry (ICP-MS)	Metals and trace elements.	The following 21 elements were detected by ICP-MS: Mg, Al, Si, K, V, Cr, Fe, Mn, Co, Ni, Cu, Zn, As, Se, Sn, Sr, Ag, Cd, Ba, Pb, and U. Elements K, Si, Mg, Al, Fe and Zn were present in about 80% of the samples, while rare trace elements such as Sr, As, Pb, V and U, were found in < 15% of the samples.
Two bituminous ground and sieved coal samples from Inner Mongolia, China [21].	X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR), and Raman	Inorganic and organic compounds	The shortcomings of XRD (failure to identify amorphous silica, metakaolinite, and anatase) can be remedied by a combined use of FTIR and Raman. In this study, amorphous silica and metakaolinite was found in the samples, demonstrating the need for spectroscopic methods other than XRD.
Suspensions of the National Institute of Science and Technology (NIST) reference material 1878a for quartz and 1879 for cristobalite (10 μ g ml) were prepared in isopropanol solution (CAS 67-63-5) [22].	Raman, XRD, and FTIR	Quartz and cristobalite	Data shows that Raman spectroscopy is a viable option for the quantification of the mass of respirable crystalline silica on filters. Raman signal intensity of the silicon at the same position was < 2% when collected sequentially. Repeatability in different positions was approximately 3%.
Four Australian black coal samples ranging in rank from semi-anthracite to bituminous [23].	XRD	Carbon structures (crystalline and amorphous carbon)	Based on X-ray scattering curves in the middle and high range of scattering angle, a technique is presented to obtain the maximum structural information on carbonaceous materials by XRD. Coal was found to contain a significant amount of highly disordered material, amorphous carbon, which gradually decreases during the coalification process.

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