Suggestion of a Cause-and-Effect Relationship Among Coal Rank, Airborne Dust, and Incidence of Workers' Pneumoconiosis

Steven J. Page and John A. Organiscak

Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, P.O. Box 18070, Pittsburgh, PA 15236; e-mail sep8@cdc.gov

Prolonged exposure to airborne respirable coal mine dust is responsible for coal workers' pneumoconiosis (CWP). Furthermore, miners who show evidence of higher radiographic categories of simple CWP are at increased risk of developing progressive massive fibrosis (PMF). As of 1990, there were nearly 130,000 coal miners in the United States.[1] This excludes mines that produce less than 10,000 tons annually and the anthracite coal mines. Estimates indicate that at age 58, an average of 7/1000 U.S. workers and 89/1000 U.K. workers will have developed PMF.[2-4] Health research studies have identified that the risk of developing and the severity of CWP are directly related to (1) the amount of respirable dust exposure and (2) the coal rank.[2-4] The rank of coal is its stage of formation in the series peat, lignite, sub-bituminous, bituminous, and anthracite (in order of increasing rank). The rank of coal can also be represented by the commercially important characteristics specified by its proximate analysis: fixed carbon, volatile matter, mineral matter, and moisture content.

CHARACTERISTICS OF COAL MINE DUST

Much research has been devoted to identifying cause-and-effect relationships between the properties and characteristics of coal mine dust and the incidence of CWP. Although evidence suggests both physical and chemical properties of coal mine dust contribute to CWP, no definitive conclusions have been reached. A great part of the difficulty is due to the confounding nature of "coal mine dust," which is not limited to coal dust itself but includes all mineral dusts produced from either within the coal seam or the rock strata surrounding the coal seam. The question is, what characteristics of coal mine dust, some of which are associated with rank, are related to the observed differences in exposure-effect relationships that have been observed?

To examine these questions, numerous studies[5-9] have investigated the correlation between mineral coatings that occlude the surface of a crystalline silica particle core and the rank of coal. The hypothesis is that the degree of surface occlusion determines, at least in part, the biologically available crystalline silica in an inverse relationship. Other studies[10-16] have investigated the free radicals (electric charges) found on fresh-fractured rock and coal from high rank coal areas. These studies have suggested these radicals on the surface of mineral dusts may be relevant to the pathophysiology that results from their inhalation. In particular, it has been found that freshly broken silica dust (responsible for silicosis) is more reactive in vivo than aged silica. Although not all inclusive, the above-mentioned studies represent perhaps the most viable argument for causative coal rank-related effects to date.

Current knowledge appears to suggest a significant cause-and-effect relationship between coal rank-related charging characteristics and the increased incidence of CWP in high rank coal regions. The two mechanisms most affected by the charging characteristics are enhanced respiratory deposition and inherent toxicity of airborne respirable dust (ARD). This suggestion is based on the following known facts: (1) higher rank coals produce a higher CWP incidence rate;[2-4] and (2) higher rank coals obtain a higher electrostatic charge on breakage.[17-19]

COAL RANK AND DUST GENERATION

Prior research has identified several relationships between coal rank and dust generation. Laboratory coal breakage studies have shown a significant and consistent positive correlation with the amount of respirable-size particles found in the product increasing with coal rank.[20-24] These studies show conclusively that either a grinding or crushing process yields specific total dust and respirable dust generation rates (milligrams of dust in product per kilogram of product) that increase with increasing coal rank. It is important to note these results were measurements of dust in the product and not measurements of airborne dust. This paper invites the reader to consider recently published research that may establish an important link between the electrostatic charging characteristics of coals and the high incidence of CWP in higher rank coals.

The Dust and Toxic Substance Control Branch at the Pittsburgh Research Laboratory has investigated ARD generation and electrostatic charging characteristics as they relate to coal rank. Organiscak and Page[17] and Page and Organiscak[18] performed laboratory crushing experiments on a range of low- to high-volatile bituminous coals to investigate the various factors influencing fresh ARD generation and liberation from the coal product. It was shown in these studies that the amount of ARD is positively correlated with moisture content and negatively correlated with electrostatic field. This was confirmed independently by Page.[19] The resultant effect of these factors is that different percentages of coal particles of respirable size are dispersed as ARD, with the largest amount of ARD produced occurring in a narrow range of low rank coals (more than one order of magnitude range in ARD compared to higher rank coals). It is significant that, for the first time, the amount of ARD produced from different coals can be predicted, based on well-known commercial coal rank parameters.

These same parameters that establish

the charge/rank relationship of coals may partially explain the increased prevalence of CWP observed with high rank coals through the mechanism of increased lung deposition. It has long been known that airborne dust particles can have a significant amount of electrostatic charge[25-29] and that this charge can place dusts in varying degrees of agglomeration.[26,29] Lifshits et al.[30] found that respirable-sized aluminum dust particles had lung deposition of 34% when uncharged and 66% when charged. Melandri[31] found that lung deposition of airborne particulate increased by up to 30% with charging properties of the airborne particulate, relative to a similar but otherwise neutral aerosol. Furthermore, Melandri suggested the lung deposition efficiency can be greatly affected by the charge distribution. This increased deposition may also be attributed to the higher lung deposition efficiency of agglomerated ultrafine submicron particles.[32,33]

As referenced earlier, numerous studies have shown that fresh-broken coal and quartz surfaces contain highly reactive free radicals (electric charges). This establishes the potential for cytotoxicity through bond formation with the cell membrane upon inhalation. Dalal et al.[15] noted that preliminary tests using the sheep red-blood cell hemolysis procedure indicated that fresh-crushed anthracite coal dust exhibits significantly higher homolytic activity than the same dust left in air for several hours. Dalal et al. also remarked that since exposure of fresh coal dust to air causes a decrease in the amount of the free radicals, as well as a decrease in the cytotoxicity, it is possible that the free radicals do contribute to the coal dust's cytotoxicity. Vallyathan et al.[16] observed that freshly ground silica dust exhibits a greater cytotoxic effect on cellular membrane integrity and that, because acute silicosis is frequently associated with occupations in which freshly fractured crystalline silica of respirable size are generated, fracture-generated silicon-based radicals may play a significant role in the pathogenesis of silicosis. Although the work by Organiscak and Page focused on the charging characteristics of freshly crushed coals, brief tests on various sandstones indicated the ARD generated exhibited much higher degrees of electrostatic charging.

CONCLUSION

In view of the work by Lifshits et al.,[30] Melandri et al.,[31] Dalal et al.,[11,15] and Vallyathan et al.,[12,13,16] the investigations of Organiscak and Page[17] on the charging characteristics of coal suggest a significant cause-and-effect relationship between the coal rank-related charging characteristics, enhanced respiratory deposition and toxicity of ARD, and the increased incidence of CWP in high rank coal regions.

Recommendations to improve the health of coal miners would necessarily focus on providing more effective dust generation and abatement in the mining of higher ranked coals through engineering control technology. The Pittsburgh Research Laboratory is currently pursuing more in-depth studies of coal charging characteristics and the use of water additives (surfactants) for water spray systems, which are widely used in coal mines to improve dust suppression and reduce miner dust exposure.

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