Pneumoconiosis in Carbon Electrode Workers

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Pneumoconiosis was diagnosed in five workers involved in the manufacture of carbon electrodes. Possible etiologies are discussed. It is generally believed that pneumoconiosis ceased to be a problem in this industry after World War II; however, the reported cases all resulted from exposures after 1940. These findings question the efficacy of recent and current engineering controls and suggest the need for further study of this industry.

Carbon electrodes are used in the primary and secondary production of a variety of metals, including steel and aluminum. In 1984, 11,256 workers were employed in the United States in 89 free-standing carbon electrode manufacturing facilities.[1] It is estimated that a considerably larger number are employed in the on-site manufacture of carbon electrodes used in the production of steel, aluminum, and other metals. In the Occupational Health Unit (OHU) and Pulmonary Medicine Clinic of West Virginia University (WVU) Medical Center, five cases of pneumoconiosis were recently diagnosed in carbon electrode workers. A current text of occupational respiratory disease contains the statement, "Apparently no new cases of pneumoconiosis have occurred in the American carbon electrode industry since the 1940's."[2] It is significant that the current cases all resulted from exposures after 1940. It is the purpose of this paper, in describing these cases, to focus attention on what may be a continuing occupational health problem.

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Carbon Electrode Process

The five workers described below worked in a free-standing plant manufacturing carbon electrodes. Most of the buildings currently in use were constructed in the early 1940s. Manufacture of carbon electrodes involves the following steps and exposures (Fig. 1).

1) Solid chunks of petroleum (green) coke left over from oil refineries are heated in a kiln to bake out impurities. The coke is then pulverized in crushers and roller mills and sized by wire mesh screens. This process produces exposure to coke dust.

2) The sized coke is mixed with solid pitch pellets and other binders, heated to 160°C, cooled, placed in a press, and extruded as solid carbon rods. This process produces pitch fumes and pitch dust.

3) The green carbon electrodes produced above are packed in coke and silica sand in bulk bake or sagger bake furnaces, and baked for 90 to 120 days. Pitch fumes are produced when the furnace tops are removed. Packing and unpacking the rods produces exposure to coke dust and silica.

4) After baking, carbon rods are impregnated with pitch under high temperature and pressure using autoclaves. This process produces significant exposures to pitch fumes.

5) After cooking, the pitch-impregnated carbon rods are heated to 2,100°C in electric arc furnaces, forming graphite. This process produces exposure to graphite dust.

6) The rods are then lathed and planed for final use, creating exposures to graphite dust.

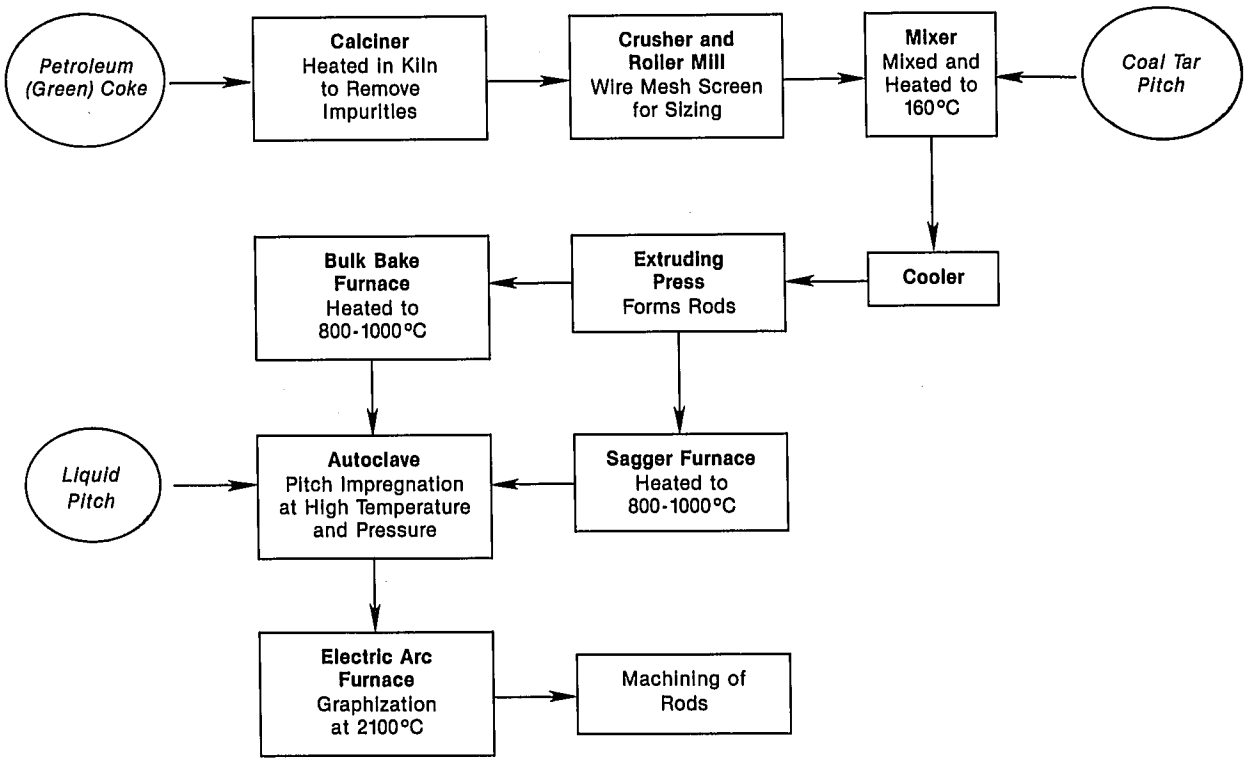

Fig. 1. General process diagram, carbon electrode production.

Potential exposures to asbestos are to be found in all the heating and furnace areas from asbestos cloth, refractories, and other asbestos material.

Case Histories

Case subjects were selected by the following criteria: 1) presence of respiratory symptoms which prompted the visit to our clinic, 2) more than 15 years job tenure in carbon electrode manufacturing, and 3) a radiograph interpreted independently by a majority of three National Institute of Occupational Safety and Health-certified "B" readers as showing category 1/0 or greater pneumoconiosis on the 1980 International Labor Organization classification.[3] The readers had no knowledge of the clinical or occupational histories. In only one case was a third reading actually required.

Case subject 1 was 49 years old when he was seen in the pulmonary clinic at WVU. He had noted exertional dyspnea and a nonproductive cough for 3 years. He was a lifelong nonsmoker.

He had worked for 24 years as a packer and unpacker of carbon electrodes in the bake furnace area and usually wore a respirator. Other work included 3 years as a plasterer, and 3 weeks in a shipyard.

Physical examination of the chest revealed minimal hyperresonance, with a slight decrease in breath sounds and no adventitious sounds, and normal heart sounds. There was clubbing of the extremities. Pulmonary function testing showed mild restriction and mild diffusing impairment (Table 1). A resting arterial blood gas breathing air demonstrated a PCO_2 of 30 torr, a PO_2 of 75 torr, and pH 7.40. The chest radiograph showed diffuse pulmonary parenchymal changes more marked in the lower zones, without pleural thickening.

An open lung biopsy revealed "marked fibrosis, with interstitial tissue and alveoli filled with coarse black pigment. Alveoli also contained crystalline material." Neither silicotic nodules nor ferruginous bodies were noted. The biopsy was subjected to extensive additional analysis, as follows.

Lung biopsy tissue exhibited a glistening greyish-black appearance with focal areas of whitish discoloration on cut surface. Histologic examination revealed diffuse interstitial fibrosis accompanied with black pigment and fibrous material. Focal areas of lymphoid infiltrate were also present. Accumulations of macrophages containing black pigment and fibers were found in the interstitium of the fibrous tissue and alveoli. There were no ferruginous bodies and occasional multinucleated giant cells were present. Examination of the lung section by polarized light showed a large number of birefringent particles and fibers. Lung sections studied by scanning electron microscopy and x-ray spectrometry showed that the mineral dust inclusions in the lung were mainly silica and aluminum silicates.

Because a large number of exogenous particles were present in the lung tissue, we studied the concentration ratios of minerals in this case. Tissue specimens as paraffin sections were deparaffinized in xylene, washed in alcohol, and dried. Sections were then ashed for six to eight hours in a low temperature oxygen plasma asher at 90 W using a pressure of 2 torr. Ash was then

TABLE 1
Clinical Findings in Five Carbon Electrode Workers

Case Subject	Job Tenure, yr	Pulmonary Function Tests*				ILO Classification[3]
		FEV_1	FVC	Ratio	DL_{CO}	
1	24	88%	75%	89%	70%	1/1 q/s, id 2/2 t/q
2	35	74%	95%	52%	68%	2/1 t/t 2/1 t/t
3	35	113%	95%	83%	86%	2/3 q/p 1/1 t/s
4	32	87%	74%	81%	73%	1/0 s/t 1/0 s/t, diffuse pl thick A-2
5	33	49%	91%	46%	ND†	1/0 q/s, em 1/0 s/t 0/1 q/r

* FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; DL_{CO}, diffusing lung capacity for carbon monoxide. Ratio is FEV_1/FVC × 100, other values are measured/predicted × 100.
† ND, not done.

suspended in deionized water and sonicated for 10 min. Aliquots of the sample were then filtered onto a 0.1-mm Nucleopore filter and air-dried. Filters were then analyzed in a scanning electron microscope equipped with an energy-dispersive x-ray analyzer interfaced with a Lemont scientific automated image analyzer. Using this automated system, 1,550 particles in randomly selected fields at a magnification of 1,000 were sized and analyzed for 31 elements found often in occupational exposures. All the particles analyzed were then classified on the basis of their major elemental make-up using standards.

The results of these studies showing the major dust burden in this case are summarized in Table 2. The exogenous particle concentration (1,973 × 10^6 particles/g, dry weight), including concentrations of silicates and crystalline silica, in the lungs of this carbon electrode worker was 4 times greater than the mean dust concentration found at autopsy in the lungs of 48 urban dwellers with no known occupational exposures (508 × 10^6 particles/g).[4]

Treatment with prednisone was begun, and continued for 3 years without improvement in symptoms or pulmonary function.

Case subject 2 was 70 years old when he was seen in the OHU at WVU. For 8 years he had noted mild exertional dyspnea and a productive cough with occasional slight hemoptysis. He reported a 12-year history of intermittent ankle edema and had been treated for atrial fibrillation.

He had a 15 to 20 pack-year smoking history, and had quit 15 years earlier.

He retired at age 65 after 35 years working as a packer and unpacker of electrodes in the bake furnace room.

Examination of the chest revealed a slightly increased anteroposterior diameter with a few fine end-inspiratory crackles. No clubbing or edema was noted.

Case subject 3 was 64 years old when he was seen in the OHU at WVU. For 5 years he had noted progressive dyspnea. He had a daily productive cough. He was a lifelong nonsmoker.

He had worked for 35 years in carbon electrode manufacturing, including 14 years machining graphite electrodes, 16 years mixing coke fines and pitch, and 5 years unloading ground coke and unpacking bake furnaces.

Examination showed a few nonpersistent basilar crackles in the left lung.

Case subject 4 was 67 years old when he was seen in the OHU at WVU. He reported progressive dyspnea for 10 years and had retired at age 62. For 3 years he noted a daily productive cough.

He had smoked a half package of cigarettes per day for 46 years, and had quit 1 year earlier.

He had worked for 32 years in carbon electrode manufacturing, primarily packing and unpacking the graphite furnace area. He usually wore a respirator. He had also worked 5 years in an underground coal mine as a brakeman.

Examination of the chest had normal results aside from the presence of a fourth heart sound.

The cardiogram showed an old inferior wall myocardial infarction.

Case subject 5 was 58 years old when first seen in the OHU at WVU. He reported 2 years of progressive exertional dyspnea and 1 year of productive cough. He had stopped working because of these symptoms. He had a 50 pack-year smoking history.

He had been employed for 33 years in carbon electrode manufacturing. While in the bake furnace area he had packed and unpacked electrodes for 18 years and worked as a laborer and mason for 10 years. He had also worked 3 years as a kiln operator and 2 years in other areas.

Examination showed the lungs to be hyperresonant, with diminished breath sounds, and faint wheezes on forced expiration.

Discussion

Pneumoconiosis has in the past been documented in workers in the carbon electrode industry.[5–7] The cited studies of carbon electrode workers described pneumoconiosis associated with exposures which took place in Britain, Italy, and Japan. In the United States, it has generally been believed that, due to modernization of

TABLE 2
Major Types of Particles Present in the Lung Biopsy Sample of a Carbon Electrode Worker

Type of Particle	Particle Concentration*	Fraction, %	Median Area Equivalent Diameter, μm
All types	2,822	100	0.65
All exogenous	1,973	70	0.70
Silica	414	15	0.81
Aluminum silicate	585	21	0.82
Kaolin	151	5	0.60
Feldspar	165	6	1.20
Iron aluminum oxide	41	1.5	0.45
Iron oxide	167	5.9	0.46
Rutile	97	4.9	0.48

* Per gram, dry weight, $\times 10^6$.

the industry after World War II, the dust hazard to carbon electrode workers is no longer an important problem.[8] However, as recently as 1972, an unpublished morbidity survey of workers from one carbon electrode plant showed significantly increased rates of obstructive airway disease, pulmonary fibrosis, and retirement due to respiratory disability (J.A. Kibelstis, National Institute for Occupational Safety and Health, 1973, unpublished data).

In the current series, all cases were diagnosed in the last 15 years, and four in the last 5 years. The manufacturing facility in which these workers were employed was constructed in the 1940s and virtually all of these exposures have occurred since that time (Fig. 2). Improvements in engineering controls have occurred in the carbon electrode industry in recent years. However, the basic manufacturing process remains unchanged and potential exists for risk to current workers. Since all of our current case subjects had exposures into the 1970s, it is unclear whether control technology has been effective.

Three of the five case subjects were current or former cigarette smokers, and this may have affected the pattern or severity of symptoms and findings in those workers. Radiographic abnormalities, predominantly irregular opacities, have been associated with tobacco smoking.[8] However, in a working population, the finding of a median reading of 1/0 by three independent "B" readers is unlikely to occur in the absence of significant dust exposure, regardless of smoking status.[9]

We have no respirable dust measurements, and thus cannot accurately characterize the causative agents. Lung disease has been found to result from several industrial exposures similar to those present in the carbon electrode industry. Two substances present in this work environment, silica and asbestos, are well recognized as causing respiratory disease.[10,11] Graphite alone has also been reported as a cause of pneumoconiosis,[12,13] although the importance of free silica in the progression of radiographic opacities in carbon-exposed workers is debated. Some studies find little effect[14] and others suggest an important contribution.[15] The role of graphite in the development of pneumoconiosis has recently been reviewed.[16]

Persons with asbestosis often have crackles on auscultation and linear or irregular radiographic shadows, predominantly at the lung bases. In contrast, silica and

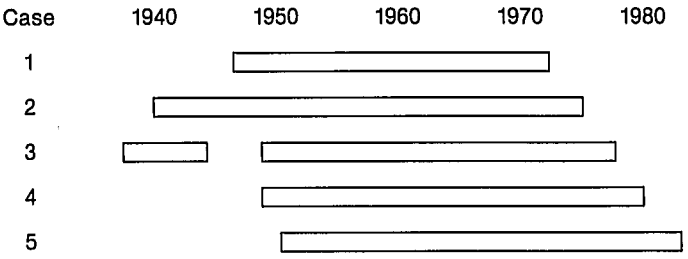

Fig. 2. Chronology of Employment in five cases of pneumoconiosis in carbon electrode workers.

coal mine dust diseases do not typically cause adventitious sounds, and result in a rounded and nodular x-ray abnormality in the upper lung zones. The clinical features of mixed dust pneumoconiosis are more variable.[8] In our series, auscultation of the chest showed a few fine basilar crackles in two workers, hyperresonance in two, and was normal in one. The pattern of radiographic abnormalities was variable. The majority of the small opacities were interpreted as the linear/irregular type. However, nearly one third of the readings showed small rounded opacities as well. No large opacities were seen (although bilateral diffuse pleural thickening was noted by one reader in case subject 4). Small opacities were recorded somewhat more often in the mid- (38%), and lower (34%) zones than in the upper zones (28%). Functional impairments associated with the radiographic abnormalities were similarly variable. Spirometry was normal in one case, showed an obstructive pattern in two, and a restrictive pattern in two. Impaired gas exchange was documented in three cases.

The lung biopsy from case subject 1 showed no ferruginous bodies or silicotic nodules. It did have considerable birefringent crystalline material, but the quantity of free silica was less than seen in typical simple silicosis. It was most marked by a coarse black pigment, presumably carbon, and a fibrous aluminum silicate.

Taken together, the variability of the clinical findings in our cases suggest a mixed dust exposure.

Conclusions

The observation of five cases of pneumoconiosis in the carbon electrode manufacturing industry suggests that

this exposure continued to pose a pneumotoxic hazard at least into the early 1960s. These findings bring into question the efficacy of control measures currently used in the industry. More research is needed to determine the adequacy of existing control technology and practices. Given the number of workers potentially exposed in the carbon electrode industry, an industrywide study of the prevalence of respiratory abnormalities in this industry is advisable at this time. Such a study should include exposure data and an evaluation of control technology. The possibility of a mixed dust etiology should be explored.

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Untidy Prose

. . . With my colleagues, I grieve for the good old days of spelling bees, the three "r's" and the vestigial apostrophe that today sometimes buzzes aimlessly over the head of a final "s."

I teach creative writing. My students teach me creative confusion. For example: "The doctor had to abandon his code of ethnics," and, "He was arrested for parking tickets and other mister meaners."

Over the years, I have recorded some of my students' greatest hits. Here are my favorites: "They came on deck yielding guns." What exemplary warfare! "She went stumbulling over rocks." Stumbulling is a far more descriptive word than stumbling. "She was frightened in the mist of her enemies." Isn't that foggy image worthy of Hitchcock? "He had a cruel shreik." "He was a drug attic." And, the most challenging: "She had to push on to her density."

—From "In the Rite Spirit," by Dorothy Evslin in *The New York Times,* Jan 16, 1988.