Chapter 8. What coal taught us about dust measurement

Silica, coal dust, and TB

In Chapter 7 we looked at how in the first quarter of the 20th century the Factory Inspectorate applied modern approaches of measurement and control to industries causing silicosis. Better control, and substitution, much reduced this disease in grinding and potteries and elsewhere, but cases still occur today where stone dust is not properly controlled.

However, in Britain from the 1930s to the 1980s coal-dust disease attracted much more occupational hygiene effort than silicosis, and this chapter shows how that effort fed into standards for silica in a curious way.

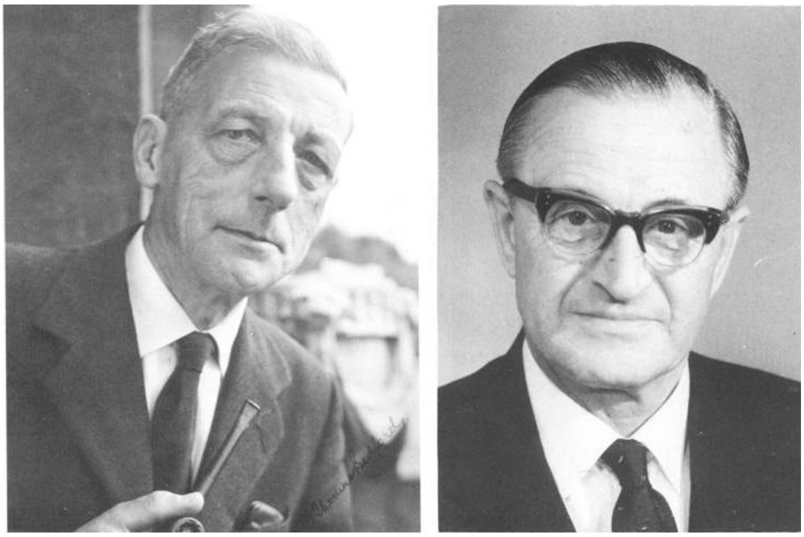

Fig. 8.1. Tom Bedford (left) and Cliff Warner, authors of the seminal 1943 report on how coal dust should be measured, and, later, founders of BOHS. The photos are from the time when they were presidents of BOHS, Bedford in 1953 and Warner in 1956.

We saw in Chapter 4 how the inhuman working conditions for women and children in mines in the 1830s and 1840s shocked the nation and led slowly to improvements. The effects of dust were less obvious, but about the same time came the first studies of the accumulation of dust in the lungs of coal miners.[1] These, however, remained controversial. Chapter 7 mentioned the confusion over the effects of silica dust and the infectious disease pulmonary tuberculosis (TB), which remained common in the population until after World War 2. There was a related confusion over the effects of coal dust, with many experts believing that although silica exposure and TB somehow worked together to increase the risk of dying, coal dust in some way usually reduced the effect of TB.[2]

Coal dust – What should we control?

Apart from the confusion over TB, the effects of coal dust were complicated. It could build up in the lung, and cause simple pneumoconiosis, with little effect on the daily life of the worker. However, coal miners could also develop the much more serious Pulmonary Massive Fibrosis (PMF), and if this was present, it might continue to progress, and lead to disability and death, even if exposure to dust stopped. PMF could occur even if the pneumoconiosis was not very severe, but it became more likely as dust accumulated. Neither simple pneumoconiosis nor PMF were apparently related to the silica in the dust.[3 4] Coal mined in different parts of the country seemed to carry different degrees of risk of pneumoconiosis, with disease being worst in the anthracite region of South-West Wales. It was known that, as with silicosis, only the fine particles could penetrate to the gas-exchange region of the lung where the damage was done, but the details of cause and effect were unclear.

By the 1930s, there were 780,000 people employed in the British coal industry, which was vital for homes and industry. The possibility of a war made conditions for coal-workers politically important. An MRC committee on their lung disease was established, and concluded that there was a form of pneumoconiosis caused by coal dust that was separate and different from silicosis. Their report also included work on the best way to measure dust, by Thomas Bedford and Clifford Warner, who were later to become founders of BOHS. They concluded that only a fraction of a percent of the coal particles which were retained in the depths of the lung were > 5 µm in diameter, and less than 20% were >3 µm, and that the hazardous factor that should be measured for hygiene purposes was the mass concentration in particles below, say 5 µm, "or perhaps the surface area".[5 6] At that time the only way of sorting by size was using a microscope. Bedford and Warner favoured collecting the dust with a thermal precipitator (which deposited the particles on a microscope cover slip) and counting particles larger than 1 µm, because this correlated well with the mass concentration of particles < 5 µm. This became the standard method of measuring dust in British coal mines until 1970; the standards applied were stricter in anthracite collieries and strictest where a tunnel was being driven into stone.[7]

Chapter 7 described similar work on silica by the Medical Inspector of Factories EL Middleton in the 1920s. Middleton had concluded that silica particles found in the lung after death were "rarely" greater than 2 µm, and he had designed his measurement method accordingly. The cut-off size for coal will be greater than for quartz, because coal is about half the density (see below), and the particle shape is different too. Taking these factors into account, Middleton's 2 µm cut-off for silica will have corresponded roughly to Bedford and Warner's 5 µm for coal.

After World War 2, the British coal industry was nationalized under the National Coal Board, which began a very big study to try to derive safe standards to control pneumoconiosis. This was the Pneumoconiosis Field Research. There were permanent staff based at 25 collieries, measuring the dust exposure of 30,000 men, whose disease was monitored by chest X-rays every 5 years. [8] At first, Bedford and Warner's method with a thermal precipitator was used, by static sampling of occupational groups, keeping track of the movement of the individual men between these occupational groups. An elaborate quality assurance scheme was necessary to ensure agreement between all the people counting the microscope slides. Despite this massive effort,

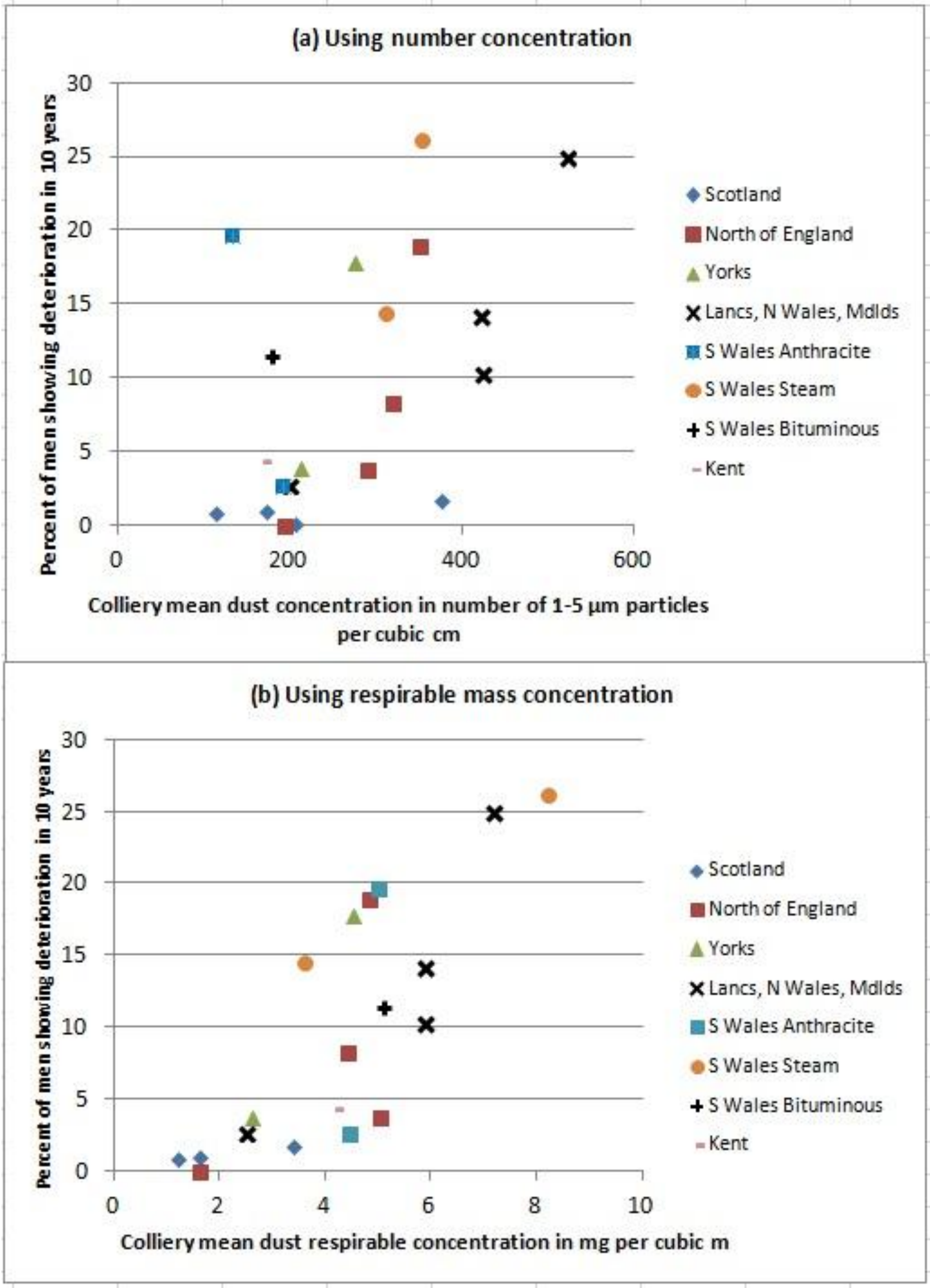

Fig 8.2. The relationship of pneumoconiosis progression and dust concentration in a huge study of British coal-miners. When the dust was measured as the number of particles in the fine size range (a), there was no useful relationship, but when the mass concentration in the respirable fraction was measured (b), this was found to be a much more useful measure of risk. Each point is a colliery mean, so it averages a range of conditions. The data used to construct these charts was taken from an IOM paper at the BOHS 1970 symposium, *Inhaled Particles III*.[9]

the study produced no useful relationship between dust exposure and pneumoconiosis progression (Fig 8.2a). The problem can be seen by comparing the South Wales and Scottish mines. As already mentioned, the Welsh mines showed much more disease at the same dust concentration.

However, during the study, an instrument became available to measure the respirable fraction gravimetrically, although still as a static instrument. The team measured the number-mass relationship by comparing the two instruments in all the important occupational groups, and converting the ten years of count data to respirable mass concentrations. This much improved the correlation (Fig 8.2b), and the Scottish and Welsh results, including the single anthracite colliery, looked as if they were part of the same relationship. In 1969, the National Coal Board established a new organization to carry the work of the PFR forward, the Institute of Occupational Medicine in Edinburgh, which in due course became independent and continues to flourish, 50 years later.

These outcomes of the PFR led to exposure limits in the coal industry based on respirable mass concentration, and incidentally illustrate the importance in occupational hygiene of measuring the component of the dust which is actually causing the disease. A hygienist using a thermal precipitator might implement controls at the higher number concentrations, but Fig 2a shows that this would mean that some of the higher-risk environments might be neglected, and instead resources might be used on environments which had a high exposure but low risk. A good correlation between environmental measure and risk (Fg 8.2b), means that control can be appropriately applied. The Coal Board's attention to dust control showed in improvement of the disease rates. In 1959, 11.2% of coalminers under 35 in South Wales had pneumoconiosis, but this had reduced to 0.6% by 1975.[10]

Measuring respirable dust

We leapt forward from Bedford and Warner's statements in 1943 about the size of particles in the lung to their vindication by the National Coal Board research presented in 1970. The work between those dates not only led to the results in Fig 8.2, but also to modern methods of measuring respirable and inhalable particles used worldwide. To understand those developments we must go back a bit.

It was known that the penetration of particles into the depth of the lung and their deposition there did not depend on the particles' physical size, but on their aerodynamic properties – most obviously the rate at which they fall out of the air, but also their inertial behaviour in the bends and divisions of the airways. Both sedimentation and inertia of a particle can be characterized by a quantity called the *aerodynamic diameter*, which is defined as the diameter of a sphere of density 1 g/cm^3 (1 kg/dm^3) which has the same terminal velocity in air as the particle: a water droplet is such a sphere. This is why silica particles found in the lung are smaller than coal particles – silica has twice the density of coal, and a similar small particle will fall twice as fast. Therefore any instrument which selected particles in the same way as the lung airways would not be like a sieve with physical holes, but must select aerodynamically. It also meant that there was no sharp cut-off in the size of particles which deposited in the lung, but a gradation. The need therefore was for an instrument with a pre-selector which removed the larger particles aerodynamically, like the lung, and which allowed the remaining most hazardous particles to be collected on a filter and weighed, so their concentration could be determined.

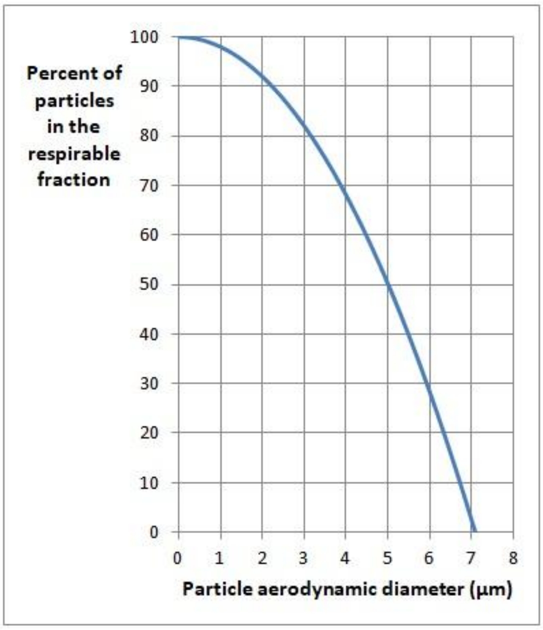

Fig.8.3. The Johannesburg or MRC definition of respirable dust.

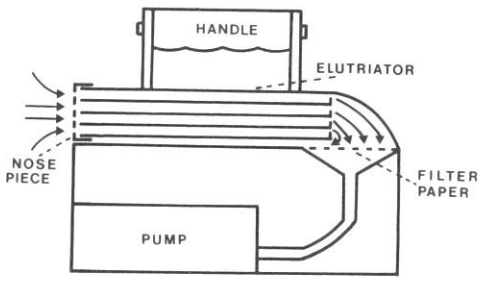

Fig 8.4. The MRE gravimetric dust sampler. The dusty air is sucked through a stack of parallel plates (the "elutriator") designed to select according to the MRC respirable definition (Fig 8.3). Photograph by courtesy of the University of Toronto Scientific Instruments Collection https://utsic.utoronto.ca/

In 1952 an MRC panel recommended that the selection curve of the preselector should be parabolic in shape, allowing through 50% of particles with an aerodynamic diameter of 5 µm (Fig 8.3).[11] This roughly matched the size of particles retained in the depths of the lung (the alveoli) which ultimately caused the disease.[12] This definition was adopted by an international conference on pneumoconiosis in Johannesburg in 1959[13], so it became known as the MRC or Johannesburg curve, and was the standard definition of respirable dust used in Britain until the 1990s. An important practical advantage was that if you pass dusty air through a stack of horizontal plates of the right size, an "elutriator", so that the heavier particles sediment out, the fraction of each size remaining fitted such a curve. Preselectors matching this definition were therefore not difficult to make. When weight-constant filters and small pumps became available, the principles were applied in coal mines by the MRE gravimetric sampler (Fig 8.4),[14] and it was this which produced the results in Fig 8.2b. This became the standard respirable dust sampler in British coal mines and for many years the reference sampler in US coal mines as well, because their permitted dust standards were based on the National Coal Board research.[15]

By the 1960s, personal sampling was recognized as a better way of measuring exposure, and at the 1965 BOHS Inhaled Particles symposium, two hygienists, Ray Higgins and Peter Dewell, introduced a miniature cyclone preselector which matched the MRC curve.[16] After various manufacturing changes, this remains in use. In the US, personal cyclones were always the sampler of choice for respirable dust, but in surface industry the cyclone and respirable definitions were somewhat different from the British one.

However, in British coal mines, the MRE sampler (Fig 8.4) continued in use as a static sampler. On longwall coalfaces, used in Britain, the air passes along the face, and it was believed that static sampling at the downwind end can satisfactorily characterize conditions on the face.

The silica anomaly

With the disappearance of deep coal-mining from Britain, silica is the commonest subject of respirable dust measurement. Respirable sampling and gravimetric standards for crystalline silica seem universal , but the reasons are probably practical rather than scientific. The 1959 Johannesburg Conference, which adopted the respirable dust definition, recommended measurement of respirable mass concentration for coal, but also recommended “in the case of quartz dust…the surface area of the respirable dust”. An ingenious South African instrument, the DISA, was made which manipulated the diffraction patterns of deposited particles to obtain the surface area concentration[17], but in the end the ease and familiarity of measuring mass concentration won. However, there has never been a justification for this approach for silica like the one for coal dust illustrated in Fig 8.2, and the importance of the surface area of silica is still an occasional subject of research.

Fig 8.5 The flow past a model head inhaling steadily through the mouth at 40 litres/min, facing and side-on to a wind of 0.7 m/sec. The flowlines are made visible by neutral-density helium-filled soap bubbles. Particle inertia makes the particles cross the flowlines where they curve, and this affects the “inhalable” concentration. (Right-hand photo courtesy of Institute of Occupational Medicine)

The inhalable fraction

By the early 1970s, measurement of respirable mass was a familiar procedure for silica or coal dust, but for the hundreds of other substances which might occur in the air as particles or droplets, many different samplers were used, and when the ranges of particle size that these collected were investigated, there were found to be big differences which varied with sampler orientation and any outside air movement. Because of this, the measurements in many cases would not have meant much. WH Walton, who 20 years before had been secretary of the MRC panel which defined respirable dust, suggested that a sensible approach was to define "inhalable" dust as what entered the mouth and nose, and to make a sampler which imitated these entry characteristics. In two papers in the mid 1970s, Ogden and Birkett investigated this in calm[18] and moving[19] air, and proposed a specification for the inhalable fraction, based on the directionally-averaged entry efficiency of the nose and mouth (Fig. 8.5). The idea started to make its way into standards, but only took off when Vincent and Mark's IOM sampler for inhalable dust became available in 1986.[20]

There remained the problem of the different European and American respirable dust definitions, but Sidney Soderholm, then at Rochester University, New York, proposed a compromise,[21] and it turned out that that the commonest American and British cyclones could both be used with the compromise by changing the flowrate. This resulted in agreement of the International and European standards ISO 7708: 1995[22] and EN 481[23]. These incorporated the new respirable convention, specification of the inhalable fraction, and also an extrathoracic fraction for dust depositing in the upper airways.

Chapters 5 to 8 have illustrated how increasing understanding and application of principles of occupational hygiene were applied to tackle the major killers of lead poisoning, silica, and coal dust. The coal dust story brings out two other things. Most development work in occupational hygiene was now outside the Factory Inspectorate, and the British researchers mentioned in this part were all prominent members of a new organization, which not only brought them together but organized conferences to debate the findings and a journal and proceedings in which many of the key papers were published. The new organization was of course the British Occupational Hygiene Society. How exactly that came about we will see in the next chapter.

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