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SIMULATION OF PAST EXPOSURE IN SLAG WOOL PRODUCTION

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Abstract—A survey of the working conditions at a Danish slag wool production factory during the early technological phase in the 1940s is presented. No exposure data, however, are available for that period. So, a full-scale simulation of the past production of slag wool has been performed. Air monitoring was carried out in the working area around the cupola furnace. The aim was to measure exposure to air pollutants other than fibres. Such exposure might have confounded a possible association between lung cancer and exposure to fibres, in the early technological phase of slag wool production. The simulation experiment demonstrated exposure to PAH, a known lung carcinogen. The effect of other concurrent exposures is difficult to assess.

Time-weighted average concentrations of particulate material ranged between 12.9 and 49.1 mg m^{-3} at the upper decks around the cupola. Corresponding concentrations of the dominant metals zinc and lead were 4.4–22.7 mg Zn m^{-3} and 0.9–4.7 mg Pb m^{-3}. Significant concentrations of PAH up to 269 μg PAH m^{-3} (4 μg BaP m^{-3}) occurred during ignition of the cupola furnace. The carbon monoxide level reached 270 ppm also during ignition.

INTRODUCTION

ONE conclusion of the International Agency for Research on Cancer (IARC) historical cohort study of MMMF production workers was that an elevated mortality for lung cancer among rock wool–slag wool workers was associated with employment during the early technological phase of this production process. Environmental conditions during the early technological phase of production were reported to be affected by the use of slag, some of which contained arsenic, and by poor ventilation, resulting in potential exposure to PAHs from furnace fumes (SIMONATO *et al.*, 1986, 1987). The early technological phase of production for the rock wool–slag wool-producing plants included in the cohort study covers mainly the late 1930s and the 1940s. As no industrial hygiene measurements were performed in those years it is very difficult to give a quantitative estimate of exposure to any of the substances in the working environment at that time.

To develop a better background for such estimates a simulation of an early rock wool production process was performed by CHERRIE *et al.* (1987). This experimental simulation was carried out in a rock wool pilot plant. The aim was to measure exposure to rock wool fibres. Possible exposures other than to fibres were not considered. In the epidemiological studies, however, the possible effects of other exposures cannot be excluded. Exposures to asbestos, polycyclic aromatic hydrocarbons (PAH), arsenic, bitumen binders and formaldehyde were mentioned (CHERRIE and DODGSON, 1986; SIMONATO *et al.*, 1986, 1987).

It was therefore decided to perform a simulation experiment aimed at measuring exposures other than to fibres. This was carried out in full scale at a Danish rock wool factory. One of the oldest production lines was taken out of the normal production and

modified for use in the experiment. At first it was intended to follow all production steps. For practical and economic reasons, it proved necessary to concentrate on the conditions around the cupola furnace.

In order to achieve conditions as close as possible to the production conditions in the early years, all available information on the raw materials, technical facilities, ventilation and work practice was collected from reports and notes, and from interviews with retired employees.

BACKGROUND

The production of rock–slag wool is in principle simple. From the beginning of the industry, production was based not on a highly developed technology, but rather on traditional workmanship and trial and error (ÖHBERG, 1987). The production process includes:

—melting the raw material (natural rock and/or slag);
—fiberization and collection of fibres;
—finishing.

PAST WORKING CONDITIONS

Raw materials

Wool production at the Danish factory began in 1937. Until 1963 the raw materials used were: granite, limestone, iron slag and steel slag. During the period 1940–1944 copper and lead slag were also used (CHERRIE and DODGSON, 1987). Slag arrived in very large lumps that had to be crushed by means of big hammers before they were transferred to a jaw crusher, from where the materials were transported by vans to the silos. All the handling of raw materials caused high generation of dust.

Furnace work

At the start of production there was one cupola furnace, which had a firebrick lining and external cooling. In 1939 a second cupola was installed which of course reduced the space around the cupolas.

Exact engineering drawings of the old cupola furnace were not available, but an old technical draughtsman at the factory elaborated sketches of the furnace and the furnace house based on memory and technical notes (Fig. 1). The furnace operation was carried out by a furnace team consisting of two men per shift. The furnace men were responsible for the maintenance of adequate flow and quality of melt to the fiberization process. For ignition of the cupola, paper and wood were used, followed by coke when there was a good fire. The raw material was loaded into the cupola in alternating layers with batches of coke. In the earliest years, the charger had to carry the raw materials by shovel from the silo outlet to the charging door in the furnace, a distance of 2–3 m. The lower edge of the charging door was approximately 1 m above the deck floor, adding to the workload of the charger. The individual raw materials were batched by the shovelful.

Normally the furnace was charged four times an hour. The charging door was kept open and occasional puffs of gas and smoke escaped the furnace through the open door.

With the high content of iron in the slag used, it was necessary to tap the iron

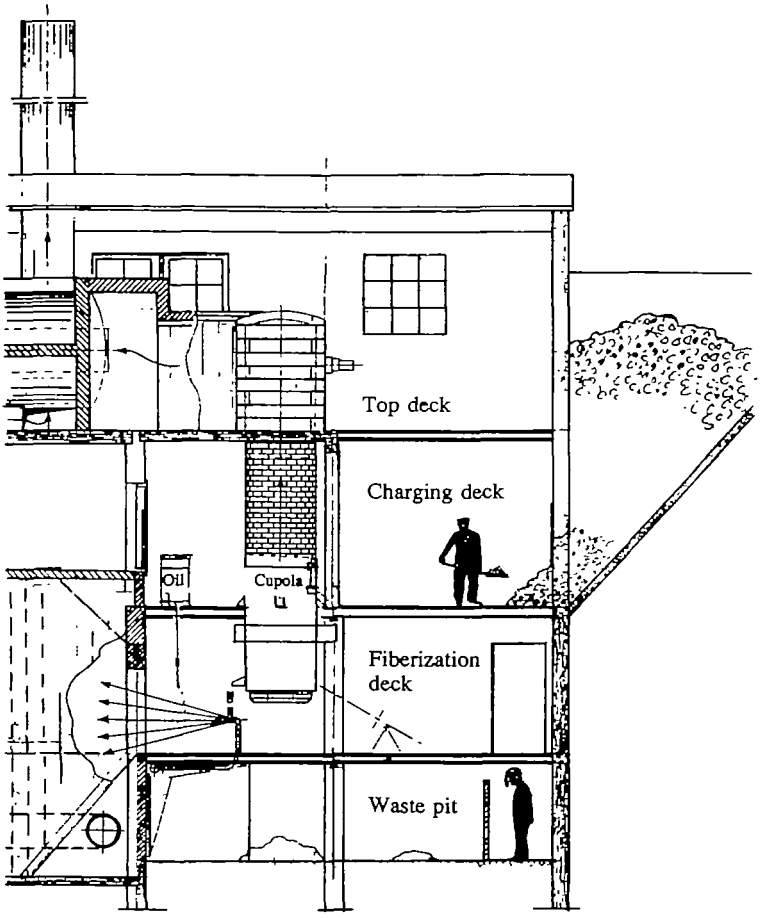

FIG. 1. Cupola furnace and furnace house.

collected in the furnace frequently, often at intervals of 1–2 h. When, after more experience and adjustments conditions became stable, tapping would normally take place twice per shift. The opening for the tapping was made using an iron bar and a sledge-hammer. In later years, oxygen lances were used instead of the iron bars.

During the early years the cupola frequently 'burned out' and then had to be emptied, knocked out. Later the normal procedure was to knock the furnace out every weekend. By knocking out the bottom of the cupola, the furnace was opened and the furnace men stood in the waste pit under the cupola to loosen the lining and slag in the furnace by hammering an iron bar up into the bottom layer. The slag and waste material dropped down into the waste pit and the men had to rush away to avoid being hit by the dropping hot slag.

A vertical boiler for production of process steam was situated at the charging deck. This boiler was later replaced by a horizontal boiler placed on the top deck. The boiler was supplementarily heated by flue gas from the cupola, which was conducted through two pipes into the boiler for burning carbon monoxide in the flue gas. Fly ash carried by the flue gas was deposited in the pipes and ducts.

The boiler had to be cleaned every weekend and a man climbed into the flue gas duct drawing a box after himself. He started to shovel ashes and soot into the box at the cupola end of the duct. His assistant pulled the full box out of the duct and emptied it into a wheelbarrow. The ashes and slag from the boiler were dropped into the waste pit through a waste duct. In a period during World War II when the boiler was fired with peat the peat dust and its ashes from the boiler were also dropped into the waste pit. This created an extreme smoke nuisance at the fiberization deck (just over the waste pit) and it was necessary to spray water at the glowing ashes.

During another period the boiler was fired with coal dust. A ball-mill was placed at the charging deck for crushing coal. A thick layer of coal dust settled on the floor, on the machines everywhere and cleaning by means of compressed air just displaced the dust and aggravated the conditions at the charging deck. The consumption of coal dust amounted to approximately 1 ton a day. Soot and fly ash from the flue was also brushed down into the waste pit from the cleaning of the cupola during the knocking out procedure.

The waste pit workers were thus exposed to dust from soot, fly ash and slag as well as metal fumes during tapping.

Fiberization

The fiberization process used during the first 15 years was steam blowing. Steam was blown through four nozzles (blow caps) towards a stream of melt flowing from the cupola outlet. The resulting fibres were collected in a collecting chamber (blow chamber) where they settled on the floor. When the chamber was filled to a height of 2 m the flow of newly produced fibres was directed to the adjacent chamber. Wooden boards were placed on top of the wool in the filled chamber and the wool was compressed by a worker stepping on the boards. The wool was then cut into 90 cm wide blocks by a long hand saw and taken out from the chamber. This so-called 'batch' process ended in 1939, when a conveyor belt was installed which made continuous production possible. The production of steam-blown wool ended in 1953 when the factory introduced a spinning machine.

The use of dust suppressants

Mineral oil was used as dust suppressant very soon (1938) after starting the wool production. At first an ordinary machine oil was used but during World War II, when mineral oil was not obtainable, various other materials were used: a mixture of skim-milk and vegetable oil was used for some years; animal fat (probably ox tallow) was also used for a while. The tallow, which was stone hard, was placed in a container close to the cupola to melt. Mixed with petroleum or diesel oil it was added to the fibres. The oil was added to the fibres approximately 0.5 m after the steam jets, i.e. before the fibres entered the blow chamber. At first the oil was supplied from a barrel placed at the charging deck. A stream of oil was made to flow—manually regulated by a screw-tap—down onto the fibres.

Despite the addition of oil, some processes were described as very dusty: particularly the production of granulated wool; and the production of stitched mats resulted in much airborne dust around the sewing machines. Two or three sewing machines were in operation, generally operated by two women and two men at each machine (in three shifts). The stitching was sealed with asphalt, which was delivered in

solid blocks and melted in an open vessel next to the sewing machine. The molten asphalt was kept warm in a trough under the machine. It was transferred to the stitching by means of rollers dipping in the asphalt.

Asphalt has also been used in several secondary productions. Since the first period of production, 'black blankets' have been produced. The wool blankets were sprayed with hot asphalt for application of paper. In this process, the worker who sprayed the blankets usually became as black as the blankets. In the late 1940s this process was abandoned and ready-made asphalt paper was used for the blankets.

The use of a formaldehyde-based binder which necessitated installation of a curing oven was not introduced before 1950.

General aspects of the working conditions

Working conditions around the cupolas in the 1940s were generally considered to be very bad. The air pollution around the cupola was serious. Retired employees have reported that the smoke sometimes was so dense that one hardly could see 1 m ahead. The workers all experienced headaches and symptoms with shivering fits followed by sweating during the night and again feeling fresh the next morning. They had from time to time observed fellow-workers fainting. An old furnace-man reported that he had charged the cupola one morning at 06.30 and later his foreman had found him lying unconscious in a wheelbarrow. It was said to be quite common that a worker had to go out in the open air and throw up. The works management had recommended that furnace-workers should spend 1–2 h in the open air before going to bed.

Up to about 1950 there was practically no ventilation or the ventilation was very ineffective. The use of binder created new air pollution problems which made installation of extract ventilation from the curing ovens necessary. The introduction of curing ovens resulted in a greater distance between the places where the wool was handled and the furnaces. This probably resulted in less pollution from the cupola area spreading to other areas of the plant.

The placing of the cupola in a furnace house separated from the other production areas by a wall in general reduced the spread of pollution from the furnace to the adjacent facilities. In some other plants the cupolas were in open connection with the other production areas. This may have caused exposure to pollution from the cupola for more workers.

THE SIMULATION EXPERIMENT

Raw materials

The composition of the charge for the experiment was based partly on old formulation data and partly on analysis of bulk samples of old wool to ensure the resulting wool had a composition similar to the old slag wool. From the old records on the raw materials used it was not possible to identify exactly all the types of slag that had been used at different times. After analysis of 13 slag samples, a Dutch blast furnace slag, a Danish steel slag and a Swedish (Laxå) copper slag were chosen (Table 1). After a preliminary experiment the amount of copper slag was increased from 5 to 15% of the charge (exclusive of coke). Based on analysis of the raw materials used in the experiments the calculated chemical composition of the charge (including coke) is given in Table 2.

TABLE 1 CHARGE COMPOSITION

Granite	100 kg
Limestone	55 kg
Blast furnace slag	220 kg
Steel slag	100 kg
Copper slag	25 kg
Total	500 kg
Foundry coke	150 kg

TABLE 2. CHEMICAL COMPOSITION OF THE CHARGE

Main components		Trace elements ($\mu g\ g^{-1}$)	
SiO_2	36.6%	Mn	7391
CaO	23.2%	Pb	7309
Al_2O_3	12.8%	Zn	941
MgO	3.7%	Cr	602
FeO	1.8%	Cu	289
Na_2O	1.5%	V	160
K_2O	1.3%	Ni	12
TiO_2	0.8%	As	7
S	0.5%	Be	3
		Cd	1

The technical facilities and experimental production

The cupola furnace used at the experiment was situated in the same place as the original furnace and modified by reduction of the inner volume with a lining of fire bricks.

Although the furnace house had been rebuilt several times, the surroundings around the cupola with the three decks were in principle unchanged (Fig. 1). The old cupola furnace operated with natural draught through a low chimney. This old chimney still existed and, for the simulation experiment, it was proposed to use this without mechanical ventilation. The environmental authorities, however, would not permit this. For this reason, mechanical ventilation had to be used, but it was kept as low as possible to simulate 'natural draught'. At the charging deck a charging door was placed in the existing furnace as it was in the old furnace. In earlier days the cupola was manually charged through this door. For technical reasons it was not possible to have manual charging during the experiment. The raw materials were mechanically charged from the top of the furnace in small batches to simulate the manual charging as closely as possible. As the charging door normally used to be kept open—due to the need for frequent charging—it was planned to keep it open during the experiments. In the first experiment, however, raw material dropped out of the open door onto the deck floor during the first charging. During the first experiment therefore the door was closed at each charging. For the subsequent experiments a grid was installed in the door opening, which made it possible to keep the door open throughout the day. For the fiberization process, it was originally planned to use the old steam-blowing operation, but again technical difficulties required the use of a spinning machine instead.

It has been presumed that the fiberization process would not influence air pollution

around the cupola much, especially as no oil or binder was to be added to the wool. From the wool chamber the wool was transported by a conveyor belt through an unheated curing oven to the take-off place, where it was manually rolled up.

Timetable for the simulation experiments

The simulation experiment was performed three times with intervals of 4 weeks. For each experiment the basic time schedule was ignition of the furnace at 07:00 with paper and wood followed by five charges of 100 kg coke. After 15–30 min the first charge of raw materials could be loaded into the furnace and about 30 min later melt would flow from the outlet and the spinner was started. The charging rate was 2000 kg h^{-1} which corresponded to a production of about 1250 kg wool h^{-1}. A tapping, to remove iron-rich melt from the bottom of the cupola, was planned for about noon, if necessary. Charging was stopped at 14:00 and final tapping and knocking out the furnace was performed at 15:00.

The experiments proceeded without major technical problems. At the first—preliminary—experiment, however, several spontaneous outbreaks of melt through the furnace bottom occurred during the day. This was due to the lining in the furnace bottom being too weak. The lining was strengthened for the following experiments. During the second experiment, the furnace operated with natural draught through only the small chimney, during the first hour, and a little later for another hour, due to a technical hitch. In this way the conditions, which had been planned for all the experiments, were accidentally obtained for those 2 h.

AIR SAMPLING AND ANALYTICAL METHODS

Air monitoring was performed at all three decks, except for the top deck during the first experiment. 'Total dust' was determined by sampling on 37 mm membrane filters in Millepore filter holders at a flow-rate of 1.9 l. min^{-1} and on 50 mm filters in a Schleicher and Schüll filter holder at a flow-rate of 20 l. min^{-1}. For determination of PAH, a sampling train consisting of a membrane filter followed by an XAD-tube was used. All samplers were placed facing downwards during sampling.

Personal monitoring was considered, but as there was very little worker activity resembling the old activities all sampling was performed as stationary area sampling. Stationary air samples were taken at a height of 1.5–2 m above the deck floor and at a distance of 1–2 m from the cupola.

Metals were detected on the filter samples by PIXE (proton-induced X-ray emission) analysis. On selected filter samples metals were determined by AAS (atomic absorption spectrophotometry) analysis or by ICP-AES (induced coupled plasma-atomic emission spectrophotometry) analysis after digestion with nitric acid. The main constituents in raw materials and bulk samples were determined by X-ray fluorescence analysis. PAH determination was performed after extraction of filters and XAD-tubes for 24 h with dichloromethane. A concentrate of the extract was analysed for 16 specified PAHs by high-pressure liquid chromatography (HPLC) using an u.v.-fluorescence detector. Carbon monoxide was determined at the sampling sites by a direct reading i.r.-spectrophotometer.

Temperature and relative humidity were also recorded during the experiments.

RESULTS

A summary of the results of the air sampling around the cupola for total airborne particulate material is given in Table 3. As the conditions during the first hour differed from the normal production period the values from this period are given separately and designated 'ignition'. The results are grouped according to sampling position (the three decks) and number of experiment (first, second and third experiment).

TABLE 3. CONCENTRATIONS OF TOTAL AIRBORNE PARTICULATE MATERIAL: TIME-WEIGHTED AVERAGE AND (RANGE) (IN mg m^{-3})

	Experiment No.		
	1	2	3
Top deck			
Ignition		67.0 (34.3–99.7)	24.4
Production		49.1 (20.4–77.6)	41.3 (28.6–49.5)
Charging deck			
Ignition	17.7	18 6 (6.6–34.7)	7.6 (5.3–9.8)
Production	12.9 (3.9–15.9)	30.4 (7.2–43.4)	20.6 (7.4–32.7)
Fiberization deck			
Ignition	5.7	23 7	7 8
Production	4.4 (2.3–8.2)	7.3 (4.9–11.3)	2.4 (1.0–4.6)
Tapping/knocking out*	12.9	4 2	9.0

*'Knocking out' was only included in the sampling period for experiment 1. During experiments 2 and 3, the fortified lining of the cupola impeded the opening of the bottom so much that only the final tapping was included in the sampling period.

Air sampling at the top deck was not originally planned, but during the first experiment air pollution at the top deck was, by a subjective judgement, found to be extremely high. Furthermore, stoking the boiler for process steam used to take place at this deck. So it was decided for the second and third experiments also to include air sampling there.

A majority of samples was analysed by PIXE analysis, by which it should be possible to determine 25 elements. Only 18 elements were present in concentrations over the detection limit. The result of the analysis of a representative air sample (from the charging deck at the second experiment during production) is shown in Table 4. The dominant metals are zinc and lead. During furnace tapping, however, high concentrations of iron were found in the samples. At the first experiment, high concentrations of iron were in general detected in the samples from the fiberization deck, probably due to the several spontaneous outbreaks of melt through the furnace bottom. A high iron content was associated with an uneven distribution of particles on the filter with coarse particles concentrated in the central area. The concentration calculation based on PIXE analysis is less reliable when much iron is present. Because of these findings, the majority of air samples from the third experiment were analysed by both AAS and ICP methods. The results of these analyses showed, however, reasonable consistency with results based on the PIXE analysis.

TABLE 4. COMPOSITION OF AIRBORNE PARTICULATE MATERIAL

Zn	63.1%
Pb	10.2%
Si	4.2%
K	2.0%
Ca	2.0%
Fe	1.9%
Al	1.5%
S	0.8%
Cl	0 3%
Cu	0.2%
Mn	0.1%
Ba	0.05%
Sn	0 05%
Ti	0.04%
Ag	0.02%
Cr	0.02%
Mo	0.01%
Sb	0 01%
Cd	n.d.
Nb	n.d.
Ni	n.d.
Rb	n d
Se	n.d.
Sr	n.d.
zr	n.d.

n.d.—not determined

A summary of the metal concentrations (Zn and Pb) during the production periods is given in Table 5. The percentage of (Zn + Pb) in the samples was 40–70%, apart from the periods when the furnace was tapped. The trace elements arsenic and chromium were detected in the air samples in very low concentration: 0.2–8 μg As m^{-3} and 1–8 μg

TABLE 5 CONCENTRATIONS OF METALS (Zn AND Pb) DURING PRODUCTION: TIME-WEIGHTED AVERAGE AND (RANGE) (IN mg m^{-3})

	Experiment No.		
	1	2	3
Top deck			
Zn		15.1 (11 0–21.8)	11.0 (7.4–13.1)
Pb		4.7 (2.3–7.9)	3.6 (2 7–4.6)
Charging deck			
Zn	4.4 (0.5–5.7)	22.7 (17.7–32.5)	8.1 (2.5–12.1)
Pb	0.9 (0.1–1.5)	3.8 (2.8–5.8)	1.2 (0.4–1.9)
Fiberization deck			
Zn	0.7 (0.6–0.7)	4.6 (4.6–4.6)	0.5 (0.5–0.5)
Pb	0.2 (0 1–0.2)	0.9 (0.9–0.9)	0.08 (0.04–0.11)

Cr m^{-3}. The highest PAH-concentration was found at the fiberization deck during the second experiment: 269 $\mu g\ m^{-3}$ of total PAHs (231 μg naphthalene m^{-3} and 38 μg other PAHs m^{-3}). A graphic representation of the determined PAH-concentrations is given in Fig. 2. The relative distribution of 16 specified PAHs in the samples taken during the ignition phase is shown in Fig. 3. The total amount of PAH in the other samples was so low that calculation of the distribution was not possible, as the concentrations for many compounds were close to or below the detection limit. High concentrations of carbon monoxide (up to 270 ppm CO) at the decks around the cupola were recorded only during the ignition phase. During the following hour the CO concentration decreased to 100 ppm or less, except in the second experiment, during which 150 ppm was recorded at the two upper decks up to 3 h after the ignition.

The temperature rose as expected during the day from rather cold morning temperatures (7–15°C) to 15–31°C in the afternoon. The relative humidity decreased correspondingly during the day.

DISCUSSION

During the ignition phase, very strong smoke pollution was observed around the cupola. This was especially true for the second experiment when natural draught only was operating from the cupola. The smoke was highly irritating and the visibility at the decks was reduced. The filter samples from the ignition phase were all black, indicating a high content of soot (carbon) particles. The highest concentrations of PAH were likewise associated with the ignition. During the production period the concentration of airborne particulate material was high—at times extremely high—at the two upper decks (time-weighted averages of 12.9–49.1 mg m^{-3}). The concentrations of the metals zinc and lead were correspondingly high at the upper decks (time-weighted averages of 4.4–22.7 mg Zn m^{-3} and 0.9–4.7 mg Pb m^{-3}). The content of zinc and lead stem exclusively from the copper slag which contained 0.7% Zn and 6% Pb corresponding to 0.09% Zn and 0.7% Pb in the charge. This demonstrates the significance of even small concentrations of volatile elements in the raw materials.

At an industrial hygiene survey performed during 1976–1978 on five rock wool–slag wool-producing plants in the United States, the highest exposure to metals was recorded for the furnace men at a plant using a lead smelter slag. The mean exposure levels were 53 μg Zn m^{-3} and 41 μg Pb m^{-3} for the cupola operator and 33 μg Zn m^{-3} and 19 μg Pb m^{-3} for the cupola charger (FOWLER, 1980). The detected concentrations of arsenic in the air samples (0.2–8 μg As m^{-3}) correspond to a content of 48 ppm As in the copper slag or 7 ppm As in the total charge. Copper slag may, however have a much higher content of arsenic than was found in the slag used in the experiment. In a survey of mineral slags a content of 1450 μg As g^{-1} in a primary copper slag has been reported (STETTLER *et al.*, 1982). A copper slag with a content of arsenic as high as 0.32% has been used in slag wool production in the United States in the early 1970s (ROE, personal communication, 1990). The use of a copper slag with an arsenic content of this magnitude must result in a significant exposure to arsenic around the cupola.

Dust measurements performed as early as 1934 in an American slag wool factory have been reported (CARPENTER and SPOLYAR, 1945). The method used (Greenburg–Smith impinger) and lack of details makes it difficult to compare the results with later

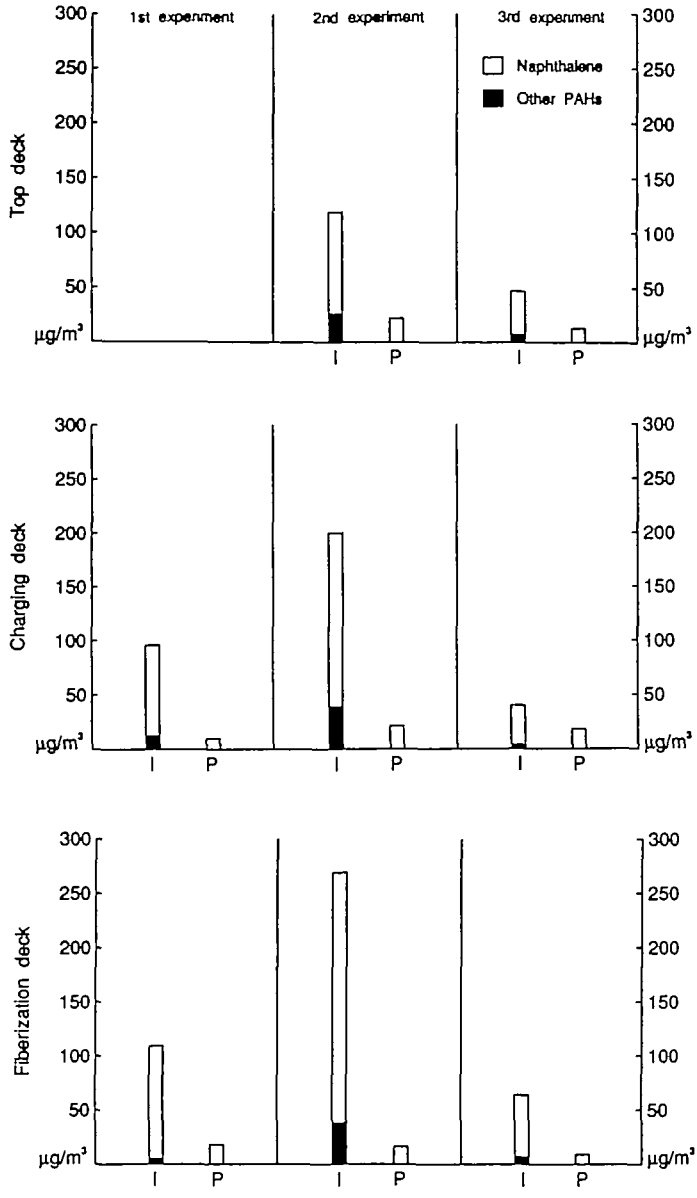

FIG. 2. Concentrations of PAHs during the ignition phase (I) and during normal production (P).

investigations. Otherwise reports on dust measurements in the rock wool–slag wool industry before the 1970s have not been found in spite of extensive information retrieval.

At an industrial hygiene survey in an American rock wool–slag wool industry an average concentration of 2.5 mg total dust m^{-3} was found in the fibre forming area ('the hot end') of slag wool production (CORN *et al.*, 1976). At a similar survey of four rock wool–slag wool factories, average concentrations in the same working areas of

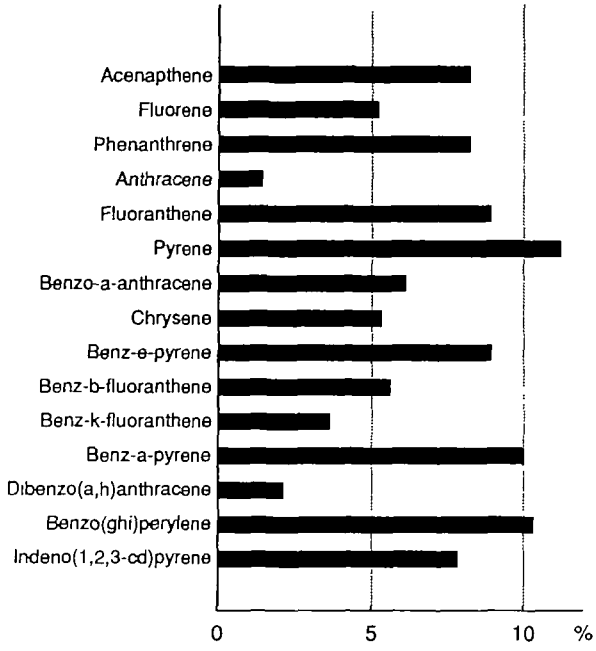

FIG 3. Relative distribution of PAHs, exclusive of naphthalene.

0.7–2.2 mg m^{-3} were reported (ESMEN *et al.*, 1978). FOWLER (1980) found a mean concentration of total suspended particulate material of 0.6–4.1 mg m^{-3} for the cupola operator and charger. In a mineral wool-producing plant in the U.K. a mean concentration of 4.8 mg total dust m^{-3} has been recorded at the fibre production line (HEAD and WAGG, 1980). In two other surveys total dust concentrations of 0.7–2.5 mg m^{-3} were demonstrated at the cupola in two American slag wool-producing plants (HAMMAD and ESMEN, 1984). Finally, in a survey of 13 European MMMF plants Ottery has reported total dust concentrations of 0.3–6, 97 mg m^{-3} at pre-production (including furnace chargers) in six rock wool plants (OTTERY *et al.*, 1984).

The formation of polycyclic aromatic hydrocarbons is clearly related to ignition of the furnace. After the ignition phase, the concentration of PAH decreased dramatically and the composition of PAH changed towards a higher percentage of volatile compounds (naphthalene) during the day. The relative distribution of the compounds less volatile than naphthalene shows that the composition was much like the composition of the airborne PAH found at the battery top in a coke plant (BJØRSETH *et al.*, 1978). Benz-*a*-pyrene (BaP) is often used as an indicator for carcinogenic PAH. The highest concentration of BaP recorded at the ignition phase during the second experiment was 4 μg BaP m^{-3} which is comparable to the exposure level at blast furnace work (LINDSTEDT and SOLLENBERG, 1982).

As no industrial hygiene measurements were performed in the early years of rock wool–slag wool production, only the reported symptoms of carbon monoxide could serve as indicator of the level of carbon monoxide concentration in those days. In a Swedish rock wool plant which had working conditions around the cupola similar to

those in this Danish plant, CO determination by indicator tubes had been performed since 1957. Exact data are not available, but concentrations over 100 ppm, the TLV of that time, were frequently reported (Öhberg, personal communication, 1988). Based on this, it is reasonable to assume that the level of exposure to CO recorded at the experiments is close to the exposure level in the old days.

The level of exposure to metal fumes, especially zinc, as found during the experiments could readily account for the symptoms of metal fume fever experienced by the furnace men in the past.

The furnace men comprise a relatively small percentage of the total workforce. During the 2 years with 'batch production' the cupola, however, was the only part of production operating in three shifts. In this way the cupola operators and chargers made up 25% of the total number of production workers in those years. Apart from the furnace men, maintenance workers have been particularly exposed to the pollution around the cupola.

External climatic conditions have undoubtedly influenced indoor pollution levels. During the second experiment (in April) it was close and rainy weather, whereas during the third experiment (in May) it was sunny and windy, with a clear sky. The periods without mechanical ventilation from the cupola during the second experiment were, however, believed to have influenced exposure levels around the cupola considerably.

CONCLUSION

Descriptions of the condition in the rock wool–slag wool-producing plants during the early technological phase indicate harsh working conditions with a low standard of general hygiene, a high level of air pollution and heavy physical work in an unpleasant thermal environment.

It is difficult—based on descriptions—to get a quantitative estimate of the pollution level. Qualified estimates were achieved by a simulation of the old production process. However, a simulation will never in practice be exactly like the original. Some parameters come close to the original, for others compromises are unavoidable. In the present simulation, manual charging of the cupola was simulated by mechanical charging in small batches. A spinner was used instead of steam blowing for fiberization. Natural draught was substituted by weak mechanical ventilation, except for the period during the second experiment when the mechanical ventilation failed. Inevitably, too, it is impossible to keep all factors constant from one experiment to another. Variations cannot be avoided, as for instance in external climatic conditions.

The exposure level during the second experiment was probably closest to the past exposure level. In this experiment, exposure around the cupola was high, especially to airborne particulate material which contained between 40 and 70% of zinc plus lead. The highest concentrations of PAH were demonstrated during the ignition of the cupola. High concentrations of carbon monoxide were also associated with the ignition phase.

Of these exposures PAH is a known lung carcinogen, and it is difficult to assess the possible lung cancer risk due to the simultaneous exposure to the very high concentration of airborne particulate material.

The simulation has demonstrated that during slag wool production, even a minimal content of volatile metals—as here zinc and lead—in the slag, could result in a high

content of these metals in the fumes around the cupola. Therefore a slag with a higher arsenic content could probably result in a substantial exposure to arsenic with a possible increased lung cancer risk.

The groups of workers exposed included the furnace men among whom the charger obviously had the highest exposure, and maintenance workers.

How useful such simulations are is of course open to discussion. A simulation gives an indication of the quality of the exposure and probably the order of magnitude of the exposure level.

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