Bitumen fume exposure during asphalt paving: Levels, composition, and exposure controls

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Summary

There is evidence that exposures to bitumen fume and PAH have declined since 1970's in the asphalt paving. However, given the uncertainty about health risks posed by bitumen fumes, it is prudent for occupational hygienists to remain vigilant and to reduce exposures as much as possible. Widespread rise in recycling of asphalt and introduction of recycled materials from other industries can potentially create new exposures and health concerns for asphalt workers. Practical steps that occupational hygienists can take in reducing exposures of asphalt pavers include keeping asphalt from overheating and retrofitting paving machines. These exposure-reducing measures can be expected to benefit all members of a paving crew. Occupational hygienists working with the asphalt industry should also be alert to changes in the composition of bitumen and its additives. New paving technologies can also be expected to alter exposure patterns during paving [Mieras, 2001]. Thus, in order to remain involved in improving working conditions among asphalt workers, occupational hygienist should establish programs for monitoring of relevant exposures, thoroughly documenting determinants of exposure, and paying particular attention to emerging issues such as dermal exposure. This is the only way to gain insights into future levels of exposure to bitumen during asphalt paving and effective means to reducing them, if necessary.

Samenvatting

De blootstelling aan bitumendampen en polycyclische aromatische koolwaterstoffen (PAK) bij asfalteren is aanzienlijk afgenomen sinds de zeventiger jaren. Echter gezien de onzekerheid omtrent de schadelijkheid van bitumendampen blijft vooralsnog voorzichtigheid geboden. Voor arbeidshygiënisten is het raadzaam bij dit soort blootstellingen naar zo laag als technisch mogelijke niveaus te streven. Het wijdverbreide hergebruik van asfalt en het (her)gebruik van materialen afkomstig van andere industrieën kan potentieel leiden tot nieuwe blootstellingen en gezondheidsrisico's bij asfalteerders. Praktische beheersmaatregelen, die een arbeidshygiënist kan adviseren teneinde de blootstelling van asfalteerders te minimaliseren, zijn het voorkomen van oververhitting van asfalt en het aanpassen van asfaltspreidmachines. Deze beheersmaatregelen zullen relevant zijn voor alle individuen binnen een asfaltploeg. Arbeidshygiënisten werkzaam in de asfaltindustrie moeten er verder op alert zijn dat samenstelling van bitumen en eventuele toevoegingen kunnen wijzigen in de tijd. Ook is het waarschijnlijk dat over niet al te lange tijd asfalteertechnieken zullen veranderen [Mieras, 2001]. Om desondanks blijvende zorg te kunnen leveren lijkt het verstandig dat arbeidshygiënisten meetprogramma's blijven uitvoeren en tegelijkertijd (veranderende) determinanten van blootstelling documenteren. Ook lijkt het raadzaam om aan dermale blootstelling bij het asfalteren meer aandacht te schenken. Alleen op deze manier zal het mogelijk blijken inzicht te houden en te krijgen in heersende niveaus van blootstelling en in effectieve beheersmaatregelen, mochten die gezien de risico's van deze blootstellingniveaus noodzakelijk zijn.

Introduction

Bitumen, derived from crude oil or naturally occurring, has been used by humans since antiquity [Broome, 1973] and according to some evidence played a role as waterproofing and binding material in construction of the Tower of Babel (Genesis 11:3). Chemically, bitumen is a complex mixture of hydrocarbons soluble in chloroform and consisting of both aliphatic and aromatic compounds, some of which bear nitrogen, oxygen or sulfur functional groups [IARC, 1985]. Forgotten for several millennia, this material started to serve humans again since the advent of industrial revolution [Broome, 1973]. In early 18th century, Erinys d'Erinys described natural bitumen deposits in Germany, France and Switzerland. However, the first bituminous road was built almost a century later, in 1810, in Lyon, France. Large-scale industrial use of bitumen started with exploitation of natural bitumen deposits in Trinidad, with first commercial shipment arriving in England in 1840's. Bitumen's main use, in terms of volume, has been in paving, as a binder for inorganic fillers in asphalt mixes. According to European Asphalt Pavement Association, there are at present approximately 4000 asphalt mixing plants in Western Europe. A typical mixing plant employs 5 to 10 individuals. These plants produce annually approximately 275 million tones of hot and 10 million tones of cold asphalt. These asphalt mixes are

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applied to road surfaces and by at least 100,000 members of paving crews across Western Europe.

In 1997, we and others initiated a study of levels and determinants of exposure among asphalt workers in eight countries (Denmark, Finland, France, Germany, Israel, the Netherlands, Norway, Sweden and Israel). The goal of the project was to support exposure assessment for the cohort study of mortality patterns among asphalt workers who are exposed to bitumen fume. This epidemiological study is led by the International Agency for Research on Cancer (IARC) and has been prompted by the ongoing concern about lung cancer risk [IARC, 1985, IARC, 1987]. Comprehensive reviews of what was known prior to 1997 about both exposure levels and health effects associated with bitumen fume and asphalt work has been published previously [IARC, 1985, Burstyn et al., 2000b, NIOSH, 2000]. Key findings of the IARC epidemiological study regarding lung cancer risk have also been releases as in internal report [Boffetta et al., 2001] and in a special issue of American Journal of Industrial Medicine [Boffetta et al., 2003a, Boffetta et al., 2003b].

This paper will focus on the new knowledge about exposure levels and their determinants in the asphalt industry that we gained in this study.

Asphalt Workers' Exposure database

Because published literature prior to 1997 did not contain sufficient data for historical exposure assessment, we set out to collect individual exposure measurements from both published and unpublished studies of the European asphalt industry [Burstyn et al., 2000a]. We constructed a database of exposure measurements, which would be used to improve our understanding of the patterns of exposure among asphalt workers. The database was developed as a stand-alone Microsoft Access 2.0 application, which could be used simultaneously in each of the national centers. No restrictions were placed on data gathered into the database, so long as it was collected in asphalt industry. However, one data set was excluded due to report from the original investigators indicating that serious errors were made in laboratory analyses. Average sampling duration for measurements included in the database was 5-6 hours. There were no grab samples among measurements that were made available to us for data entry. The majority of the measurements were personal, with 24% of samples being stationary area measurements (12% in road paving). The reported sampling strategy and reasons for sampling were documented and used as covariates in subsequent analyses. Exposure data included in the database comprised measurements of exposure levels, plus supplementary information on production characteristics and exposure controls. Production characteristics were documented in terms of type of asphalt paved, asphalt temperature and environmental conditions at the time of measurements (wind strength and its direction, precipitation, etc). Some of the documented exposure controls included composition of asphalt, personal protective equipment use, existence of cabins with doors on machines and specific local exhaust ventilation systems. Not all data points in the database had information on all of the above contextual variables, producing a highly unbalanced data set. The database contained data from early 1970's to late 1990's. The database was successfully implemented in eight countries, demonstrating flexibility and data security features adequate to the task. The database allowed retrieval and consistent coding of 38 data sets, of which 34 have never been described in peer-reviewed scientific literature. As of February 1999 the database consisted of 2007 sets of measurements from persons or locations, however it continues to grow with addition of new data from USA, Germany and Italy. Information gathered into the database is available upon request from the authors.

Trends in exposure

Once the database of industrial hygiene measurements in the asphalt industry was constructed, it was used to created models of bitumen fume, organic vapour and polycyclic aromatic hydrocarbons (PAH) exposure intensity among asphalt paving workers [Burstyn et al., 2000b]. Individual exposure measurements from pavers (N=1581) were available from all countries enrolled in the study. There was a wide variation in measured bitumen fume exposure levels: geometric mean exposure (GM) for bitumen fume was 0.28 mg/m^3 with geometric standard deviation (GSD) 6.8 for all paving operations, and GM was 2.29 mg/m^3 (GSD=6.3) for mastic paving. (Mastic paving is an operation in which asphalt is heated to temperatures that are higher than those encountered in most common road paving jobs (200-230°C), carried in buckets to paving sites from the kettle, and applied to surfaces by means of hand trowel; some advances in mechanizing mastic paving have been made). Likewise for benzo(a)pyrene, GM was 9 ng/m^3 (GSD=6.8) during all paving operations, but during mastic paving GM for benzo(a)pyrene was 62 ng/m^3 (GSD=8.8). Correlation patterns between exposure measures were examined and factors

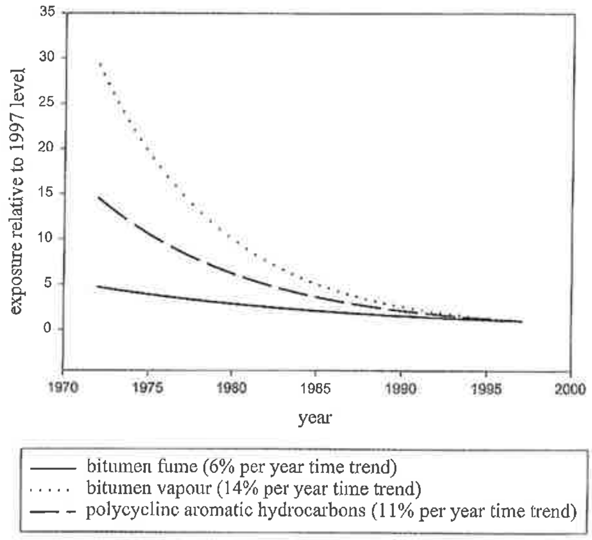

Figure 1. Predicted time trends in bitumen fume, bitumen vapour and polycyclic aromatic hydrocarbon exposures, adjusted for production characteristics and sampling methods (from Burstyn et al. 2000b)

affecting exposure were identified using statistical modeling (mixed-effects models). These models explained 56% of between-worker variance in exposure to bitumen fumes, 54% of between-worker variance in exposure to bitumen vapours, and 79% of between-worker variance in exposure to benzo(a)pyrene. Empirical adjustments for sampling methods have been made in mixed effects models. All exposures steadily declined over 20 years prior to 1997 (Figure 1). Mastic paving, re-paving (recycling of asphalt surfaces), surface dressing (application of hot binder to road surface, followed by spreading of gravel on top of it), and oil gravel paving (application of cold bitumen-based binder to road surfaces, an old technique mostly used on country roads in Scandinavia) were significant determinants of bitumen fume exposure. The highest bitumen fume exposures were observed during mastic paving in enclosed spaces and re-paving that involved heating of the old asphalt with propane burners. Coal tar use dictated PAH exposure levels, however coal use has been discontinued in Western Europe (in 1991 in the Netherlands). Asphalt temperature did not appear to be a strong predictor of bitumen fume exposure (Figure 2), although elevated asphalt temperatures (on the order of 200°C) in mastic paving versus regular road paving (on the order of 130-160°C) were probably responsible for high bitumen fume exposure during mastic laying. It was also observed that across Europe, different sampling and analytical methods were used that had large impact on the observed

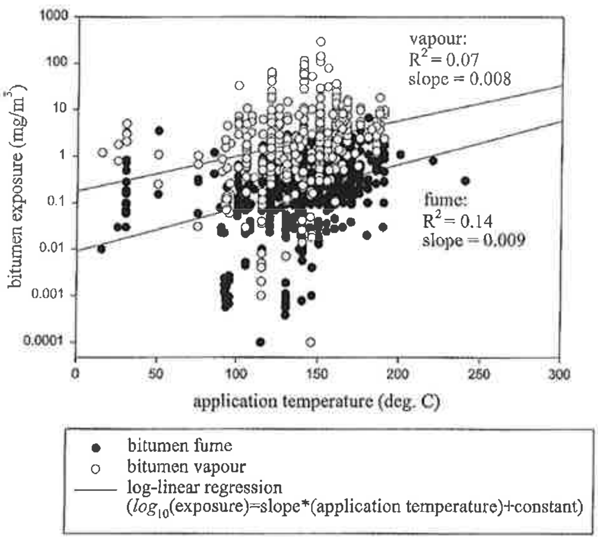

Figure 2. Influence of application temperature on bitumen fume (n=855) and bitumen vapour (n=411) exposures in non-mastic applications (from Burstyn et al. 2000b)

exposure levels, emphasizing the need to standardize monitoring methods for semi-volatile compound such as bitumen. The association of re-paving with increase exposure to bitumen fume and benzo(a)pyrene deserves a special attention, since re-paving (recycling) activities are on the increase [Burstyn and Kromhout, 2000a]. Furthermore, paving of reclaimed or recycled asphalt can lead to introduction of new hazardous emissions into bitumen fume. For example, alarms have been raised about change in toxicity of emissions during asphalt paving due to use of rubber from recycled tires in asphalt mix [Miller et al., 1999].

Do members of the same paving crew doing different jobs experience similar exposures?

There have been numerous speculations that persons performing different jobs within a paving crew have different bitumen fume exposure. We used information in the Asphalt Workers' Exposure database to address this question objectively by investigating whether a crew of paving workers is uniformly exposed to bitumen fume and benzo(a)pyrene [Burstyn and Kromhout, 2000b]. Data on paving workers with up to six repeated exposure measurements were extracted from the database of exposure measurements (N=591). The uniformity of exposures to bitumen fume, and benzo(a)pyrene was evaluated while grouping individuals by job titles, primary tasks, crew membership and use of coal tar. The estimated ranges within which 95% of individual mean exposures were expected to fall ($_{BW}R_{0.95}$) were used to assess exposure uniformity. Persons employed within a crew performed different functions (jobs) on the same project. We found that there was substantial variability in exposures between paving crews, as well as persons holding the same "job" or doing the same "task", but each crew was uniformly exposed to bitumen fume and benzo(a)pyrene ($_{BW}R_{0.95}$ 2 and 1, implying that the ratio in exposures between the most highly and the least exposed person in a group is 2 and 1, respectively). However, workers within one and the same crew engaged in paving with coal tar-containing binders were not uniformly exposed to benzo(a)pyrene. Thus, in modern asphalt paving in the Netherlands one can expect all members of a paving crew to have similar bitumen fume exposure. This was later confirmed for inhalation exposure to bitumen during asphalt paving in the Netherlands in 1998, although dermal exposure to bitumen fume condensate might not be uniform with a paving crew [Burstyn et al., 2002a]. Therefore, exposure controls for paving operations can be expected to benefit all members of a paving crew.

Innovative engineering exposure control measure from Norway

Some exposure data sets retrieved for the epidemiological study had unique supplementary information that could be exploited in order to identify measures that can reduce exposure concentrations in workplace and to better understand composition of bitumen fume [Burstyn et al., 2002b]. Data from a two-year survey conducted in Norway (1991-92) contained a very detailed documentation of production conditions (grade of bitumen and asphalt used, and emulsion use) and control measures. 320 samples of airborne organic matter were gathered (279 from paving). Median personal bitumen fume measurements ranged from 0.03 to 0.15 mg/m³ and were similar in paving and asphalt mixing. According to principal component analysis there were three independent sets of PAHs: (a) PAHs lighter than 228 g/mol, (b) 4- to 6-ring PAHs non-detectable in 80-90% of samples and (c) naphthalene. Some NO_2 (1/49) and CO (12/58) concentrations near paving equipment exceeded 15 minute Norwegian exposure limits, 2 ppm and 25 ppm respectively. Changing sampling methods midway through the study had significant impact on measured bitumen fume levels. In analyses restricted to 1992 portion of the survey (i.e. with uniform sampling methods), lower application temperatures did not reduce bitumen fume exposures, but the interplay between bitumen hardness and asphalt temperature was complex, and we concluded that it was reasonable to recommend keeping asphalt temperature as low as possible and to avoid overheating asphalt [Brandt and de Groot, 1999]. Retrofitting a paving machine with ventilated tarp that covered paving machine's screed (Figure 3) produced at least a five-fold reduction in exposure to airborne organic matter. Similar results were obtained in experimental evaluation of this control measure [Norwegian Road Research Laboratory, 1992]. This control measure is analogous to the method recently proposed by National Institute of Occupational Safety and Health

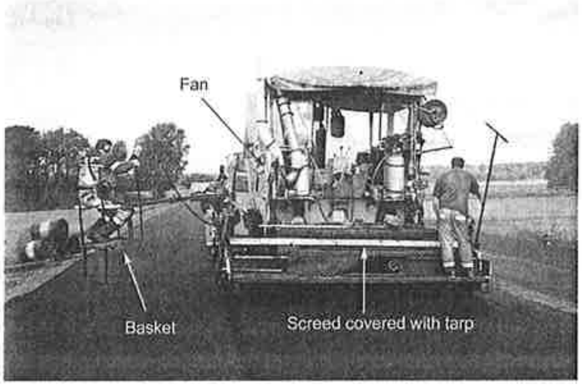

Figure 3. Paving machine in Norway circa 1992 equipped with special carrying basket for screedman, and the screed covered by tarpaulin and ventilated by a fan (from Burstyn et al. 2002b)

[NIOSH, 1997, Mead et al., 1999, Mead et al., 1999]. Work in tunnels increased PAH exposures, but general ventilation partially counteracted this effect.

Importance of benzo(a)pyrene content of asphalt binder

A data set from France had information on benzo(a)pyrene content of asphalt. This unique piece of information was used to study a relationship between chemical composition of asphalt and airborne benzo(a)pyrene exposures (Burstyn and Kromhout, 2000b) In these data three types of binder were used: bitumen fluxed with petroleum oil (6 samples, one crew), bitumen modified by "vapo cracking residue" (8 samples, one crew), and bitumen mixed with coal tar of various quality (20 samples, 3 crews). Petroleum oil contained <1 mg/kg benzo(a)pyrene and "vapo cracking residue" contained 440 mg/kg benzo(a)pyrene. On average, the benzo(a)pyrene content of the coal tar used in binder varied from 1670 to 7900 mg/kg. The amount of coal tar added to the asphalt binder was substantial: up to 50% in so-called "tar bitumen". Benzo(a)pyrene in binder can come from either bitumen itself or additives (petroleum oil, "vapo cracking residue" and coal tar in this case). We observed a very strong correlation between the benzo(a)pyrene content of the binder used in surface dressing and that of the additives ($r=0.99$, $p<0.0001$, $n=34$), supporting the notion that bitumen is not the primary source of benzo(a)pyrene in the binder. Personal benzo(a)pyrene exposures increased as the

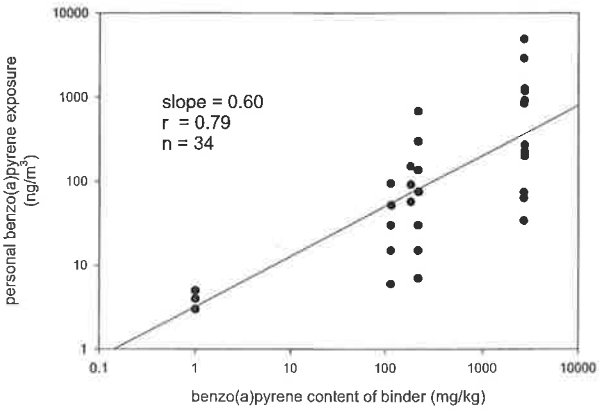

Figure 4. Correlation between benzo(a)pyrene content of binder and personal benzo(a)pyrene exposure levels in surface dressing (from Burstyn and Kromhout 2000b)

benzo(a)pyrene content of a binder becomes greater (Figure 4). These results indicate that occupational hygienist need to be vigilant about PAH content of additives to bitumen, and be alert to variations in composition of the bitumen itself.

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