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Exposure to Rubber Fume and Rubber Process Dust in the General Rubber Goods, Tyre Manufacturing and Retread Industries

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This study assesses the current patterns and levels of exposure to rubber fume and rubber process dust in the British rubber industry and compares and contrasts the data obtained from the general rubber goods (GRG), retread tyre (RT) and new tyre (NT) sectors. A total of 179 rubber companies were visited and data were obtained from 52 general rubber goods, 29 retread tyre and 7 new tyre manufacturers. The survey was conducted using a questionnaire and included a walk-through inspection of the workplace to assess the extent of use of control measures and the nature of work practices being employed. The most recent (predominantly 1995–97) exposure monitoring data for rubber fume and rubber process dust were obtained from these companies; no additional sampling was conducted for the purpose of this study. In addition to the assessment of exposure data, evaluation of occupational hygiene reports for the quality of information and advice was also carried out.

A comparison of the median exposures for processes showed that the order of exposure to rubber fume (E, in mg m^{-3}) is: E_{moulding} (0.40) ≈ $E_{\text{extrusion}}$ (0.33) > E_{milling} (0.18) for GRG; E_{press} (0.32) > $E_{\text{extrusion}}$ (0.19) > $E_{\text{autoclave}}$ (0.10) for RT; and E_{press} (0.22) ≈ $E_{\text{all other}}$ (0.22) for NT. The order of exposure to rubber fume between sectors was E_{GRG} (0.40) > E_{RT} (0.32) > E_{NT} (0.22). Median exposures to rubber process dust in the GRG was E_{weighing} (4.2) ≫ E_{mixing} (1.2) ≈ E_{milling} (0.8) ≈ $E_{\text{extrusion}}$ (0.8) and no significant difference ($P = 0.31$) between GRG and NT sectors. The findings compare well with the study carried out in the Netherlands [Kromhout *et al.* (1994), *Annals of Occupational Hygiene* 38(1), 3–22], and it is suggested that the factors governing the significant differences noted between the three sectors relate principally to the production and task functions and also to the extent of controls employed.

Evaluation of occupational hygiene reports indicated a number of shortcomings including lack of suitable and sufficient information with regard to sampling and analytical methods in use, poor sampling strategy, lack of appreciation regarding true rubber process dust, and a poor understanding of the principles of control for substances assigned maximum exposure limits. Crown Copyright © 2000 Published by Elsevier Science Ltd on behalf of British Occupational Hygiene Society. All rights reserved.

Keywords: rubber fume; rubber process dust; occupational hygiene reports; rubber industry

INTRODUCTION

Epidemiological studies have suggested that chronic exposure to rubber fume and rubber process dust may be associated with lung, pharyngeal, oesophageal and stomach cancers across wide sectors of the industry (Baxter and Werner, 1980; IARC, 1982; Sorahan *et al.*, 1986, 1989; Veys, 1992; Kogevinas *et al.* 1998). Although a specific carcinogen has not been clearly identified, rubber fume has been shown to contain small and variable amounts of mutagenic substances (Sorsa *et al.*, 1982; Baranski *et al.*, 1989). In epidemiological investigations the import-

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ance of occupational exposures in determining the excesses in diseases found in the rubber industry has become less clear with the progress of time (Straughan, 1998). This has been attributed to a lack of a clear time–dose response and to confounding factors including geographic and socio-economic variables. Furthermore, there has been little reliable task-specific exposure data which would show the long-term trends in occupational exposure and help us understand the causal and confounding factors in epidemiological investigations. A recent study examining occupational exposure trends in a broad range of industries has suggested that there is a significant lack of reliable exposure data reported in the occupational hygiene literature and that this may be due to the lack of reporting by occupational hygienists (Symanski *et al.*, 1998).

For the rubber industry a number of studies on exposure assessment was reported in the literature during the 1970s and 1980s (Parkes *et al.*, 1975; Nutt, 1976; HSE, 1981; McKinnery and Heitbrink, 1984; Wolf, 1989). These studies focused on exposure to airborne particulates, including the cyclohexane-soluble fraction, *N*-nitrosoamines and solvent vapours. More recently studies have also begun to focus specifically on the likely sources of exposure, the effectiveness of controls at reducing exposure, and the usefulness of protocols for the systematic workplace investigation of exposure to chemical agents in the rubber industry (Swuste *et al.*, 1993; Kromhout *et al.*, 1994; Tongeren *et al.*, 1995; Swuste and Kromhout, 1996). Earlier studies had reported significant differences in exposure to rubber process dust and fume between the tyre and general rubber goods sectors (Parkes *et al.*, 1975; HSE, 1981). However, a recently conducted study of exposures in the Dutch rubber industry (Kromhout *et al.*, 1994) suggests that the earlier reported differences between the tyre and general rubber goods sectors were not apparent.

Rubber fume is fume evolved in the mixing and milling of natural rubber or synthetic elastomers, or of natural rubber and synthetic polymers combined with chemicals, and in the processes which convert the resultant blends into finished products or parts thereof, and include any inspection procedures where fume continues to be evolved. Rubber process dust is defined as the mixed dust arising in the stages of rubber manufacture where ingredients are handled, weighed, added to or mixed with uncured material or synthetic elastomers. It does not include dust arising from the abrasion of cured rubber (HSC, 1997). For rubber fume and rubber process dust a no-observed-adverse-effect-level (NOAEL) has not been identified, and in the UK, occupational exposure to rubber fume and rubber process dust are subject to specific controls for carcinogens under the Control of Substances Hazardous to Health (COSHH) Regulations 1999 and the Carcinogens Approved Code of Practice (HSE, 1999a). Rubber fume and rubber process dust have been assigned maximum exposure limits (MELs) under COSHH of 0.6 mg m^{-3} cyclohexane-soluble material (CSM) and 6.0 mg m^{-3}, respectively, and these limits refer to an 8-hour time-weighted average (8-h TWA) exposure (HSE, 1999b). The COSHH Regulations require that the exposure to rubber fume and rubber process dust should not exceed the MEL when averaged over the 8-h reference period and should be reduced as low as reasonably practicable below the MEL. In addition, specific occupational exposure limits for individual components, such as carbon black, will also apply and may influence the control measures employed.

Occupational exposure limits are set by the Health and Safety Commission (HSC) on the recommendations of the Advisory Committee on Toxic Substances. The limits are subject to reviews which take into account, amongst other factors, the typical exposure levels encountered in the industry of concern. The limit set for fume in 1987 involved a phased reduction from 0.75 mg m^{-3} to 0.6 mg m^{-3} in 1991; while for rubber process dust the limit was set at 8.0 mg m^{-3} in 1987, and because industry was able to achieve lower levels than this, the limit was further reduced in 1995 to 6.0 mg m^{-3}. There are three reasons why exposure data are of vital importance to any future review of the risks from rubber fume and rubber process dust. These are:

- to link the findings of any epidemiological studies of ill-health effects to exposure levels;
- to establish current levels of compliance; and
- to form a view as to what is ‘as low as is reasonably practicable’ for this industry, these substances and these manufacturing processes.

With these in mind the Health and Safety Executive (HSE) undertook a two-year survey to determine current occupational exposure levels to rubber fume and rubber process dust in the general rubber goods, tyre manufacturing and retread industries in Britain. The immediate objectives were to gather exposure data from the factories’ own occupational hygiene reports, identify the processes and work activities where highest exposures were being recorded and compare and contrast, where appropriate, data obtained from the different industries studied. In addition to assessing the current exposure levels, the survey was also designed to focus on factors that influence exposure and its assessment, particularly with a view to generating qualitative information on awareness of the risks, suitability and sufficiency of risk assessments, adequacy of controls, and suitability and sufficiency of information contained in occupational hygiene reports provided by consultants to the rubber industry.

SURVEY DETAILS

The rubber companies contacted in the survey were selected from the HSE database of known factories, and constituted a representative cross-section of the rubber industry. A total of 179 companies manufacturing rubber products were visited during the survey. The first phase of the study, conducted during 1996–97 involved 117 companies, approximately 20% of the total number of general rubber goods manufacturing premises. The second phase, conducted during 1997–98, involved 62 companies and included 9 (75%) new tyre and 53 (30%) retread tyre manufacturers. Statistical analysis of the quantitative exposure data and qualitative information in the reports was carried out for 52 general rubber goods companies, 29 retread tyre and 7 new tyre manufacturing companies. Table 1 provides information on the employee size distribution, number of companies, and the number of rubber fume and rubber process dust monitoring results obtained.

The survey was conducted using a questionnaire, designed in consultation with HSE occupational hygienists, to obtain the relevant information on the awareness of risks, the suitability and sufficiency of the COSHH assessment, and the adequacy of controls being employed for reducing exposure. Each company was visited by an HSE inspector who completed a questionnaire, using the guidance notes provided. In addition, a walk-through inspection of the workplace was done to assess the extent of use of control measures and the nature of work practices. A copy of the most recent (predominantly 1995–97) exposure monitoring report for rubber fume and rubber process dust was also obtained.

The exposure monitoring reports were examined to assess the suitability and sufficiency of the information provided by occupational hygienists to the rubber industry. The OH reports selected for analysis of qualitative information did not contain those in which sampling had been done by the rubber company and where the OH report provided only analytical results. This resulted in the selection of 42 (out of a possible 52) OH reports from the general rubber goods companies and 29 (out of a possible 36) OH reports from the new and retread tyre companies. These OH reports were categorised as follows: 'brief reports' containing only skeletal information; 'intermediate reports' providing information on monitoring, controls and interpretation of the results; and 'comprehensive reports' which provided in-depth information on most aspects of occupational hygiene relevant to assessing exposure and which made recommendations for improvement. The criteria used to categorise the reports related to details of sampling and analysis, assessment of work practices and work conditions prevailing during monitoring, interpretation of results with regard to the relevant limit of exposure, and where necessary recommendations based on the monitoring results and use of appropriate controls. The sampling and analytical methodologies were reported by most of the intermediate and comprehensive reports and these were as required by MDHS 47 (HSE, 1987).

RESULTS

Prior to the description of results and discussion it is worth pointing out the factors that may have influenced the collection of occupational hygiene data reported in this study. It should be borne in mind that the occupational hygiene reports may not give data representative of exposure. For example, the hygienists may have focused on worst-case exposures to determine whether the MEL was exceeded or they may have worked with poor sampling strategies, set by the companies, which did not allow an estimate of the highest exposures.

Table 1. Summary information on the number of rubber companies, employees, and rubber fume and rubber process dust samples (personal 8-h TWA) included in the analysis from the survey

	General rubber goods (GRG)					New and retread tyres (NRT)				
	No. of companies	Rubber fume samples		Rubber process dust samples		No. of companies (RT/NT)[a]	Rubber fume samples		Rubber process dust samples	
No. of employees		All data	Personal (8-h TWA)	All data	Personal (8-h TWA)		All data	Personal (8-h TWA)	All data	Personal (8-h TWA)
< 10	2	8	6	8	6	18 (18/0)	87	53	2	–
11–24	7	42	34	31	23	7 (7/0)	33	32	1	1
25–199	25	187	119	195	129	2 (2/0)	55	32	0	0
> 200	15	208	165	197	161	7 (0/7)	43	32	30	23
Not known	3	22	17	18	16	2 (2/0)	7	3	8	2
Total data	52	467	341	449	335	36 (29/7)	225	152	41	26

[a]RT: retread tyre companies; NT: new tyre companies.

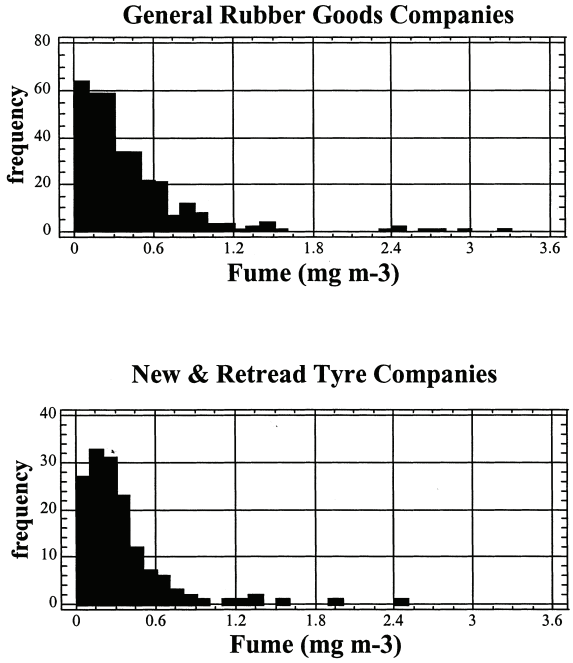

Fig. 1. Histograms of personal exposure data for rubber fume from GRG and NRT companies.

Amongst all the data obtained from both the general rubber goods (GRG) and new and retread tyre (NRT) companies, there were 493 personal exposure results for rubber fume with 19% above or equal to the MEL (0.6 mg m^{-3}) and almost 5% exposures were twice the MEL. Similarly, out of the 361 values for personal exposure to the dust samples reported as rubber process dust ~5% were above or equal to the MEL (6.0 mg m^{-3}) and less than 2% were twice the MEL. Histograms for rubber fume and the reported rubber process dust are shown in Fig. 1 and 2. The distributions were strongly skewed but not necessarily log-normal. The medians and inter-quartile ranges were therefore used to characterise the distributions, and the non-parametric Mann–Whitney (Wilcoxon) test was used to compare the medians. All personal exposure data included in the analysis were 8-h TWA results and when discussing personal exposures an 8-h TWA (mg m^{-3}) is implied, unless otherwise stated.

Exposure to rubber fume

The overall data for personal exposure to rubber fume in both the GRG and NRT companies are presented in Table 2. The difference in median exposures from GRG ($N = 341$; $m = 0.30$) and NRT ($N = 152$; $m = 0.24$) firms was not statistically significant ($P = 0.13$), but a significantly higher proportion, 22% of all exposure results, from GRG firms were in breach of the MEL (exposure $\geq$ 0.6 mg m^{-3}) compared with 13% from NRT companies. For all exposures in breach of the MEL in GRG ($N = 75$; $m = 0.81$) and NRT ($N = 19$; $m = 0.80$) companies, the difference in median exposure was not statistically significant ($P = 0.63$). However, process controls for fume and working conditions within NRT companies vary considerably and the

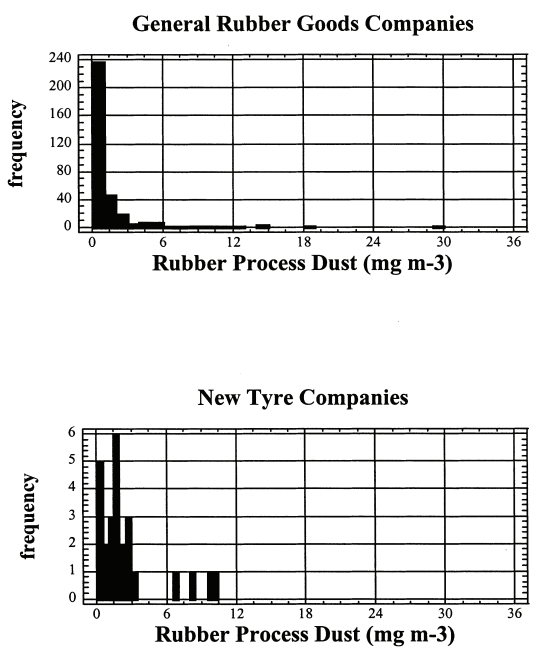

Fig. 2. Histograms of personal exposure data reported for rubber process dust from GRG and NRT companies.

Table 2. Summary of results for rubber fume from general rubber goods and new and retread tyre companies

Process	General rubber goods (GRG)							New and retead tyres (NRT)						
	No. of samples	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL	No. of samples	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL
		Personal 8-h TWA exposure ($mg\,m^{-3}$)							Personal 8-h TWA exposure ($mg\,m^{-3}$)					
Weighing	1	–	–	–	–	0.28	0	–	–	–	–	–	–	–
Mixing	8	0.09	0.06	0.04–0.13	0.03	0.23	0	1	–	–	–	–	0.8	1
Milling	42	0.34	0.18	0.1–0.47	0.02	2.4	7 (17)	6	0.48	0.37	0.06–0.46	0.05	1.55	1 (17)
Extrusion	18	0.54	0.33	0.23–0.83	0.09	1.53	6 (33)	13	0.21	0.21	0.10–0.25	0.04	0.48	0
Calenderring	–	–	–	–	–	–	–	4	0.1	0.07	0.03–0.17	0.03	0.22	0
Moulding	151	0.53	0.4	0.2–0.63	0.01	3.2	49 (33)	–	–	–	–	–	–	–
Curing	2	0.17	0.17	0.03–0.37	0.03	0.31	0	–	–	–	–	–	–	–
Autoclave	4	0.44	0.39	0.20–0.68	0.07	0.9	1 (25)	18	0.34	0.13	0.04–0.24	0.01	2.41	2 (11)
Tyre press	–	–	–	–	–	–	–	66	0.35	0.29	0.17–0.43	0.06	1.22	9 (14)
Not specified	58	0.32	0.21	0.08–0.44	0.01	1.47	8 (14)	–	–	–	–	–	–	–
Other	57	0.24	0.15	0.06–0.28	0.01	1.45	4 (7)	44	0.33	0.26	0.14–0.40	0.02	1.94	6 (14)
All results	341	0.41	0.3	0.13–0.52	0.01	3.2	75 (22)	152	0.33	0.24	0.13–0.40	0.01	2.41	19 (13)

Table 3. Summary of results for rubber fume from new tyre and retread tyre companies

Process	New tyres (NT)							Retead tyres (RT)						
	No. of samples	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL	No. of samples	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL
		Personal 8-h TWA exposure ($mg\,m^{-3}$)							Personal 8-h TWA exposure ($mg\,m^{-3}$)					
Mixing	1	–	–	–	–	0.8	1	–	–	–	–	–	–	–
Milling	5	0.56	0.38	0.36–0.46	0.06	1.55	1	1	–	–	–	–	0.05	–
Extrusion	4	0.24	0.22	0.21–0.27	0.2	0.3	0	9	0.2	0.19	0.05–0.25	0.04	0.48	0
Calenderring	3	0.12	0.11	0.03–0.22	0.03	0.22	0	1	–	–	–	–	0.03	–
Autoclave	1	–	–	–	–	0.61	1	17	0.33	0.1	0.04–0.2	0.01	2.41	1
Tyre press	14	0.23	0.22	0.15–0.32	0.06	0.45	0	52	0.38	0.32	0.18–0.52	0.06	1.22	9
Other	4	0.13	0.14	0.13–0.14	0.12	0.14	0	40	0.35	0.29	0.15–0.41	0.02	1.94	6
All results	32	0.29	0.22	0.14–0.35	0.03	1.55	3 (9)	120	0.34	0.25	0.13–0.42	0.01	2.41	16 (8)

rsonal exposures to rubber fume at presses and autoclaves in new tyre, retread tyre and general rubber goods companies

.	Operatives sampled	Samples	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL
			Personal 8-h TWA exposure (mg m^{-3})					
	At press only	11	0.2	0.19	0.12–0.28	0.06	0.35	0
	All samples	25	0.2	0.19	0.12–0.23	0.03	0.46	0
es	At press only	3	0.34	0.35	0.22–0.45	0.22	0.45	0
	All samples	7	0.6	0.45	0.3–0.8	0.22	1.55	3 (43)
		32	0.29	0.22	0.14–0.35	0.03	1.55	3 (9)
	At press only	29	0.41	0.34	0.2–0.57	0.06	1.22	6 (21)
	All samples	49	0.36	0.26	0.18–0.50	0.02	1.4	7 (14)
	At autoclave only	11	0.1	0.05	0.02–0.15	0.01	0.4	0
	All samples	16	0.18	0.1	0.04–0.33	0.01	0.55	0
es	At press only	21	0.34	0.29	0.15–0.36	0.08	1.13	3 (14)
	At autoclave only	5	0.61	0.2	0.16–0.24	0.04	2.41	1 (20)
	All samples	55	0.38	0.25	0.13–0.40	0.02	2.41	9 (16)
		120	0.34	0.25	0.13–0.42	0.01	2.41	16 (13)
	Moulding presses	151	0.53	0.4	0.2–0.63	0.01	3.2	49 (33)

subdivided data for new tyre (NT) and retread tyre (RT) sectors are shown in Table 3. Comparison of the medians indicates the order of exposure (E, mg m^{-3}) as:

$$E_{\text{moulding}}\ (0.40) \approx E_{\text{extrusion}}\ (0.33) > E_{\text{milling}}\ (0.18)$$

for GRG

$$E_{\text{press}}\ (0.32) > E_{\text{extrusion}}\ (0.19) > E_{\text{autoclave}}\ (0.10)$$

for RT

$$E_{\text{press}}\ (0.22) \approx E_{\text{all other}}\ (0.22) \text{ for NT}$$

In GRG no significant difference ($P = 0.9$) in the median exposures for the moulding and extrusion processes was found whereas in RT a significant difference ($P = 0.039$) between exposure groups in tyre presses and extrusion existed. Difference in exposures between press operatives in GRG and RT was significant ($P = 0.001$) and similarly significant difference ($P = 0.01$) existed between press operatives in RT and NT companies. For extrusion processes the difference in median exposures between GRG and RT was also significant ($P = 0.01$). However, because of insufficient data for the NT companies it was not possible to adequately compare the individual processes, except presses, with those in other sectors. Nevertheless, limited data for extrusion indicated that there was no significant difference ($P = 0.4$) between NT and RT exposures, and within NT processes there was no significant difference ($P = 0.85$) between exposure data for press operatives and the combined fume exposure data for all other processes. This latter finding was somewhat surprising and it may be a result of the small number of samples for all other processes in the NT sector.

The data for the new tyre and retread companies can be further divided as shown in Table 4. The proportion of samples exceeding the MEL were similar, 9% for new tyre and 13% for retread companies. However, there were significant differences for the exposures occurring at presses in the NT and RT companies. For premises operating presses only, the median exposure at NT companies ($N = 11$; $m = 0.19$) was about half that in RT companies ($N = 29$; $m = 0.34$) and no breach of the MEL existed for NT press workers while it was 21% for RT presses. Even when all the samples from NT companies ($N = 25$; $m = 0.19$) and RT firms ($N = 49$; $m = 0.26$) operating only presses are compared the difference still remains significant ($P = 0.012$). Similarly a significant difference ($P < 0.001$) in the median exposures for presses in GRG and RT was found; 33% of all samples taken at GRG moulding were in breach of the MEL as compared with 18% at RT presses

Table 5. Summary of results for rubber fume personal exposure ≥MEL (0.6 mg m^{-3}) from general rubber goods, new tyre and retread tyre companies

Company type	Operatives sampled	No. (%) of samples ≥MEL	Personal 8-h TWA exposure (mg m^{-3})					
			Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥2 × MEL
New tyres	At press only (14)	0	–	–	–	–	–	0
	All other samples (18)	3 (17)	0.99	0.8	0.61–1.55	0.61	1.55	1 (6)
	All samples (32)	3 (9)	0.99	0.8	0.61–1.55	0.61	1.55	1 (3)
Retread tyres	At press only (52)	9 (17)	0.87	0.76	0.71–0.96	0.71	1.22	1 (2)
	All other samples (68)	7 (10)	1.27	1.02	0.63–1.94	0.62	2.41	3 (4)
	All samples (120)	16 (13)	1.03	0.76	0.7–1.22	0.62	2.41	4 (3)
General rubber goods	At press only (151)	49 (33)	1.03	0.76	0.63–0.99	0.6	3.2	8 (5)
	All other samples (190)	26 (14)	1.03	0.92	0.74–1.21	0.61	2.4	8 (4)
	All samples (341)	75 (22)	1.03	0.81	0.68–1.11	0.6	3.2	16 (5)

(samples taken at presses only). In summary, the data suggest significant ($P \approx 0.01$) differences in exposures at presses and the following order of exposure (E, mg m^{-3}) to fume and percentage samples in breach (B) of the MEL emerges:

$$E_{\mathrm{GRG}}\ (0.40) > E_{\mathrm{RT}}\ (0.32) > E_{\mathrm{NT}}\ (0.22)$$

$$B_{\mathrm{GRG}}\ (33\%) > B_{\mathrm{RT}}\ (17\%) \gg B_{\mathrm{NT}}\ (0\%)$$

Fume exposures for RT companies that operated only autoclaves were the lowest ($N = 11$; $m = 0.05$) when compared with any other process in NT or RT companies, with no sample breaching the MEL. In contrast, RT companies operating both presses and autoclaves had higher fume exposure at autoclaves ($N = 5$; $m = 0.2$) compared with companies using autoclaves only ($N = 11$; $m = 0.05$) and the difference was significant ($P = 0.001$).

Table 5 compares the fume exposure data in breach of the MEL for the three sectors. No significant difference ($P = 0.22$) was found for median exposures in the GRG sector between press operatives ($m = 0.76$ mg m^{-3}) and operatives involved in all other work ($m = 0.92$ mg m^{-3}). For the RT sector, the median exposure for press work ($m = 0.76$ mg m^{-3}) was significantly different ($P = 0.01$) and lower than for other work ($m = 1.02$ mg m^{-3}). Inter-sector comparison for sample $\geq$ MEL for press workers showed no significant difference ($P = 0.78$) between GRG and RT median exposures, each being 0.76 mg m^{-3}. However, the proportion of samples exceeding the limit of twice the MEL was 2% for presses in RT, whereas it was 5% for GRG. In terms of the total fume exposure data that were in breach of the MEL for all the processes in the three sectors, there was no significant difference ($P > 0.87$) in the median exposures, each being ~0.8 mg m^{-3}.

Exposure statistics for GRG, NT and RT companies by number of workers employed (categorised as <10, 11–24, 25–199 and >200) showed no difference ($P > 0.05$) for median exposures between GRG and RT firms in each of the employee size ranges considered. The analysis of data also revealed that company size, in terms of the number of employees, was not a factor affecting breach of the MEL. Thus for GRG companies there appeared to be no significant difference between large or small companies.

Exposure to rubber process dust

In most RT companies there was an absence of processes that generate rubber process dust. The personal exposure results for 'rubber process dust' included in the analysis were 335 samples from GRG and 26 samples from NT firms (Tables 6 and 7). It is important to point out that in GRG companies ~35% of all the results reported were at moulding (Table 6), the highest for any process monitored. However, rubber dust samples reported at moulding and post-extrusion operations represent exposure to nuisance dust (threshold of air concentration 8-h TWA, total inhalable dust of 10 mg m^{-3}) and as a result the MEL for rubber process dust does not apply. Therefore, the data reported in Table 6 for processes likely to result in exposure to other than 'true' rubber process dust are not further analysed in this study. However, this point is further discussed in the section describing quality of occupational hygiene reports.

Data from weighing, mixing and milling, and extruding (WMME) operations in the GRG sector (Table 6), showed that highest exposures arise in weighing operations. The median of results from weighing was significantly different ($P < 0.01$) from mixing, milling or extrusion and comparisons between mixing, milling and extrusion processes showed that there was no statistical difference ($P > 0.3$) in the median exposures for these processes. Similarly, 22% of samples breached the MEL in weighing whereas the combined data for mixing, milling and extrusion processes had 5% of samples in breach of the MEL. Thus, in terms of ranking median exposures (E, mg m^{-3}) to rubber process dust in the GRG sector the order was:

$$E_{\mathrm{weighing}}\ (4.2) \gg E_{\mathrm{mixing}}\ (1.2) \approx E_{\mathrm{milling}}\ (0.8) \approx E_{\mathrm{extrusion}}\ (0.8)$$

Inter-comparison between GRG and NT sectors for rubber process dust exposures reported for weighing, mixing, and milling (see Table 7) shows that there is no significant difference in the median exposures ($P = 0.31$) and that the number of samples breaching the MEL are 9% for both GRG and NT. Statistical analysis based on size of employees for GRG companies showed that for WMME processes there was no difference ($P > 0.13$) between any of the four groups, categorised as <10, 11–24, 25–199 and >200 employees.

Quality of occupational hygiene reports

As noted earlier, owing to the uncertainty of the remit of the occupational hygienist employed, caution needs to be exercised in making judgements on some aspects of the OH reports. However, despite this, several findings are worthy of note as they would not be affected by the hygienist's remit. Amongst the 15 'brief reports' from GRG and NRT companies, 40% did not refer to the sampling method used; 27% did not refer to the method used for the analysis of rubber fume and dust; and 67% did not compare the exposures with the relevant maximum exposure limits.

In most of the intermediate and comprehensive reports, there was no evidence to suggest that any particular restriction had been placed on the hygienist's scope for assessing exposure and controls, and for making the necessary recommendations for improvement in controls. Key findings to emerge from the analysis of 27 'intermediate reports' include: the almost 100% reporting of the sampling and analytical methods (but 89% of the reports gave no information on the sampling strategy; and 48% made no reference to the work conditions and work practices); 19% made no mention of the presence or absence of controls; 48% did not make reference to the ALARP principle (requiring exposure to substances with a MEL to be reduced to 'as low as reasonably practicable') in assessing adequacy of controls; and 48% made no recommendations for improving controls. In comparison, amongst the 29 comprehensive reports between 80 and 100% met all of the above criteria, except that regarding sampling strategy, of which about 16 (55%) of the reports made no mention. Amongst the 28 (44%) reports where either the MEL for rubber fume or rubber process dust had been breached recommendations for improvements were made in 23 (82%) cases. In contrast, amongst the 18 reports where no breach of the MEL was noted, only in 4 (22%) cases were recommendations for improvements made.

DISCUSSION AND CONCLUSIONS

In order to adequately explain the variations in exposure to rubber fume and rubber process dust across the three sectors of the rubber industry as well as any intra-sector variations, it is necessary to have sufficient quantitative information relating to a number of parameters, including the type of rubber in use, the process conditions, the rates of fume production and removal by control measures, the nature of work practices that bring the worker into the fume, and the background build-up of fume in the work area (Kromhout *et al.*, 1994; Kromhout and Heederik, 1995; Tongeren *et al.*, 1995). However, it has been shown that even when quantitative information relating to aspects of production and controls is acquired and used in linear regression models to unravel the factors affecting exposure, there is insufficient correlation between exposure and the various exposure indices that are supposedly the prime controlling variables (Kallokoski, 1990; Hawkins *et al.*, 1992; Kromhout *et al.*, 1994). Thus, for example, the linear regression model explained only 50% of the fume exposure variability, with presence of LEV accounting for a twofold reduction in exposures in a survey of the Dutch rubber industry (Kromhout *et al.*, 1994). It has been suggested that the unexplained variance results from the lack of reliable estimates of the contributions of work activities not normally considered in such models, and to the differences in work styles and task content within a company as well as between companies (Kromhout *et al.*, 1994).

Bearing in mind the points noted above, it is clear that there is a number of limitations of a cross-sector survey of the type reported here, related principally to the survey design. The information gathered on the process and control aspects was qualitative and subjective. There was no quantitative information on production and tasks (types of rubbers in use, the temperature of cures, the active work time spent on handling curing products, the frequency of tasks etc.) or adequacy of controls (the effectiveness of the LEV enclosure, the effective capture velocity around the source of fume etc.). In addition, the qualitative information collected at the time of the survey may not reflect the actual process/work conditions that existed during the sampling period. Furthermore, it is known that a single judgement reflecting the adequacy of controls at a number of processes in any one company is likely to be invalid given the variations in process conditions and effectiveness of controls that are

Table 6. Summary of results for personal exposures to the reported 'rubber process dust' in general rubber goods (GRG) companies

Process	Samples (N)	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. (%) of samples ≥MEL (6.0 mg m^{-3})
		Personal 8-h TWA exposure (mg m^{-3})					
Weighing (1)[a]	18	4.9	4.2	1.0–5.6	0.4	14.4	4 (22)
Mixing (2)[a]	18	2.6	1.2	0.4–2.3	0.2	18.6	2 (11)
Milling (3)[a]	46	1.3	0.8	0.5–1.4	0.02	9.2	1 (2)
Extrusion (4)[a]	10	2.3	0.8	0.5–4.7	0.2	7.7	1 (10)
Moulding	116	0.9	0.7	0.4–0.9	0.02	14.3	–
Curing	2	0.25	0.25	0.2–0.3	0.2	0.3	–
Autoclave	1	–	–	–	–	1.1	–
Not specified	56	0.9	0.5	0.3–0.8	0.1	14.7	–
Other	68	1.8	0.6	0.3–1.3	0.01	29.5	–
Processes 1–4	92	2.3	1	0.5–2.95	0.02	18.6	–
All results	335	1.5	0.7	0.4–1.2	0.01	29.5	–

[a]Samples taken at processes other than 1–4 are considered not to be rubber process dust (see text).

Table 7. Comparison of personal exposures to rubber process dust in the general rubber goods and new tyre companies

Company type	Process	Samples (N)	Mean	Median	Q_1–Q_3	Minimum	Maximum	No. of samples ≥MEL	Statistical significance (Mann–Whitney)
			Personal 8-h TWA exposure (mg m^{-3})						
GRG	Weighing, mixing and milling	82	2.3	1	0.5–2.9	0.02	18.6	7(9)	$m_{GRG} \neq m_{NT}$ $P = 0.31$
New tyres	Weighing, mixing and milling	22	2.2	1.6	1.0–2.2	0.1	9.64	2 (9)	

normally seen within a workplace (Piney *et al.*, 1988; Cralley and Cralley, 1989). Because of this, and the complexity of the parameters affecting workers' exposure, the qualitative information was thought unsuitable to explain the variation in the exposures. Thus the qualitative information and the practical experience of the processes, work conditions and controls employed is used, where appropriate, to supplement the exposure information and point to the likely causes that may affect exposures.

Exposure to rubber fume

The lack of a significant difference in the median fume exposures for all the operations in the GRG, RT and NT sectors of the rubber industry was somewhat surprising, but the relatively higher percentage of exposures in excess of the maximum exposure limit (MEL = 0.6 mg m^{-3}) in GRG (22%) as compared with RT (8%) and NT (9%) was consistent with the findings of earlier studies (HSE, 1981, 1989). Similarly, these results are consistent with the comprehensive Dutch study conducted in 1988 (Kromhout *et al.*, 1994; Swuste and Kromhout, 1996) (Table 8). Our findings of fume exposures in the three sectors combined show that 27% of all samples were in excess of the MEL as compared with 42% reported by the Dutch study, and that 44% of the British rubber companies had at least one sample in excess of the MEL as compared with 30% of rubber companies in The Netherlands.

However, when the fume exposure data were examined specifically for potentially high fume generating operations, such as moulding presses, the differences in the average exposures in the three sectors became apparent. The higher personal exposures to rubber fume found for work involving moulding presses in the general rubber goods (GRG), as compared with the retread tyre (RT), sector can be explained by a number of factors relating to production and tasks. These include more presses operating in GRG premises, and more significantly the higher frequency of curing in GRG; typical cure times are approximately 3 and 20 minutes for GRG and RT presses, respectively. In addition, work practices in GRG presses require a relatively closer contact with the moulded rubber product during removal from the mould and during trimming tasks that are carried out immediately after the product is removed from the mould. Thus a higher throughput in GRG presses and a relatively higher degree of personal contact create potentially higher fume exposures than in RT press work. Adequacy of control measures, such as LEV, and their effective utilisation will also contribute to exposure. However, approximately 30% of both the GRG and RT firms were considered to have an adequate assessment of the risks and apparently had effective controls in place, so adequacy of control does not explain the relatively higher exposure recorded at GRG.

Fume exposures for retread companies that operated only autoclaves were lower than any other process in the new or retread tyre companies. The main reason for this is the low frequency and limited duration of exposures for work involving autoclaves—the exposure arising primarily during unloading of autoclaves. For example, average exposure encountered during unloading was found to be ~1.0 mg m^{-3} and the operation lasted usually 30 min to an hour, generally once a day, resulting in an 8-h TWA exposure of ~0.1 mg m^{-3}. Companies operating both presses and autoclaves have a generally higher throughput as compared with companies using only autoclaves, and as a result a greater potential problem of buffing dust contamination, and these appear to be possible reasons for the higher exposures recorded at autoclaves in these companies. Buffing dust may contain up to 10% cyclohexane-soluble material (HSE, 1994), but its contribution to the higher fume exposures in retread presses has not yet been fully evaluated (Willoughby, 1998). Assuming the 10% figure, it is possible to check for the likely influence of buffing dust on fume exposure. Fume levels at presses in retread tyre companies were approximately twice those noted for new tyre presses, and it would require ~3 mg m^{-3} of buffing dust for a typical fume sample to account for the higher retread results. Examination of reported figures for total particulate matter collected for fume samples from RT presses shows that the contribution of buffing dust could at best account for only ~10% of the retread excess, so buffing dust does not explain the difference. In addition to buffing dust, dust from release agents (chalk, zinc stearate, talc etc.) can also contribute to the apparently higher fume exposures, but the extent of this problem is also not fully understood. Studies (HSE, 1994; Willoughby, 1998) to investigate contamination by zinc stearate in GRG and retread tyre firms have found that the CSM in fume samples from presses could be inflated by ~2–20% by this cause. However, since release agents are used in all three types of companies to a more or less similar extent, any such inflation would apply equally to all three sectors and thus would not explain the noted differences in exposures. Thus, the order of increasing fume exposure, and the percentage of exposures exceeding the MEL for rubber fume, namely $E_{GRG} > E_{RT} > E_{NT}$, cannot be said to have been influenced by fume exposure confounders such as buffing and dusts from release agents.

In terms of the underlying reasons for the differences in exposures found for the three sectors of the rubber industry it is useful to compare the companies where one or more exposures was in breach of the rubber fume MEL with those companies where all exposures were reported to be less than the MEL. In doing so we recognise that a single breach of the MEL is not necessarily a guide to a company's fume control profile. Table 9 compares the statistics for awareness of risks, adequacy of risk assessment for exposure to rubber fume and the adequacy of controls in order to assess the likely factors contributing to the high exposures. The analysis reveals that ~50% of the GRG and RT companies in breach of the MEL appeared to be aware of the risks of exposure to rubber fume whereas in companies where no breach was reported the awareness of risks was slightly higher: 62% and 77% for GRG and RT companies, respectively. Thus in GRG firms where a breach of the MEL was reported only 3 (13%) had a suitable assessment and adequate controls as compared with 13 (45%) in which no breach of the MEL existed. Similarly, for RT firms where a breach of the MEL was reported no company had an adequate risk assessment and adequate control as compared with 9 (53%) in which no breach of the MEL existed. This pattern was repeated for the NT companies (Table 9).

Some of the most frequently reported causes for classification of assessments as unsuitable included failure to take into account all processes, work practices and the manner in which workers were being exposed; the lack of review of an assessment

Table 8. Comparison of rubber fume exposure statistics for presses in the GRG, RT and NT sectors of the British and Dutch rubber industries

Rubber industry sector	Parameter	This study, 1997–98	Dutch study, 1987–88 (Kromhout, 1999)
General rubber goods (GRG)	No. of samples	151	86
	No. of companies	52	6
	Mean fume exposure (mg m^{-3})	0.53	0.7
Retread tyres (RT)	No. of samples	52	5
	No. of companies	29	2
	Mean fume exposure (mg m^{-3})	0.38	0.4
New tyres (NT)	No. of samples	14	72
	No. of companies	7	2
	Mean fume exposure (mg m^{-3})	0.23	0.46

Table 9. Classification of rubber fume exposure data in terms of breach of MEL, awareness of risks, adequacy of risk assessment and controls

Company type	Selection criteria (breach if at least one sample[a] is ≥MEL[b])	No. (%) of companies	No. (%) aware of risks	No. (%) with adequate risk assessment	No. (%) with adequate controls	No. (%) with both adequate assessment and controls
General rubber goods	No breach	29 (56)	18 (62)	13 (45)	17 (59)	13 (45)
	At least one breach	23 (44)	12 (52)	6 (23)	7 (30)	3 (13)
Retread tyres	No breach	17 (57)	13 (77)	9 (53)	10 (59)	9 (53)
	At least one breach	13 (43)	7 (54)	2 (15)	5 (39)	0
New tyres	No breach	4 (67)	4 (100)	3 (75)	3 (75)	3 (75)
	At least one breach	2 (33)	2 (100)	0	1 (50)	0

[a]Personal (8-h TWA).
[b]Rubber fume MEL is 0.6 mg m^{-3}.

to take account of workplace changes and work practices; failure to include all activities resulting in exposure; absence of a fume control strategy to prevent exposure or minimise spread of fume; absence of the requirement to periodically assess suitability of controls and levels of exposure; and poor monitoring strategy leading to misleading and unrepresentative values for the typical exposure. These findings are indicative of the possible underlying reasons for the differences between two types of companies and suggests that in firms where a breach of the MEL had occurred, a combination of factors primarily relating to the suitability of assessment and adequacy of controls are most likely to be responsible. Lack of effective control owing to a poor conceptual approach to preventing or minimising exposure, lack of segregation and failure to prevent spread, ineffective design or lack of maintenance of LEV, poor work practices and lack of effective utilisation of controls by workers were noted to be the most reported reasons for the inadequacy of controls. These findings are broadly in keeping with the study carried out in The Netherlands (Kromhout *et al.*, 1994), and it is suggested that the factors governing the significant differences noted between the three sectors relate principally to the production and tasks functions and also to the extent of controls employed.

Exposure to rubber process dust

The relatively higher average exposures for rubber process dust arising from weighing (~2–3 times higher than for mixing, milling and extrusion; Table 6) are consistent with earlier studies (HSE, 1981, 1989) and with the Dutch study (Kromhout *et al.*, 1994). Although dust-suppressed powders were most commonly found to be in use, higher exposures at weighing are primarily related to work involving powder handling including bag opening and emptying operations which at times involve significant short-term high exposures. The presence of ventilation has been found to have little effect on exposures to rubber process dust (Kromhout *et al.*, 1994). However, in our study we found that GRG premises where rubber process dust exposures were in excess of the MEL (6 mg m^{-3}) were particularly lacking in adequate LEV control as compared with premises where no breaches of the MEL were reported. The apparent similarity of rubber process dust exposures for mixing, milling and extrusion operations is also consistent with the Dutch study (Kromhout *et al.*, 1994) and can be explained by the fact that during these operations workers are normally relatively remote from the source of the dust.

The lack of significant difference in rubber process dust exposures arising from weighing, mixing and milling operations in the GRG and NT sectors (Table 7) is somewhat surprising. Earlier studies

(Parkes *et al*., 1975; HSE, 1981) reported that there was a significant difference between the tyre and the general rubber goods sectors. However, although this may have been the case in the past, Kromhout *et al*. (1994) found no significant difference between the two sectors. One reason for this is the general trend in the lowering of exposures that has occurred over the last three decades in the rubber industry in Britain as a result of the efforts both of the industry itself and the introduction of lower exposure limits for rubber process dust. The percentages of rubber process dust exposures across the GRG and NT sectors in excess of the 6 mg m^{-3} recorded for weighing and mixing operations in the 1987–88 survey (HSE, 1989) were about three times as high as in 1997–98 (the present study). Similarly in the rubber industry in The Netherlands it has been noted that greatest achievements have been realised in the reduction and elimination of the dust hazards in the last decade (Swuste and Kromhout, 1996). As a result of this the difference in the average rubber process dust exposures between the sectors as reported by Parkes *et al*. (1975) and HSE (1981)may not now be so marked.

Quality of occupational hygiene reports

The main finding to emerge from the analysis of the information contained in the occupational hygiene reports is that where brief reports are provided they are lacking in the essential information necessary to assess whether the sampling and analysis had been carried out as required (HSE, 1987). With regard to the intermediate and comprehensive reports, while it is recognised that a full report may not be necessary on every occasion for a company to come to the correct conclusions, there was a number of evident shortcomings. The primary lack was noted to be with regard to a sampling strategy. A suitably designed sampling strategy, especially where only a fraction of the workers is sampled, is crucial for an adequate risk assessment and for determining the adequacy of the controls employed (HSE, 1997). It could be argued that the occupational hygienists carry out this function but do not record the necessary details in the reports. However, a thorough examination of a number of comprehensive reports examined in this study indicates that the sampling strategy may be frequently ill-conceived and that it is likely to under-represent the actual average exposures and may also miss the highest exposures.

In relation to rubber process dust, the reporting of total particulate dust as rubber process dust at moulding and other operations was one finding that was surprising. From the occupational hygiene reports it is quite apparent that the sampling at moulding was being conducted for the purpose of measuring exposure to rubber fume and that the hygienists were erroneously reporting the total particulate dust collected as rubber process dust. Of the total dust samples (361) reported, the actual proportion that could be regarded as rubber process dust was about 32%. Because there is an apparent lack of understanding about where 'true' rubber process dust exposures arise, it may be difficult to arrive at a true picture of the actual exposures to rubber process dust. As a result inappropriate advice may be provided to rubber companies regarding the adequacy of controls for rubber process dust. Another concern is that in some of the intermediate and comprehensive reports where exposures were close to the MELs, the reference to the results being 'adequate because exposure was below the MEL' clearly disregards the COSHH requirement that exposure should be reduced as far as reasonably practicable below the MEL. This is thought to arise from a poor understanding of the principles of control for substances assigned MELs and it indicates a possible confusion between the two types of occupational exposure limits—MELs and occupational exposure standards (OESs). HSE is conducting a review of the occupational exposure limit framework which will consider this and other practical concerns.

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