Respiratory disease in foundry workers

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ABSTRACT A survey was carried out in a steel foundry in Brisbane to evaluate the nature and frequency of respiratory symptoms and to assess ventilatory function. The foundry used many moulding processes including the Furane, Isocure, Shell, carbon dioxide, and oil sand systems. Nasal symptoms and wheeze were often reported, particularly by workers in the general foundry and core shop, and on a semiautomated line. By contrast, workers in the aftercast section not exposed to fumes or vapours from the various moulding processes reported these symptoms less often. Of 46 workers exposed to moulding fumes and vapours, 11 had developed a wheeze while working at the foundry. Wheeze and other respiratory tract symptoms were often attributed by the workers to exposure to substances at work, particularly from the Shell process which uses phenol formaldehyde resin and hexamethylenetetramine. Symptoms were reported also, but less often, on exposure to materials used in the Furane process (urea formaldehyde and furfuryl alcohol) and the Isocure process (methylene diphenyl diisocyanate, phenol formaldehyde, and dimethylethylamine). Ventilatory function studied over Monday and Friday showed small and inconsistent changes. The six subjects working on the semiautomated line showed a small decrease in FEV₁ ($\pm$ SEM) (208 ± 70 ml) only on Monday; this differed significantly from that in 17 aftercast workers (9 ± 50 ml, $p < 0.05$). Ventilatory function recorded before work on Monday morning showed no evidence of chronic airway obstruction in any group. Most environmental measurements were below the threshold limit values (TLV) except in the general foundry, where furfuryl alcohol was detected at concentrations of up to 50 ppm and formaldehyde at 4 ppm. The onset of symptoms in relation to exposure to various fumes and vapours suggests that both irritant and hypersensitivity mechanisms are present. As environmental modifications had occurred recently the apparent hypersensitivity may relate to past exposure levels above the TLV.

Foundry workers are exposed to numerous emissions in the workplace. In the past silicosis resulted from exposure to quartz containing sands used for moulding.¹ Several studies have shown an excessive prevalence of respiratory symptoms, suggesting that chronic bronchitis and airways obstruction may result from inhaling various substances in this industry.^{2,3}

Several processes use isocyanates and resin systems such as urea formaldehyde and phenol formaldehyde in the production of cores and moulds. Such materials are potential irritants or sensitisers and have been associated with asthma like syndromes.⁴⁻⁸

Recently, a worker at a steel foundry in Brisbane

developed asthma that was thought to be related to inhaling fumes or vapours at work. To determine whether or not this was an isolated incident, a survey of the workforce was undertaken to describe the prevalence of respiratory tract symptoms and to determine whether there was any objective evidence of respiratory disease in workers that might be ascribed to occupational factors.

Material and methods

INDUSTRIAL PROCESS

The study was undertaken at a steel foundry that specialises in producing castings for heavy industry and rolling stock. Castings are produced by pouring molten metal into a mould cavity. The mould that is formed in a box determines the external shape of the

casting. Cores are placed into the mould cavity and determine the internal shape of the casting.

There are two separate major casting areas within the foundry. When a small number of castings is required these are produced in the general foundry by a jobbing mould method using the Furane process. For a large number of castings a semimechanised method uses a high pressure greensand moulding process (hereafter called the line). In both areas cores of varying composition are placed in the mould cavities. Workers in the casting areas are exposed to fumes arising from the various core and mould materials after metals at high temperatures have been poured into the mould cavities.

After the castings have cooled they are transferred to the aftercast section where they are subjected to various finishing procedures such as shot blasting, grinding, and cutting. Those working in the aftercast area were not exposed to any of the resin fumes or vapours found in the rest of the foundry. Nevertheless, they were clearly exposed to some fumes—for example, from welding—and to dusts from the finishing procedures. The aftercast section was the only area in the foundry that could provide sufficient workers with whom we could compare those exposed to resin fumes and vapours elsewhere.

In a separate area cores are produced by several different processes, which include the following:

Furane process—"Chemrez 204" (urea formaldehyde resin condensed with furfuryl alcohol) is mixed with phosphoric acid (as a catalyst) and sand.

Isocure process—A complex polyurethane resin is formed by mixing methylene diphenyl di-isocyanate (MDI) dissolved in petroleum hydrocarbon solvents and phenol formaldehyde resin dissolved in petroleum solvents with dimethylethylamine (DMEA) as a catalyst.

Shell process—Phenol formaldehyde resin is used with a catalyst, hexamethylenetetramine.

Carbon dioxide process—Sodium silicate is mixed with either various glycerol acetates or carbon dioxide gas under pressure.

Oil sand process—"Maidex" (acid hydrolysed starch and drying oil) is mixed with sand. The cores are baked in an oven at between 350°C and 550°C for several hours.

PERSONNEL

At the time of the survey 49 workers were employed in the core shop and general foundry, and on the semiautomated line. Of these, 46 took part in the survey: one was absent from work for other than medical reasons and two refused to take part. Of the 114 workers in the aftercast section, 19 were selected randomly to participate in the survey and of these, two refused.

QUESTIONNAIRE AND RESPIRATORY FUNCTION ASSESSMENT

A modified MRC questionnaire⁹ was administered and in addition each worker was asked, "Have you ever had any problems at work after exposure to dust, gases, or fumes?" The nature of any reported symptoms was noted together with the particular process or area where these symptoms occurred. The best of three satisfactory forced expiratory manoeuvres on a Vitalograph dry spirometer was analysed to provide the forced expiratory volume in one second (FEV₁), the forced vital capacity (FVC), and maximum mid-expiratory flow (MMEF). Ventilatory function was recorded at the beginning and end of the shifts on Monday and Friday of one week. Observed values were compared with predicted values.¹⁰

ENVIRONMENTAL MEASUREMENTS

After completion of the survey various environmental contaminants were measured. The conditions appeared to be representative of those existing at the time the lung function tests were performed. Furfuryl alcohol, DMEA, and xylene levels were determined, using the Miran infrared absorption spectrometer. Formaldehyde concentrations were measured using the chromotropic acid visible absorption spectrometer and Drager tubes, and MDI was measured by colorimetric analysis.

Results

Table 1 gives a description of the groups of subjects studied. Workers from the aftercast section were generally older than the other subjects and, together with those in the general foundry, had worked for a longer period in the plant. Six of those in the aftercast section had worked at the foundry for five years or more, compared with nine in the general foundry, four in the core shop, one on the line, and two of those working both on the line and in the core shop. Total cigarette consumption was similar in all groups, even though aftercast workers tended to smoke slightly more heavily.

Table 1 also shows the frequency of usual symptoms. There were no significant differences in the frequencies of chronic cough, chronic sputum production, and breathlessness among the various groups. Twenty of the 46 working in the core shop and casting areas reported asthma or wheezy breathing. Eleven of these 20 developed the symptoms after starting work at the foundry. Of these 11, five reported that their symptoms appeared after at least several months at the foundry and then to exposures estimated to be lower than those which had been tolerated previously. Other acute symptoms at work

Table 1 Description of exposure groups and prevalence of respiratory symptoms. (Figures in parentheses indicate number of workers who attribute wheeze to a specific environmental factor at work)

	Work area				
	Aftercast	General foundry	Core shop	Line	Core shop/line
No exposed	17	15	17	6	8
Age* (years)	39.1 ±3.4	32.9 ±3.7	26.6† ±2.1	25.3† ±3.7	32.0 ±4.8
Height* (cm)	175.8 ±2.3	174.6 ±1.4	175.9 ±1.5	178.9 ±2.0	180.1 ±2.5
Cigarette consumption* (No per day)	10.7 ±2.7	9.2 ±3.5	10.7 ±4.1	9.3 ±6.0	8.3 ±3.3
Worked in foundry (years)	6.1 ±2.0	8.7 ±1.8	3.3 ±0.8	3.6 ±2.1	4.6 ±2.0
Smoking status:					
Never	4	4	3	1	1
Ex-smoker	3	5	6	0	3
Current	10	6	8	5	4
Usual symptoms:					
Chronic cough	4	2	4	1	2
Chronic phlegm	4	2	4	2	3
Breathless on hills	2	0	4	0	1
Asthma or wheeze	4	6	8	2	4
Onset while at foundry	3 (1)	2 (1)	5 (3)	2 (1)	2 (1)
Onset before at foundry	1 (0)	4 (1)	3 (2)	0	2 (1)
Acute symptoms at work:					
Sneezing	0	6	6	1	2
Rhinorrhoea	3	7	5	2	2
Nasal obstruction	4	3	5	2	1
Cough	5	0	3	1	1
Sputum	7	0	3	0	1
Wheeze	1	2	5	1	2

*Values expressed as mean ± SEM.

†Differ significantly from aftercast workers ($p < 0.05$).

were more often reported by those working in the core shop and in the general foundry. This was true particularly for the nasal symptoms of sneezing, rhinorrhoea, and obstruction. Those working in the aftercast section tended to report the symptoms of cough and sputum more often whereas only four workers reported a wheeze.

Each worker was asked if his acute respiratory symptoms occurred while working with any particular process in the plant. Table 2 shows their responses. Workers tended to move around from process to process, thus explaining the relatively larger numbers within the various groups reported by process. Workers only infrequently associated

acute symptoms with exposure to the carbon dioxide and oil sand processes. By contrast, exposure to the Isocure, Furane, and Shell processes often resulted in nasal and conjunctival irritation and wheeze. Wheeze was reported most often on exposure to the Shell process.

Objective evidence of an effect of environmental exposure at work on lung function during the working week was sought by comparing changes in ventilatory function over Monday, over Friday, and over the week in the various groups. These results appear in table 3. When compared with the aftercast workers, only those working on the line showed a significantly greater fall in ventilatory function over

Table 2 Frequency of acute symptoms attributed to exposure to specific core making processes

	Process				
	Carbon dioxide	Oil sand	Isocure	Furane	Shell
No exposed	39	37	37	42	23
Symptoms:					
Wheeze	1 (3%)	0	3 (8%)	2 (5%)	5 (22%)
Cough	1 (3%)	0	2 (5%)	3 (7%)	2 (9%)
Sputum	1 (3%)	0	2 (5%)	2 (5%)	2 (9%)
Nasal irritation	1 (3%)	0	7 (19%)	7 (17%)	5 (22%)
Eye irritation	0	1 (3%)	6 (16%)	9 (21%)	6 (26%)

Table 3 Lung function on Monday morning and changes at work

	Work area				
	Aftercast	General foundry	Core shop	Line	Core shop/line
No exposed	17	15	17	6	8
Change in FEV ₁ (ml):					
Over Monday	- 9 ± 50	- 57 ± 61	- 62 ± 64	- 208* ± 70	- 38 ± 118
Over Friday	- 8 ± 40	+ 4 ± 31	- 54 ± 36	+ 73 ± 85	+ 10 ± 53
Over week	- 15 ± 88	- 105 ± 54	- 53 ± 48	- 182 ± 82	+ 26 ± 94
Monday morning function:					
FEV ₁ (% predicted)	89.5 ± 3.1	84.6 ± 3.7	89.2 ± 2.2	98.8 ± 3.3	85.4 ± 4.1
FVC (% predicted)	91.4 ± 2.6	84.1 ± 2.9	90.6 ± 1.8	98.6 ± 2.9	87.8 ± 4.6
FEV ₁ /FVC (%)	80.4 ± 1.8	83.1 ± 2.0	82.4 ± 1.9	83.6 ± 2.6	80.4 ± 1.6

All values expressed as mean ± SEM.

*Differs significantly from change in aftercast workers ($p < 0.05$).

the Monday shift. All other changes over Monday, and all changes over Friday and over the week, were small and did not differ significantly between the aftercast workers and those in other areas.

Objective evidence of a chronic effect was sought by comparing the Monday morning values of the various groups. There were no significant differences in the FEV₁, FVC, and FEV₁/FVC between the aftercast workers and those in other areas. All mean values of FEV₁ and FVC were below those predicted for all groups, particularly for those working in the general foundry and in the line and core shop. Further evidence of a long term effect was sought by analysing the relationship between FEV₁ and duration of employment. No relationship was found.

ENVIRONMENTAL MEASUREMENTS

Furane process—The concentration of furfuryl alcohol in the breathing zones of operators dispensing from the mixing machine in the core shop varied from 3 to 8 ppm. In the general foundry concentrations varied from 10 to 50 ppm. Formaldehyde could not be detected in the core shop but was found in the general foundry at 2 to 4 ppm.

Isocure process—MDI concentrations in the core making area were recorded at 0.001 ppm or less and above the line at 0.001–0.003 ppm.

Shell process—Only formaldehyde levels were measured in relation to this process. The lower limit of detection by the Drager tube method was 1 ppm and no formaldehyde above this level was detected.

Carbon dioxide process—No specific hazards were considered likely in this process. Carbon dioxide was measured in the breathing zones of several workers and found to be similar to that naturally occurring at 0.003%.

Oil sand process—As the chemicals used in this process were thought to be of low toxicity, no measurements were made.

Discussion

Workers in the foundry reported acute upper and lower respiratory tract symptoms relatively often. By contrast with those working in the aftercast section who often noted cough and sputum production, those working in the core shop and casting areas often noted sneezing, rhinorrhoea and nasal obstruction, the symptoms of rhinitis, and wheeze, a symptom indicating lower airway obstruction. The onset of these symptoms could often be related to specific exposures especially from the Shell process. Symptoms were reported less often when working with the Isocure and Furane systems, but it must be emphasised that whereas the Furane process had been used for many years, the Isocure had been introduced into the plant only 12 months previously. Possibly the latter process may in time result in a higher frequency of respiratory symptoms.

There are probably several mechanisms producing lower airway obstruction in these workers. That about half the subjects who developed a wheeze at work noted this symptom with initial exposures suggests an irritant effect. By contrast, the remaining half noted a delay of some months before the development of this symptom, which suggests a hypersensitivity mechanism.

Despite the frequency of the symptom of wheeze in those working in the core shop and the casting areas, only those working on the line showed a statistically significant change in ventilatory function. Furthermore, this occurred only over the first day of the working week and was not associated with

any changes over the week or over Friday.

Two previous studies of foundry workers have shown abnormal ventilatory function, although the mould and core making processes in the foundries studied were not stated.^{2,3} One study showed both obstructive and restrictive abnormalities in almost 50% of workers²; the other showed progressive obstruction in workers over 30 months.³ Another study of foundry workers showed an excess prevalence of the symptoms of chronic bronchitis and obstructive ventilatory function in a group exposed to the Isocure process when compared with a group working elsewhere in the foundry.⁶ The Furane process uses a urea formaldehyde resin and the Isocure and Shell processes phenol formaldehyde resin. Exposure to phenol formaldehyde resin, particularly for more than five years, results in chronic airway obstruction.⁴

The present study failed to find any evidence of airway obstruction, as indicated by FEV₁/FVC, in workers exposed to various core making processes when compared with a group not so exposed. The finding of the low mean FVC in all groups is difficult to interpret. It may indicate a restrictive disorder in all groups or perhaps the inappropriateness of the predicted values. This lack of objective evidence of chronic airway obstruction must be interpreted with some caution. The groups are relatively small and possibly reflect a "survivor population" when perhaps those who had developed significant and persistent symptoms transferred to other sections in the plant or left the foundry.

Those working in the aftercast section had a relatively high prevalence of symptoms of lower airway irritation, probably reflecting exposure to considerable quantities of dust and fumes in this area. Thus the use of this group as a control was not particularly satisfactory, but they constituted the only group of sufficient numbers with which we could compare those exposed to the products of various core and mould systems.

Most environmental measurements were found to be below the presently accepted threshold limit values (TLV). In the general foundry, however, furfuryl alcohol was detected at concentrations of up to 50 ppm (TLV—short term exposure limit: 10 ppm) and formaldehyde at 4 ppm (TLV—time weighted average: 2 ppm). Probably in the past levels in areas other than the general foundry would have been higher as improvements in ventilation had occurred in these areas in recent times. These higher past exposures may have been responsible for the apparent sensitisation of some workers. Even though the levels found in this study were generally below the TLV, the frequency of acute symptoms at work indicates that work practices need to be modified

further. The reassessment of the frequency of symptoms after such modifications may indicate levels of the various materials below which airway reactions will be unlikely. In sensitised individuals, however, it may be impossible to achieve levels sufficiently low to prevent the development of symptoms. Furthermore, there is some evidence that symptoms may develop as a result of inhaling complex combustion products of the various processes.⁷ Such products have yet to be identified and will thus restrict the use of atmospheric levels of known chemicals as a method of limiting disease experience in this industry. Furthermore, disease may result from an interaction of several chemicals, again limiting the use of levels of individual substances.

Continuous biological monitoring of those working in the core shop and casting areas should now form an integral part of a health and safety programme at foundries. Further work is required to identify more clearly specific materials responsible for both the irritant and hypersensitivity mechanisms of airway inflammation. Detailed prospective studies of all workers in this industry, including those leaving, are necessary to provide a more definitive statement on the possible existence of a permanent effect.

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