# CHAPTER 4

# RESULTS AND DISCUSSION

The results, observations and findings are presented herein and discussed as far as the data permit in four major sections.

## 4.1 SOURCE AND GENERATION OF TWO DUST TYPES AT THE PAINT MANUFACTURING PLANT

The paint manufacturing processes for the solvent-based paint and the water-based paint at the plant are basically similar except for one major difference. In the solvent-based paint manufacturing process, there is the additional production step (dispersion) which involves additional grinding and mixing with beads to disperse the pigments in small quantity of solvent-resin mixture. This production step is conspicuously absent in the water-based paint manufacturing process (see Figure 7 and Figure 8).

## 4.2 PARTICLE SIZE ANALYSES

The COULTER LS 230 Particle Size Analyzer operates on particle size diameter ranging from 0.375 μm to 2000 μm, measured in terms of volume weighted mean diameter D(4,3).

### 4.2.1 Solvent-Based Paint Dust

#### 4.2.1.1 Particle Size Diameter, D(4,3)

Table 5 presents the weekly values of the particle size diameter over the sampling period of 12 weeks.

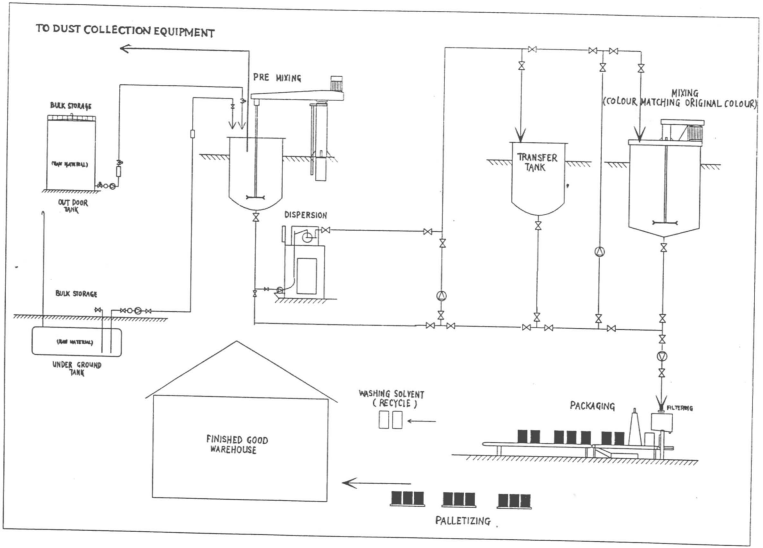



**Figure 7 Solvent-Based Paint: Process Flow Diagrams**

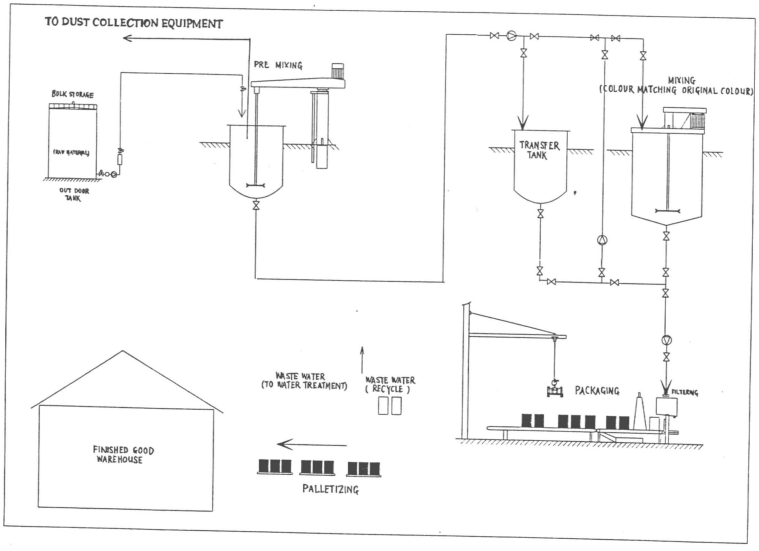



**Figure 8 Water-Based Paint:Process Flow Diagrams**

**Table 5 Solvent-Based Paint Dust: Particle Size Diameters and Distribution**

| Week | Volume Weighted Mean Diameter (μm) D(4,3)±Standard Deviation | Mode (μm) |
|---|---|---|
| 1 | 0.970±0.652 | 0.571 |
| 2 | 0.923±0.635 | 0.571 |
| 3 | 0.941±0.631 | 0.571 |
| 4 | 0.960±0.649 | 0.571 |
| 5 | 0.950±0.628 | 0.571 |
| 6 | 0.936±0.631 | 0.571 |
| 7 | 0.921±0.625 | 0.571 |
| 8 | 0.926±0.644 | 0.571 |
| 9 | 0.928±0.627 | 0.571 |
| 10 | 0.929±0.631 | 0.571 |
| 11 | 0.959±0.651 | 0.571 |
| 12 | 0.945±0.651 | 0.571 |
| Mean | 0.941±0.016 | 0.571 |

The volume weighted mean particle diameter, D(4,3) shows a slight variation, varying from 0.921 μm to 0.970 μm. The mean particle diameter is 0.941±0.016 μm. Figure 9 (a to c) shows the variation patterns over the sampling period.

For the solvent-based paint dust, there are two modes in the particle size diameter distributions as indicated in Figure 9 (a to c). One predominant mode is at 0.571 μm.

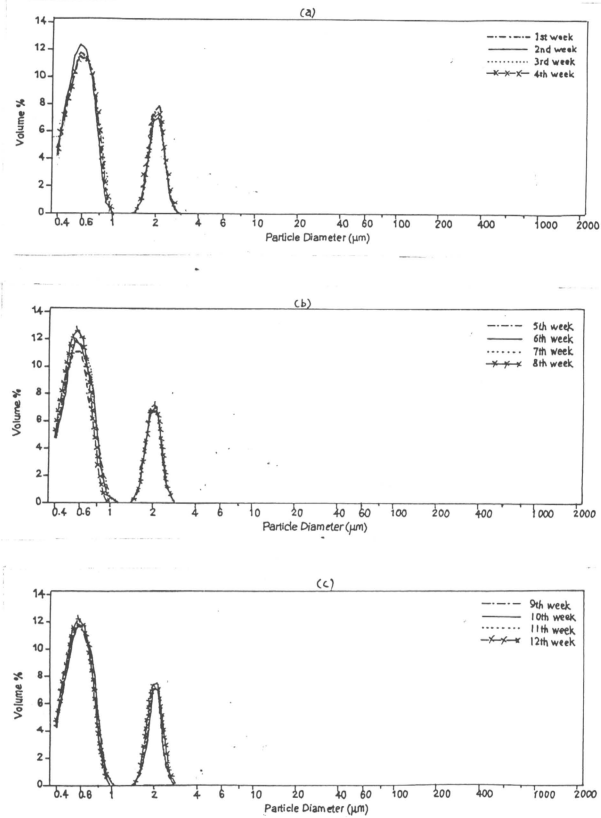



**Figure 9 Comparison of Particle Size Diameter D(4,3) Distribution Patterns for the 12 Weekly Samples of Solvent-Based Paint Dust**

This peak value of 0.571 μm appears consistently over the sampling period of 12 weeks and it comprises 11% to 12% of the total volume of the sample analysed for the twelve samples.

Another second mode is at 2 μm which comprises between 7% to 8% of the volume. Such general distribution pattern suggests a bi-modal distribution. The bi-modality is probabaly due to the presence of two distinct groups of particles in the dust samples:namely, one group has particle size diameter D(4,3) of 0.571 μm and another group has particle size diameter of 2 μm, though the latter group constitutes only 7%-8% of the sample.

#### 4.2.1.2 Particle Size Diameter: Cumulative Distribution Patterns

The cumulative distribution patterns for the particle size diameters of solvent-based paint dust samples for each week of the sampling period is shown in Table 6. For the given percentage volume, there is no significant variation in the particle size diameter except for 75% volume where the standard deviation is ±0.354 μm. For the 75% voulme, the particle size diameter varies from 0.848 μm to 1.656 μm. Overall, 10% of the volume of the sample has particle size diameter less than or equal to 0.449±0.040 μm, 25% with particle size diameter less than or equal to 0.522±0.006 μm, 50%(median) less than or equal to 0.638± 0.012 μm, 75% less than or equal to 1.117±0.354 μm and 90% less than or equal to 2.081±0.012 μm. The cumulative distribution curves are compared with the corresponding curves for the water-based paint dust (see later).

**Table 6 Solvent-Based Paint Dust:Cumulative Distributions of Particle Size Diameters**

| Week | 10.00% Volume sample | 25.00% Volume sample | 50.00% Volume sample | 75.00% Volume sample | 90.00% Volume sample |
|---|---|---|---|---|---|
| 1 | 0.452 | 0.527 | 0.649 | 1.656 | 2.101 |
| 2 | 0.444 | 0.515 | 0.625 | 0.848 | 2.072 |
| 3 | 0.452 | 0.527 | 0.647 | 0.907 | 2.077 |
| 4 | 0.450 | 0.524 | 0.644 | 1.582 | 2.095 |
| 5 | 0.456 | 0.533 | 0.659 | 0.939 | 2.078 |
| 6 | 0.451 | 0.524 | 0.643 | 0.891 | 2.075 |
| 7 | 0.448 | 0.520 | 0.635 | 0.855 | 2.065 |
| 8 | 0.441 | 0.509 | 0.616 | 0.857 | 2.080 |
| 9 | 0.449 | 0.522 | 0.639 | 0.865 | 2.069 |
| 10 | 0.447 | 0.520 | 0.635 | 0.864 | 2.072 |
| 11 | 0.449 | 0.522 | 0.641 | 1.596 | 2.097 |
| 12 | 0.444 | 0.515 | 0.626 | 1.543 | 2.091 |
| Mean | 0.449±0.004 | 0.522±0.012 | 0.638±0.012 | 1.117±0.354 | 2.081±0.012 |

Note: All values in μm indicating particle diameter less than for a given percentage volume

### 4.2.2 Water-Based Paint Dust

#### 4.2.2.1 Particle Size Diameter, D(4,3)

Table 7 presents the weekly values of the particle size diameter over the sampling period of 12 weeks.

**Table 7 Water-Based Paint Dust:Particle Size Diameters and Distribution**

| Week | Volume Weighted Mean Diameter (μm) D(4,3)±Standard Deviation | Mode(μm) |
|---|---|---|
| 1 | 8.006±6.720 | 8.536 |
| 2 | 8.159±5.910 | 9.371 |
| 3 | 8.039±6.920 | 9.371 |
| 4 | 8.006±6.090 | 8.536 |
| 5 | 8.315±6.560 | 9.371 |
| 6 | 8.421±6.520 | 9.371 |
| 7 | 8.208±6.610 | 8.536 |
| 8 | 7.965±6.290 | 12.400 |
| 9 | 8.441±6.690 | 9.371 |
| 10 | 8.290±6.270 | 10.290 |
| 11 | 8.465±7.130 | 8.536 |
| 12 | 7.901±6.670 | 11.290 |
| Mean | 8.185±0.201 | 9.582±1.204 |

The volume weighted mean particle diameter D(4,3) also shows a slight variation (range: 7.901 μm to 8.465 μm), the mean being computed to be 8.185± 0.201 μm. Figure 10 (a to c) shows the variation patterns over the sampling period.

In contrast to the observed bi-modal pattern of the solvent-based paint dust, there are the first (peak) mode and the second and the third lower modes for the water-based paint dust. The predominant mode occurs at 9.582 μm and varies slightly over the sampling period of 12 weeks. This peak mode comprises about 4% of the volume of the sample analysed. Unlike the solvent-based paint dust, the water-based paint dust shows variations in the modal values from 8.536 μm to 12.400 μm. There are second and third modes at 0.8 μm and 30.00 μm particle size diameters respectively. Each of these modes comprises 1.0-1.5% of the volume of the sample analysed. These 3 modes suggest the presence of three distinct groups of particles in the water-based paint dust.

#### 4.2.2.2 Particle Size Diameter: Cumulative Distribution Patterns

The cumulative distribution pattern for the particle size diameter for each week of the sampling period is shown in Table 8. Unlike the solvent-based paint pigment, the water-based paint pigment shows considerable variation in the particle size diameter especially for the 90% volume where the upper limit particle diameter ranges from 16.38 μm to 18.59 μm where the standard deviation is ±0.687 μm. No significant variations in particle size diameter are noted for the other percentage volume of the sample. Overall, 10% of the volume of the sample has particle size diameter less than or equal to 1.095±0.088 μm, 25% with particle size diameter less than or equal to 3.173±0.200 μm, 50% (median) less than or equal to 6.631±0.303μm ,75% less than or equal to 11.600±0.333 μm and 90% less than or equal to 17.400±0.687μm.

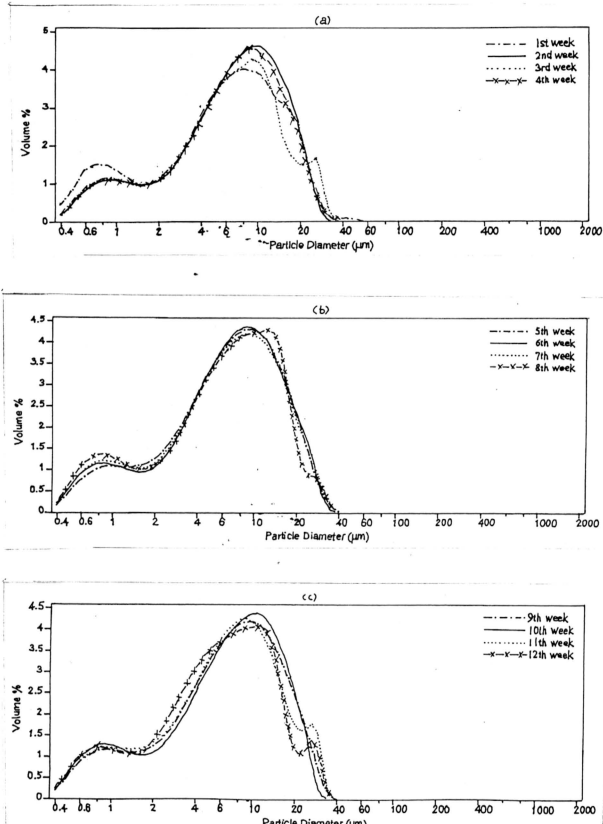



**Figure 10 Comparison of Particle Size Diameter D(4,3) Distribution Patterns for the 12 Weekly Samples of Water-Based Paint Dust**

The cumulative distribution curves are compared with those for the solvent-based paint dust.

**Table 8 Water-Based Paint Dust:Cumulative Distributions of Particle Size Diameters**

| Week | 10.00% volume sample | 25.00% volume sample | 50.00% volume sample | 75.00% volume sample | 90.00% volume sample |
|---|---|---|---|---|---|
| 1 | 0.967 | 2.924 | 6.221 | 11.40 | 17.70 |
| 2 | 1.187 | 3.485 | 7.006 | 11.72 | 16.78 |
| 3 | 1.017 | 2.883 | 6.107 | 11.10 | 17.58 |
| 4 | 1.204 | 3.359 | 6.616 | 11.29 | 16.75 |
| 5 | 1.233 | 3.299 | 6.767 | 11.75 | 17.51 |
| 6 | 1.134 | 3.424 | 6.916 | 11.90 | 17.92 |
| 7 | 1.064 | 3.143 | 6.611 | 11.63 | 17.57 |
| 8 | 0.978 | 3.037 | 6.605 | 11.58 | 16.38 |
| 9 | 1.138 | 3.225 | 6.836 | 12.06 | 18.15 |
| 10 | 1.041 | 3.241 | 7.008 | 12.08 | 17.46 |
| 11 | 1.116 | 3.107 | 6.630 | 11.65 | 18.59 |
| 12 | 1.056 | 2.949 | 6.156 | 11.09 | 16.44 |
| Mean | 1.095±0.088 | 3.173±0.200 | 6.631±0.303 | 11.600±0.333 | 17.400±0.687 |

Note: All values in μm indicating particle diameter less than for a given percentage volume

### 4.2.3 Comparison of Cumulative Distribution Curves for Solvent-Based Paint Dust and Water-Based Paint Dust

As explored above, the volume weighted mean particle diameter D(4,3) for solvent-based paint dust and water-based paint dust are 0.941±0.016 μm and 8.185±0.201 μm respectively computed based on 12 weekly samples. The corresponding ranges of D(4,3) are 0.921-0.970 μm and 7.901-8.465μm (see Table 9). This comparison suggests that the solvent-based paint dust is finer than the water-based paint dust. The water-based paint dust is coarser by nine times than the former.

**Table 9 Comparison of Mean Particle Diameter for Solvent-Based and Water-Based Paint Dust.**

| Sample | Sample Size | Volume Weighted Mean Particle Diameter D(4,3) (μm) | |
|---|---|---|---|
| | | Mean | Range |
| Solvent-Based Paint Dust | 12 | 0.941±0.016 | 0.921-0.970 |
| Water-Based Paint Dust | 12 | 8.185±0.201 | 7.901-8.465 |

Figure 11 (a to l) presents the cumulative distribution curves of the two dust types for the twelve weekly samples. Although fluctuating, the curves indicate consistently that the solvent-based paint dust is finer than the water-based paint dust. This reinforces the derived conclusion that the water-based paint dust is coarser than the solvent-based paint dust. However, greater accuracy and convincing conclusion can only be obtained if the sample size is increased and/or sampling is conducted on a long-term basis (e.g. yearly-basis).

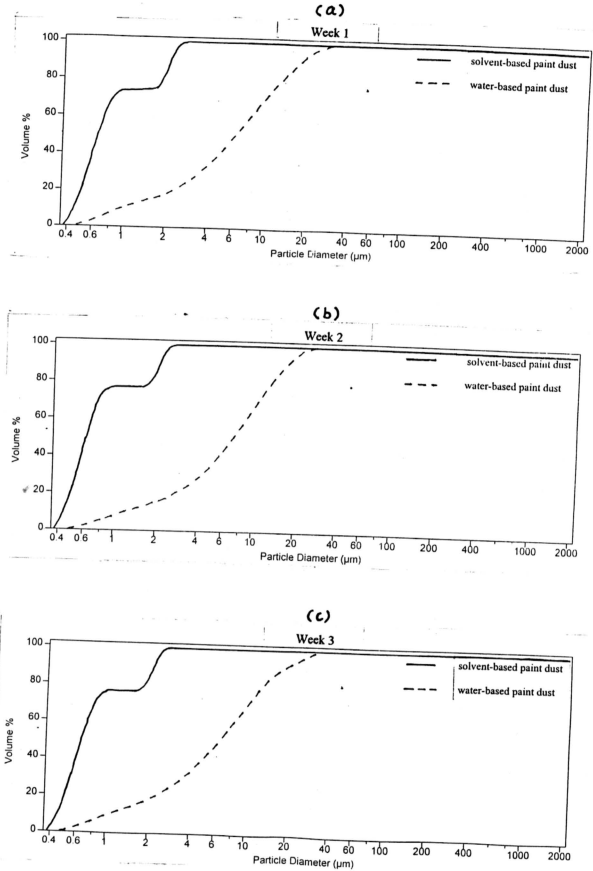
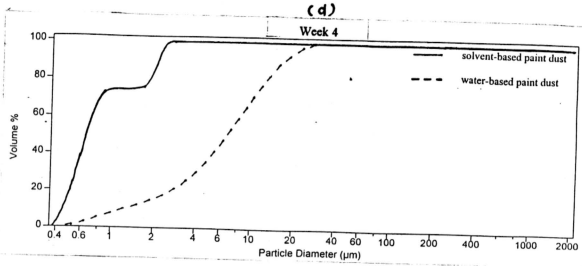
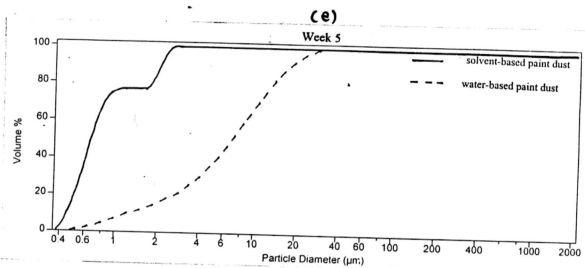



**Figure 11 Cumulative Distribution Curves of Particle Size Diameter analysed for the Weekly Samples(12 Weeks) of Solvent-Based Paint Dust and Water-Based Paint Dust**



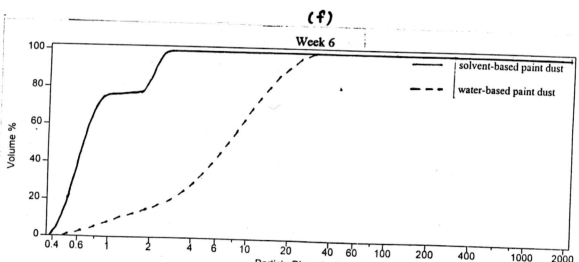
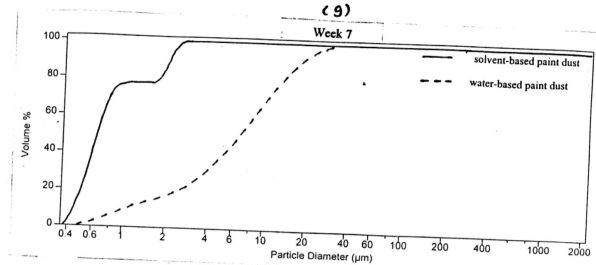
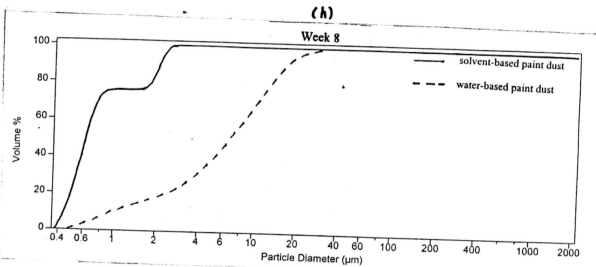
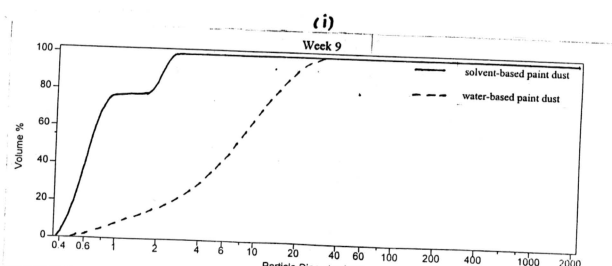




**Figure 11(Continued)**

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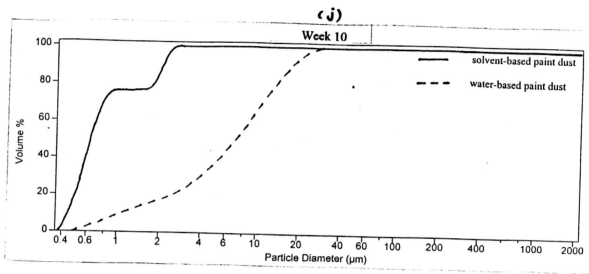
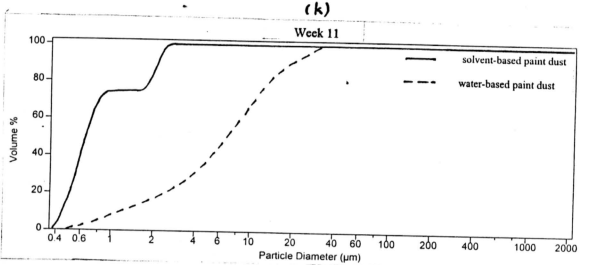


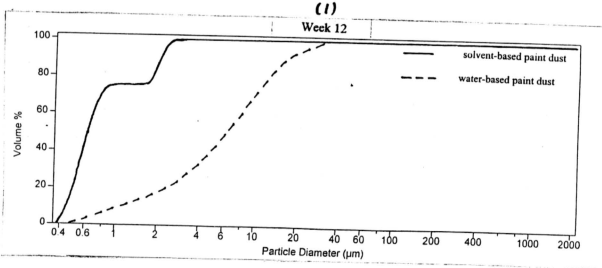




**Figure 11 (Continued)**

## 4.3 ELEMENTAL COMPOSITION AND CONCENTRATIONS IN DUST SAMPLES

### 4.3.1 Preliminary Analyses

Initial preliminary analyses were carried out on 8 elements:namely, arsenic, cadmium, chromium, cobalt, copper, nickel, lead and zinc. Table 10 shows the preliminary results of the 8 elements. It was observed that the concentrations of cadmium, chromium, cobalt and nickel in the water-based paint dust were too low and too close to the detection limits of the ICP-AES instrument for these elements. Although the concentrations of these elements were relatively higher (especially chromium) in the solvent-based paint dust, nevertheless, for purposes of comparison and discussion, only arsenic, copper, lead and zinc were selected and studied in detail. Cadmium, chromium, cobalt and nickel were therefore excluded from further analyses and discussion.

**Table 10 Preliminary ICP-AES Results of the Initial Eight Elements**

| Element | Solvent-Based Paint Dust | Water-Based Paint Dust |
|---|---|---|
| arsenic | 0.196 | 0.040 |
| cadmium | 0.011 | 0.001 |
| chromium | 11.546 | 0.025 |
| cobalt | 0.019 | 0.003 |
| copper | 3.100 | 0.017 |
| nickel | 0.034 | 0.016 |
| lead | 31.345 | 0.114 |
| zinc | 60.913 | 3.309 |

Note: All values in mg/L (1 mg/L $\equiv$ 1 mg/kg)

### 4.3.2 Solvent-Based Paint Dust

The mean concentrations of the selected elements over the sampling period are 0.10 ± 0.02 mg/g for arsenic, 1.55±0.55 mg/g for copper, 15.68±11.78 mg/g for lead and 30.46±10.58 mg/g for zinc. Table 11 shows the concentrations for the selected elements for the weekly samples. The range values are 0.065-0.130 mgAs/g, 0.761-2.945 mgCu/g, 6.595-49.310 mgPb/g and 13.588-48.508 mgZn/g of the samples analysed. The variations are significantly wide for lead and also for zinc.

**Table 11 Concentrations of As, Cu, Pb and Zn in Solvent-Based Paint Dust Over 12-Week Sampling Period. Data are the Mean Value(n=2 Replicates) with Relative Percent Difference in Parenthesis**

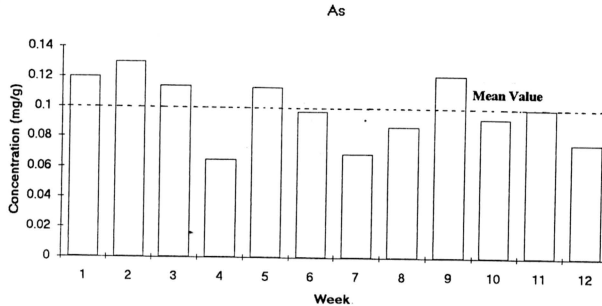
| Week | As(mg/g) | Cu(mg/g) | Pb(mg/g) | Zn(mg/g) |
|---|---|---|---|---|
| 1 | 0.120(86.4%) | 1.427(36.7%) | 9.003(32.1%) | 32.809(34%) |
| 2 | 0.130(28.1%) | 1.376(28.6%) | 49.310(25.7%) | 42.147(27.3%) |
| 3 | 0.114(3.3%) | 1.540(3.9%) | 26.512(2.5%) | 48.508(2.9%) |
| 4 | 0.065(29.3%) | 1.262(40.8%) | 10.488(33.2%) | 16.606(36.5%) |
| 5 | 0.113(8.4%) | 1.714(8.1%) | 11.027(9.5%) | 37.190(11.9%) |
| 6 | 0.097(1.9%) | 2.945(5.6%) | 13.392(2.5%) | 37.574(1.1%) |
| 7 | 0.069(31.8%) | 1.804(27.5%) | 9.553(25.7%) | 23.177(24.7%) |
| 8 | 0.087(2.1%) | 1.662(13.4%) | 16.163(9.1%) | 21.564(14.3%) |
| 9 | 0.121(2.4%) | 1.582(9.5%) | 12.952(6.6%) | 13.588(3.0%) |
| 10 | 0.092(33.2%) | 0.761(12.3%) | 6.595(20.9%) | 24.759(17.3%) |
| 11 | 0.099(9.4%) | 1.722(5.6%) | 14.623(26.6%) | 35.037(5.8%) |
| 12 | 0.076(7.1%) | 0.811(5.6%) | 8.476(3.1%) | 32.560(0.7%) |
| Mean | 0.099±0.022 | 1.551±0.554 | 15.675±11.784 | 30.460±10.576 |

The concentration profile for each element is shown in Figure 12. Some variations about the mean value are observed for each element. This may be due to the inconsistent mixing of raw materials.

Comparison of elemental concentrations indicated that zinc is the predominant element present followed in decreasing order of concentrations by lead, copper and arsenic. The concentration of arsenic is almost insignificant. However, caution must be exercised as not to simply conclude that no arsenic is present. The concentration of arsenic may be too low for it to be detected by the ICP-AES under the determined conditions. Figure 13 gives the relative concentrations of the 4 elements as comparison by means of a histogram.

### 4.3.3 Water-Based Paint Dust

The mean concentrations of the selected elements over the sampling period are 20.65±6.11μg/g for arsenic, 9.14±14.65 μg/g for copper, 57.46±22.42 μg/g for lead and 1660±1260 μg/g for zinc. Table 12 shows the concentrations for the selected elements for the weekly samples. The corresponding range values are:10.33-30.43 μgAs/g, 1.86-54.62 μgCu/g, 12.75-94.78 μgPb/g and 430-4650 μgZn/g of the sample analysed. The variation is again significantly wide for zinc and also for lead.



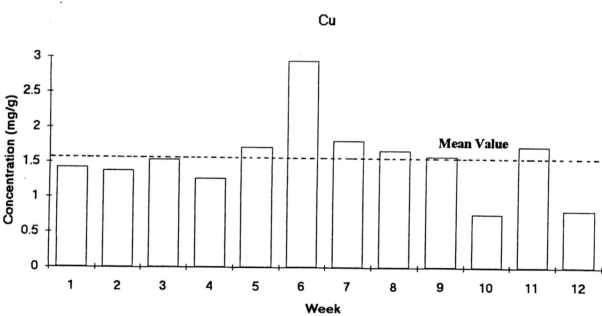




**Figure 12 Concentration Profiles of As and Cu for Solvent-Based Paint Dust**

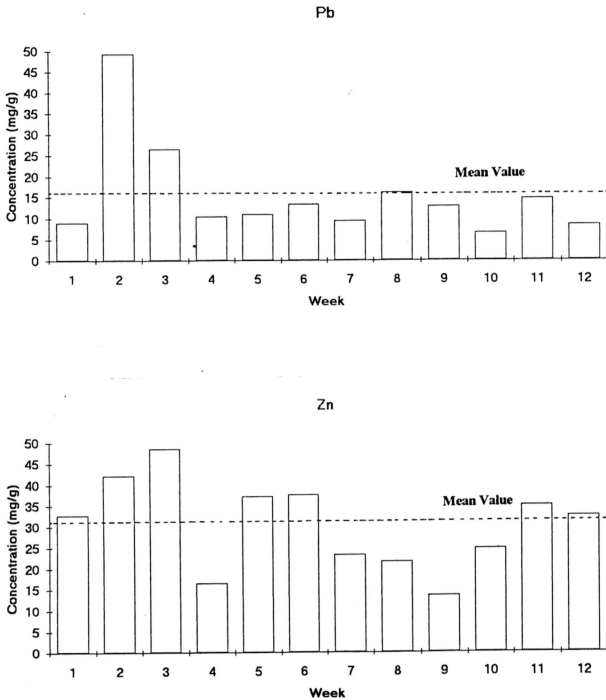



**Figure 12(Continued) Concentration Profiles of Pb and Zn for Solvent-Based Paint Dust**

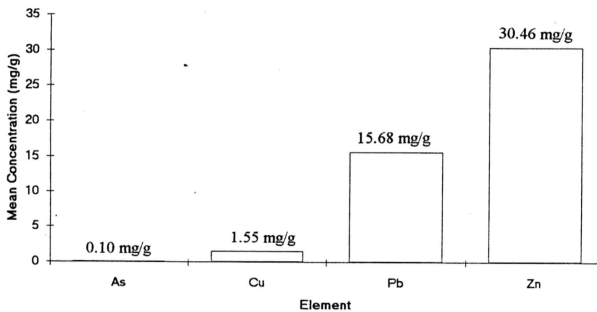



**Figure 13 Relative Concentrations of As, Cu, Pb and Zn in Solvent-Based Paint Dust**

**Table 12 Concentrations of As, Cu, Pb and Zn in Water-Based Paint Dust Over 12-Week Sampling Period. Data are the Mean (n=2 Replicates) with Relative Percent Difference in Parenthesis.**

| Week | As (μg/g) | Cu (μg/g) | Pb (μg/g) | Zn (mg/g) |
|---|---|---|---|---|
| 1 | 10.33 (28.6%) | 11.71 (137.4%) | 12.75 (15.7%) | 0.88 (11.7%) |
| 2 | 14.67 (10.5%) | 5.21 (51.4%) | 75.94 (16.7%) | 4.65 (6.1%) |
| 3 | 23.91 (5.4%) | 54.62 (184.1%) | 65.4 (13.0%) | 2.26 (2.3%) |
| 4 | 22.82 (22.2%) | 4.80 (101.8%) | 43.79 (15.2%) | 0.43 (11.6%) |
| 5 | 23.91 (10.8%) | 2.96 (9.1%) | 48.78 (13.0%) | 1.02 (29.8%) |
| 6 | 29.34 (4.8%) | 4.73 (42.0%) | 65.96 (7.6%) | 1.58 (1.9%) |
| 7 | 16.84 (9.8%) | 10.44 (133.3%) | 36.58 (12.1%) | 0.78 (1.3%) |
| 8 | 17.93 (34.9%) | 2.19 (20.4%) | 75.94 (24.6%) | 2.66 (47.7%) |
| 9 | 23.91 (10.8%) | 4.21 (52.5%) | 94.78 (4.2%) | 2.97 (2.3%) |
| 10 | 14.67 (10.5%) | 1.86 (0.8%) | 36.58 (18.2%) | 0.66 (17.4%) |
| 11 | 19.02 (9.2%) | 2.58 (24.0%) | 63.19 (17.8%) | 1.20 (45.0%) |
| 12 | 30.43 (23.3%) | 4.38 (40.6%) | 69.84 (6.2%) | 0.77 (1.6%) |
| Mean | 20.65±6.11 | 9.14±14.65 | 57.46±22.42 | 1.66±1.26 |

The concentration profile for each element is shown in Figure 14.

Variation about the mean value is also observed for each element as is the case for the solvent-based paint dust. This again could be due to the inconsistent mixing of raw materials within some permissible range of allowance.

Comparison of elemental concentrations indicated that zinc is the predominant element present followed in decreasing order of concentration by lead, arsenic and

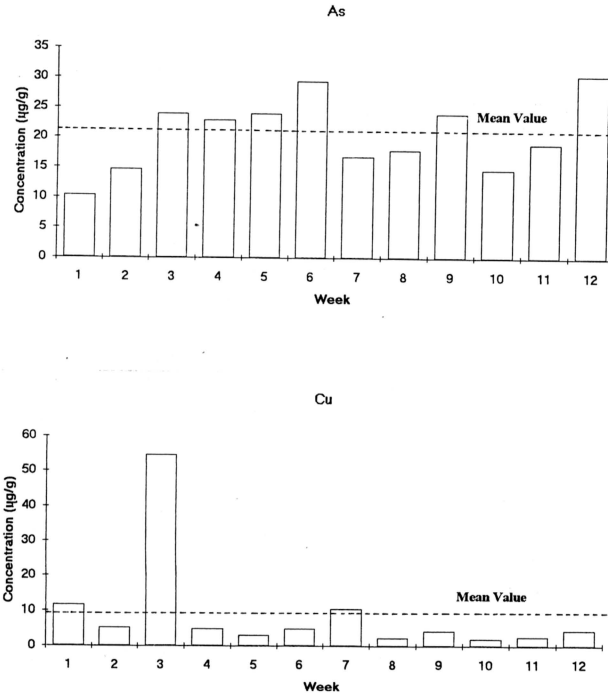
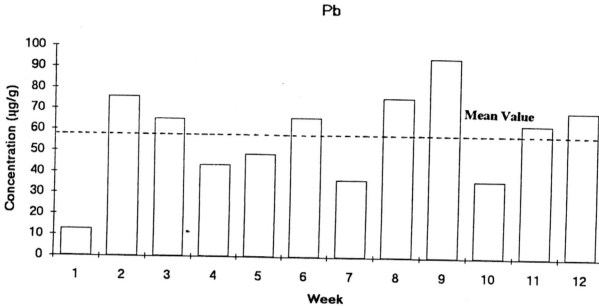



**Figure 14 Concentration Profiles of As and Cu for Water-Based Paint Dust**



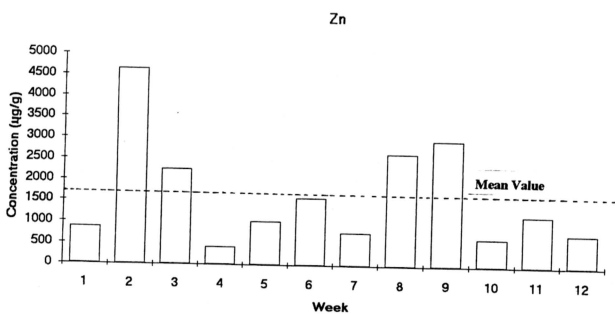




**Figure 14(Continued) Concentration Profiles of Pb and Zn for Water-Based Paint Dust**

copper. The concentration of copper, however, is almost insignificant compared to zinc and lead. Figure 15 is a histogram of the relative concentrations.

### 4.3.4 Comparison of Chemical Concentrations of the Four Selected Elements for Solvent-Based Paint Dust and Water-Based Paint Dust

The mean concentrations of the 4 selected elements in the solvent-based paint dust are significantly higher than the corresponding mean concentrations in the water-based paint dust. For As, Cu, and Pb, the difference is by more than an order of magnitude (i.e. mg/g vs μg/g). For Zn, the concentrations in the solvent-based paint dust is 30 times (i.e. mg/g) than the water-based paint dust. The reason for the much higher elemental concentrations in the solvent-based paint dust is probably due to the much finer dust particle of the solvent-based paint dust which may have greater absorption capacity than the water-based paint dust (Godish, 1991; Natusch and Wallace, 1974). Figure 16 is a histogram of the relative concentrations for the two dust types.

## 4.4 COMPARISON OF PARTICLE SIZE DIAMETERS AND THE CHEMICAL CONCENTRATIONS

The finer solvent-based paint dust appears to contain significantly higher concentrations of the 4 elements than the coarser particle size of the water-based paint dust. This relationship has an implication on the toxicity of particle to human health (Godish, 1991; Natusch and Wallace, 1974). It has been reported that higher morbidity and mortality rates usually appear to be associated with finer particulate matter apparently due to its higher toxicity nature (Ortolano, 1997). However, size-dependent toxicity of dust, aerosol and other particulate matter needs further detailed

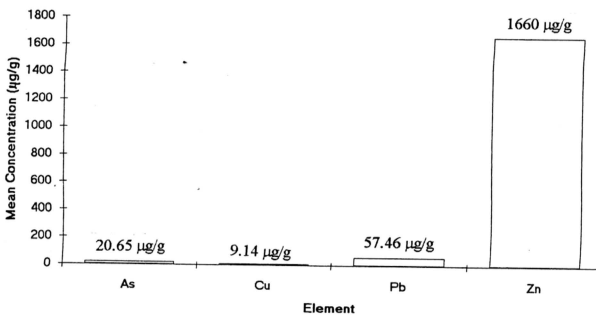



**Figure 15 Relative Concentrations of As, Cu, Pb and Zn in Water-Based Paint Dust**

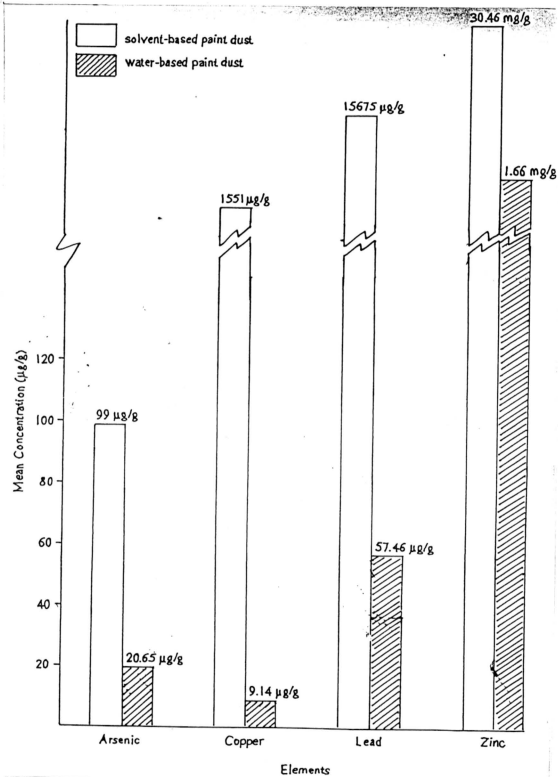



**Figure 16 Comparative Concentrations of the Four Elements for the Two Dust Types**

study and monitoring programme. Refined biomonitoring techniques such as bioassays and biomarkers coupled with exposure assessment and epidemiological studies on sensitive receptor will elucidate such toxicological aspects more conclusively. The present study approach and methodology can usefully contribute towards such multidisciplinary study in analysing the emissions (stressor) of the paint dust to any receptor(s) of interest in a holistic manner.