

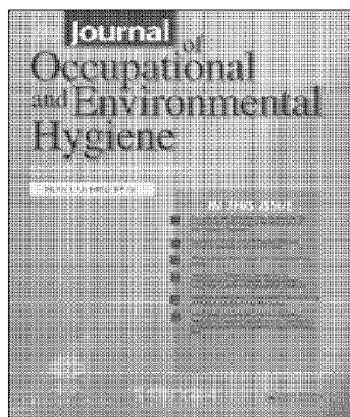
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Benzene Exposure in Industries Using or Manufacturing Paint in China—A Literature Review, 1956–2005

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A systematic review of the Chinese literature was conducted from 1956 to 2005. The survey included both online and manual searching, as well as expert discussions aimed at providing insight into factors affecting benzene exposure levels in paint/coatings industries. Data extracted from 204 papers included: (1) year of occurrence, (2) type of paint/coatings products, (3) type of industries where the products were used or produced, (4) job titles and work activities, (5) type of literature searched, (6) working conditions whenever data were available, and (7) exposure levels. Most benzene measurements were short-term samples for comparison with the Chinese maximum allowable concentration standard. The accuracy and precision of the sampling and analytical methods were not reported. The distribution of benzene concentrations was tested and found to fit neither normal nor lognormal distributions. Analysis of variance (comparison for more than two groups) and t-test (comparison for two groups) were conducted on Blom-transformed benzene concentration data. The overall median benzene exposure levels were 215, 82, 31, and 6 mg/m³ during the periods 1956–1978, 1979–1989, 1990–2001, and 2002–2005, respectively. Mean benzene exposure was significantly lower for paint manufacturing than paint spraying. No significant difference was found among paint types and benzene exposure for paint application. Benzene exposure was significantly higher in workplaces judged to have poor ventilation. No significant differences were found in benzene exposure as a function of industry type. Even though substantially lower when compared with levels in the past, recent benzene exposure measurements suggested that many facilities in the paint/coatings industries in China still have benzene concentrations that are above the current China occupational exposure limit for benzene (6 mg/m³ as a time-weighted average). Benzene concentrations from the present exercise, while not directly supporting quantitative retrospective exposure estimating, provide insight on relative benzene

exposure for painting tasks in the reported industries over time.

[Supplemental materials are available for this article. Go to the publisher's online edition of the Journal of Occupational and Environmental Hygiene for the following free supplemental resource: tables detailing benzene concentration for different types of painting and other tasks in Chinese industry.]

Keywords benzene poisoning, coatings, exposure assessment, industrial hygiene, occupational health, organic solvents

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INTRODUCTION

Exposures to benzene, toluene, xylene, styrene, and other organic solvents have long been recognized as major occupational hazards in industries using or manufacturing paint/coatings. Yin et al.⁽¹⁾ studied 528,729 workers exposed to benzene or benzene mixtures in China and showed that 280,000 (53%) were paint workers. Dosemeci et al.⁽²⁾ estimated historical exposure to benzene in China in multiple industries and multiple occupations, involving 672 factories in 12 cities in China. The highest benzene exposure was observed among rubber workers and painters (spray, electrostatic, drip painters, and paint mixers). Paint manufacturing workers were also highly exposed,⁽²⁾ averaging benzene levels greater than 20 ppm (64 mg/m³).

Early paints and coatings were unique combinations of natural oils and resins that generated relatively little environmental impact. This type of paint was still used in China during the 1950s through early 1970s. Since the late 1980s, the types of paint and coatings used in China have grown and can be categorized into three broad types: (1) oil-based, (2) water-based, and (3) powder coatings. Oil-based coatings include oleoresin, natural resin, phenol resin, and bituminous coatings. More stringent environmental regulation and rapid development of material sciences resulted in increasing use of less toxic, even "zero VOC" products (e.g., powder coatings, UV curing coatings, and some colloidal coatings). The ratio of production of oil-based to synthetic resin coatings in China has been falling since the early 1980s.⁽³⁾

This report presents the result of a systematic review of the Chinese literature from 1956 to 2005. The objective was to summarize the Chinese literature on benzene exposure in industries using or manufacturing paint/coatings in China for the period 1956–2005. The temporal trends of benzene exposure levels in the paint/coatings industries in China were analyzed, and some factors affecting worker exposure were identified. These factors provide insight for a subsequent relative ranking of exposures in this industry.

METHODS

Literature Search

Computerized searches were carried out using the Chinese Biomedical Literature Database, China National Knowledge Infrastructure, and the Super Star Reader Database, which covered the period between 1978 and 2005. Key words used in these searches included the Chinese equivalents of the following technical terms: paint/coatings manufacturing, paint/coatings application (spray, brush, immersion), oil-based coatings, water-based coatings, paint/coatings thinners, benzene and organic solvents exposure, benzene poisoning (aplastic anemia, leukemia), industrial hygiene, and occupational health.

Additional searches of print references for pre-1978 data supplemented the online searches, particularly for information describing the development of production technology and chemical compositions. This included reviews of conference proceedings, which partially covered publications before 1978 (a few articles covering years between 1956 and 1978), and professional inquiries regarding the historical development of industrial technologies in the paint/coatings industry with experts at universities and industrial institutions.

From each publication, the following information was extracted, as available:

- Benzene concentration in air measurements: number of samples; minimum, average, and maximum benzene concentration; year and type of sampling; analytical method
- Work task: spray painting, brush painting, immersion painting, paint mixing, paint manufacturing, other

- Industry group: construction, transport, vehicle/ship/aircraft manufacturing, sport equipment, handicraft/toy manufacturing, machinery equipment manufacturing
- Workplace ventilation information, if provided by the report author
- Paint type: nitrocellulose, alkyd resin, amino resin phenolic resin, polyester paint
- Paint solvent type: benzene, toluene, xylene, gasoline as specified by the report author
- Type of report: Case reports included articles that were initially published following the occurrence of a benzene poisoning case(s); industrial hygiene (IH) surveys including benzene monitoring data and any related benzene poisoning and/or suspected cases found during the survey; other reports included articles of relevance, such as toxicological investigations, summary reports, or short communications
- Number of benzene poisoning cases reported, if any
- Location (city) of the study.

Analysis

The arithmetic means and medians for the reported data were calculated, and the association between average benzene concentration of the exposure and other factors listed above were assessed as follows:

- Where only a range of benzene concentrations was provided by the authors, the arithmetic mean of minimum and maximum reported values was taken as the average. If only a maximum value was provided, the analysis was based on arithmetic mean of the maximum and zero. If only the minimum was given, then that observation was regarded as missing.
- The distribution of benzene concentrations was tested and found to fit neither normal nor lognormal distribution. Data subsets for paint application (spray, brush, immersion, mix) and for paint making were neither normal nor log-normal. Because the data were highly skewed, the medians instead of the means in each subgroup were better indicators of central tendency of original data. For the same reason, rank-based transformations (below) were performed so that parametric statistics such as t-test and analysis of variance (ANOVA) could be used to compare different transformed groups. Rank-based nonparametric statistics for original data were used to confirm the results.
- Because the data were neither normal nor log-normal, parametric analysis techniques such as t-test and ANOVA were not applicable without transformation. To transform the data into normal distribution, they were ranked in orders. Then the rank of the *i*-th data point was changed into a normal score that corresponded to the *i*-th data point had the data set been normally distributed. The algorithm for the transformation⁽⁴⁾ was:

$$y_i = \Phi^{-1} \left(\frac{r_i - 0.375}{n + 0.25} \right) \quad (1)$$

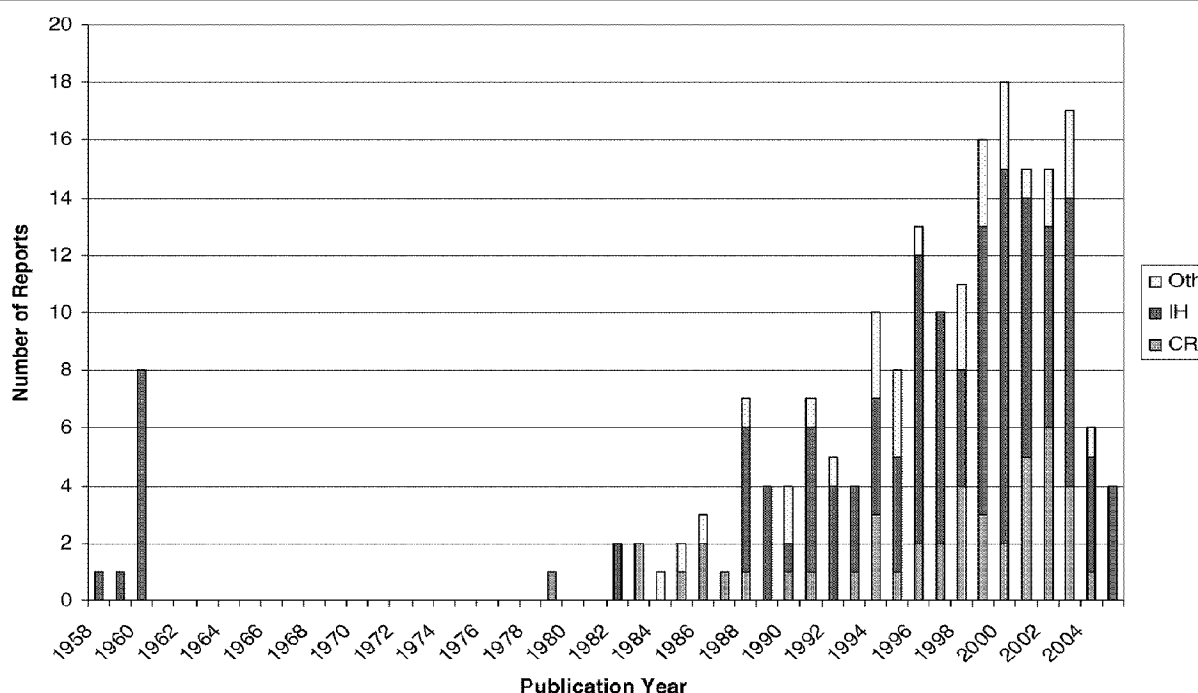


FIGURE 1. The distribution of reported articles by years: CR-case report initially published following the occurrence of a benzene poisoning case, IH-industrial hygiene survey, Oth-other report including toxicology, summary reports, or short communications.

where r_i is the rank of the i -th observation and n is the number of nonmissing observations; Φ^{-1} is the probit function, or the inverse of the standard cumulative normal function. The transformed data were then normally distributed with mean = 0 and standard deviation = 1. The subset of paint application and paint-making data after transformation were both normal. As a result, t-test and ANOVA could be applied to the transformed data in subsequent analysis. However, the numbers in the tables from the subsequent results section are presented as observed values for the ease of interpretation.

- ANOVA (comparison for more than two groups) and t-test (comparison for two groups) were conducted on the Blom-transformed⁽⁴⁾ benzene concentration data. Because paint-making activities had a generally lower mean benzene concentration than other activities, most analyses were done for paint-using industries and paint-making industries separately except for the ANOVA for job activities, where paint-making and the subcategories of paint-using activities were analyzed together. The pair-wise comparisons within groups after ANOVA were adjusted for multiple comparisons. ANOVA and t-test results from the transformed data were verified by Kruskal-Wallis (nonparametric counterpart for ANOVA) and Wilcoxon (nonparametric counterpart for t-test) tests for untransformed data. Results using these alternate tests were consistent.

The criterion for statistical significance was set at $p < 0.05$. All analyses were performed using the statistical software SAS 9.1.3.

RESULTS

Search Results

The literature search resulted in 204 papers of benzene poisoning case reports, industrial hygiene surveys, and other reports (toxicological studies and article reviews) published in 51 Chinese refereed medical journals or other sources (including four conference proceedings) from 1956 to 2005 (Figure 1). In China, according to the National Diagnostic Criteria of Occupational Benzene Poisoning,⁽⁵⁾ benzene poisoning was classified as *observation case*, *acute poisoning (mild and severe)*, and *chronic poisoning (mild and severe)* depending on the exposure history, clinical symptoms and signs, and the feature of hematological tests. However, the information reported in the literature was often limited to case classification (e.g., observation, acute benzene poisoning, chronic benzene poisoning) without elaboration on clinical signs or exposure history.

The collected data covered 24 provinces, municipalities, and autonomous regions, representing 77% of the 31 administrative regions in China. About half the reported papers were from the most developed industrial areas in the coastal regions, including Guangdong, Jiangsu, Zhejiang, Shandong, Liaoning

provinces, and Shanghai municipality; one-quarter from the Central and South China regions; and the remaining quarter from Northeast, North, Northwest, and Southwest regions. This distribution by geographical location was expected, as it was primarily dependent on the status of economic development and industrialization.

The distribution of information sources was associated with the economic development during the time period covered. The number of published articles increased with the development of economic reform in the late 1980s and peaked between the mid-1990s and early 2000 when demand for paint and coatings was high in the shipbuilding, automobile, machinery, household electric appliances, toys, and house reconstruction industries.

The majority of the literature ($n = 180$) covered industries where paint and coatings were used, including shipbuilding, automobile, furniture, household electric appliances, machinery, toys, arts/crafts, stationery, sports equipment, and house decorating. Fewer articles ($n = 24$) reported benzene exposure in the paint or coatings manufacturing industry.

Most of the air sampling approaches represented relatively short-term samples, typically from workers' breathing zones. There were three common sampling and analytical methods used for the measurement of benzene in workplace air in China. The earliest employed an impinger with solvent through which the air was bubbled, followed by a colorimetric analysis. The next method employed glass syringe grab sampling, with gas chromatographic analysis, which was the method used for most of the data reported in the reviewed literature. This glass syringe collection method may have continued well into the 1990s.

The most recent method used a single-section charcoal tube with a 20-min sampling period at a normal flow rate of 200 mL/min, also with gas chromatographic analysis (Table I). Information was not available to compare the accuracy, precision, limit of quantification, and interferences for these different methods.⁽⁶⁾

Data extracted from the search results were tabulated, translated, and sorted by task for spray painting, brush painting, immersion painting, paint mixing, and paint making in the online supplemental Appendix Tables A-I through A-VI, respectively. Where the source reports identified air sampling results for two tasks, the data were included in both tables. In many cases, the source reports did not include details related to sampling and analysis, sample number, or factors that could potentially influence benzene exposure, such as ventilation, task, paint type, or industry type. In most cases,

the authors of the source reports did not provide information on task frequency or duration that could have enabled estimation of full-shift exposure. Available information was tabulated.

Benzene Exposure Trend

The 204 reports yielded 428 data sets. Five sets of data showed extremely high benzene concentrations (above 20,000 mg/m³) that the authors reported were based primarily on simulation tests to replicate certain acute poisoning episodes. These were excluded from subsequent statistical analysis. Reports of accidental or emergency benzene exposures were also excluded from subsequent analysis. The final analysis was based on 407 sets of benzene concentration values representing more than 5500 reported air samples (Figure 2). These data showed a skewed distribution as illustrated in Figures 3A and 3B. When Blom-transformed, the data and subsets were normally distributed and could be subjected to parametric statistical analysis.

To assess the benzene concentration trend over time, 317 data sets that included both workplace air benzene concentrations and the year of measurement were usable. The pattern of benzene exposure was examined in four time periods, based on economic development stages: (1) 1956–1978 (pre-economic reform); (2) 1979–1989 (open policy and the beginning of economic growth); (3) 1990–2001 (further industrial development and growth); and (4) 2002–2005 (after passage of the Occupational Disease Prevention and Control Act in 2002 and implementation of new occupational exposure limit [OEL] for benzene). Descriptive statistics for these periods are listed in Table II.

Substantial differences were found between the median and mean of each group. The skewness of the data suggested that the median was a better measure to assess untransformed data. To compare the benzene level of each subgroup, ANOVA for rank-based Blom-transformed concentration and nonparametric Kruskal-Wallis test for untransformed concentrations were conducted. Pair-wise comparisons were conducted for transformed benzene concentration (paint using) with adjustment for multiple comparisons using Tukey's method (same for all other ANOVA unless otherwise specified). The average benzene level was significantly higher in Period 1 (1956–1978) than three other later periods; the level in Period 2 (1979–1989) was significantly higher than Period 3 (1990–2001) and Period 4 (2002–2005). Periods 3 and 4 were not significantly different. Generally, the mean exposure levels over the 1956–2005 periods suggested a downward trend.

TABLE I. Summary of Sampling and Analytical Methods by Time Period

Period	Sampler	Flow Rate (mL/min)	Sampling Time (min)	Analytical Method
1950s–1960s	Impinger	200	10	Colorimetry
1970s–1980s	Glass syringe	100 mL (volume)	1	Gas chromatography
1990s–present	Charcoal tube	200	15–20	Gas chromatography

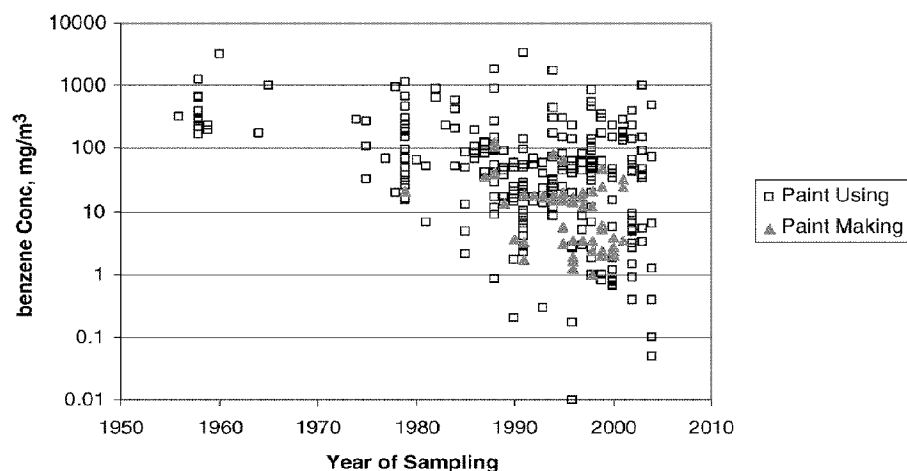


FIGURE 2. Average benzene concentration measurements in China for period 1956–2005. Average benzene concentrations from 266 paint-using reports (includes spray, brush, immersion painting, and paint mixing) and from 59 paint manufacturing reports. The average benzene level was significantly higher for paint-using industries as a whole than for paint manufacturing as determined by the Wilcoxon test.

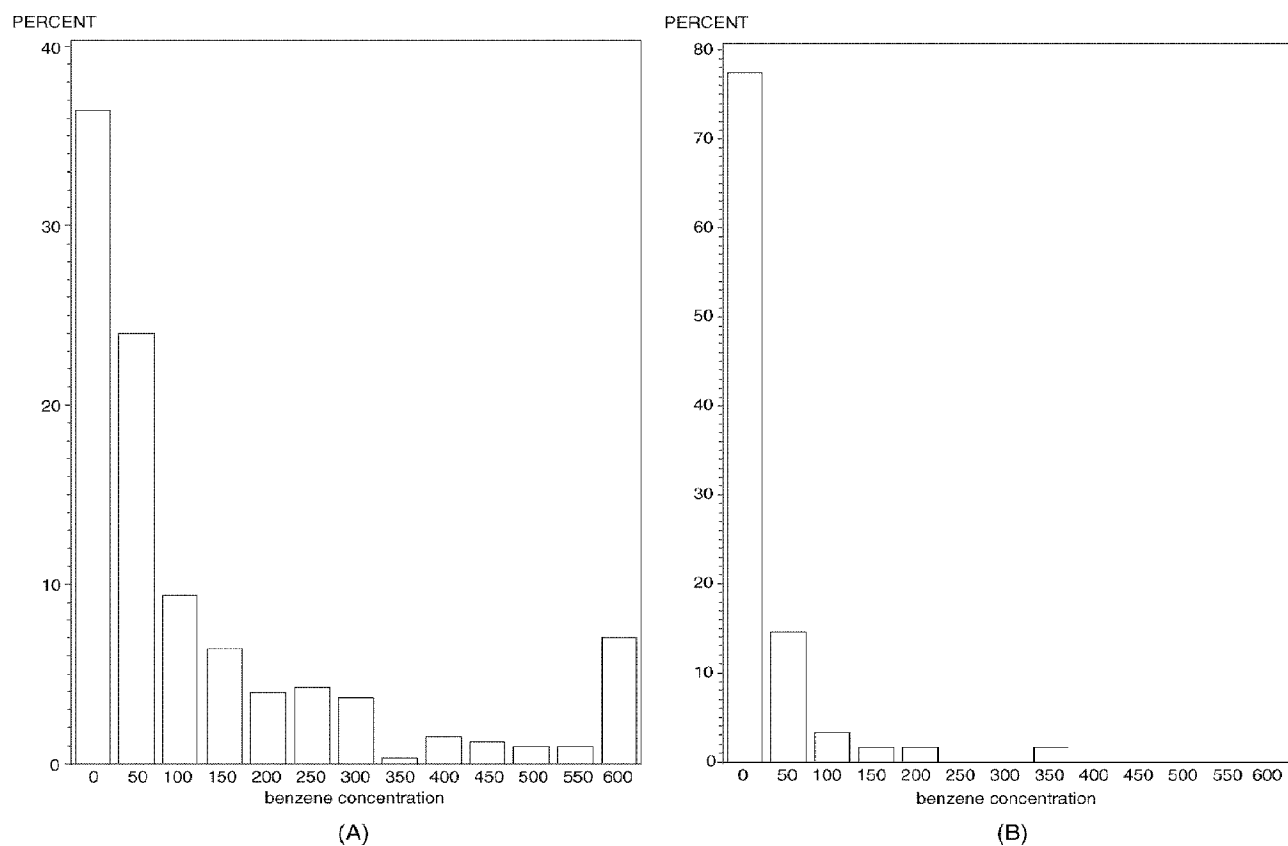


FIGURE 3. (A) Paint-using frequency distribution histogram. Untransformed average benzene concentration (concentration in mg/m^3). The column corresponding to "0" concentration represents observed concentrations below $25 \text{ mg}/\text{m}^3$. (B) Paint-making frequency distribution histogram. Untransformed average benzene concentration (concentration in mg/m^3). The column corresponding to "0" concentration represents observed concentrations below $25 \text{ mg}/\text{m}^3$.

TABLE II. China Benzene OELs and Mean Benzene Concentration (mg/m³) for Different Historical Periods

Period	Description	OEL (mg/m ³)	Mean	N	Std. Dev.	Median	Maximum	Minimum
1	1956–1978	50 (MAC)	336.84	47	503.77	215.00	3212.30	15.00
2	1979–1989	40 (MAC)	191.77	75	309.87	82.4	1827.50	0.00
3	1990–2001	40 (MAC)	125.5	158	344.59	31.33	3373.50	0.00
4	2001–2005	6 (PC-TWA) 10 (PC-STEL)	81.73	37	187.46	6.46	991.50	0.00

The benzene exposure level for the four historical periods were compared using ANOVA on transformed data. The mean concentrations of these periods were significantly different ($p < 0.0001$). The result was confirmed by Kruskal-Wallis test, and pair-wise comparisons between groups were adjusted for multiple comparisons using Tukey's method. The China OEL prior to 2002 was a maximum allowable concentration without averaging time, and compliance was assessed by short-term sample. The OEL from 2001–2005 was 6 mg/m³ permissible concentration 8-hour TWA; 10 mg/m³ permissible concentration as a short-term exposure limit. N refers to number of source data sets and does not add to 407 due to missing data from source reports. The average benzene level was significantly higher in Period 1 (1956–1978) than three other later periods; the level in Period 2 (1979–1989) was significantly higher than Periods 3 (1990–2001) and 4 (2002–2005). Periods 3 and 4 were not significantly different.

Report Type and Benzene Poisoning Cases

Sixty-four articles reported 527 cases of benzene poisoning at various stages of severity. Of those, 35 articles that were identified as “case reports” covered 120 cases of benzene poisoning (23%); 25 articles that were identified as “IH surveys” covered 297 cases of “benzene poisoning” and/or “suspected benzene poisoning” (56%); and 4 articles that were identified as “others,” which described the toxicity, occupational exposure, and health effects of benzene in paint/coatings industry covered 110 cases of related “benzene poisoning” (21%).

The regional and year distributions of reported benzene poisoning cases were consistent with the number of papers being reported and the amount of paint and coatings produced in the specific areas during the same periods. For example, more than 70% of the total cases were reported from East China and Central South China; both having similar proportions of the total annual production of 1.8–2.0 million tons of China manufactured-paint and coatings produced and used in 1999–2001.^(7,8)

Pair-wise comparisons were conducted on transformed data for report type and whether benzene poisoning was reported for the paint-using groups. Paint making was not analyzed due to too few observations. Mean benzene concentration for different report types was summarized in Table III. Mean benzene concentration in case reports was significantly higher than that

in industrial hygiene surveys and other reports, while the mean concentrations in the latter two did not differ significantly. Data on mean benzene concentration for reports of benzene poisoning cases vs. nonpoisoning cases are summarized in Table IV. Results were based on a t-test for the Blom-transformed concentrations and Wilcoxon test for untransformed concentrations. The p-value in Table IV is the result of t-test. Mean benzene concentration was significantly higher in reports of benzene poisoning than in other reports.

Benzene Workplace Air Concentrations by Work Activity for Industries Using or Manufacturing Paint

One hundred eighty articles identified job activities associated with benzene air concentrations in paint use or paint manufacturing. A total of 330 samples of benzene exposure levels were associated with five main work activities: (1) brush painting, (2) spray painting, (3) paint mixing, (4) immersion painting, and (5) work processes in paint manufacturing. As shown in Table V, for all years, benzene air concentrations by work activity can be characterized generally as: brush painting > spray painting > paint making. Pair-wise comparisons were conducted on transformed data for job/task type.

Mean benzene concentration was significantly lower in paint manufacturing than spray painting, but the rest of the categories did not show a significant difference. The benzene air concentrations for the paint-using industry as a whole

TABLE III. Mean Benzene Concentration (mg/m³) for Different Types of Reports (Paint-Using)

Description	Mean	N	Std. Dev.	Median	Maximum	Minimum
Case report	291.91	43	369.62	171.50	1758.10	1.00
IH investigation	163.72	213	387.66	50.20	3373.50	0.00
Other	94.11	73	181.56	31.58	1035.00	0.00

The benzene air concentrations for different report types were compared using ANOVA on transformed data. The mean benzene air concentrations of these report types were significantly different ($p = 0.0113$). Mean benzene air concentration for case reports was significantly higher than for industrial hygiene survey and other reports as determined by pair-wise comparison, while the mean concentrations in the latter two did not differ significantly. The result was confirmed by Kruskal-Wallis test, and pair-wise comparisons between groups were adjusted for multiple comparisons using Tukey's method. N refers to number of source data sets and does not add to 407 due to missing data from source reports.

TABLE IV. Mean Benzene Concentration (mg/m³) for Benzene Poisoning and Nonpoisoning Cases (Paint Using)

Benzene poisoning cases reported?	Mean	N	Std. Dev.	Median	Maximum	Minimum
No	110.43	256	257.84	37.05	3212.30	0.00
Yes	356.48	73	535.34	151.10	3373.50	1.00

The mean benzene exposure levels for benzene poisoning and nonbenzene poisoning cases were significantly different as determined by Wilcoxon test ($p < 0.0001$). The result was confirmed by t-test on transformed data. N refers to number of source data sets and does not add to 407 due to missing data from source reports.

(including spray painting, brush painting, paint mixing, and immersion painting) were significantly higher than those from the paint manufacturing industry using Wilcoxon test (Figure 2).

Benzene Workplace Air Concentrations by Type of Paint/Coatings Used or Produced

Forty-one articles identified the type of paint/coatings that were used or produced at work, which consisted of nitrocellulose paint (20 articles), alkyd resin paint (9), amino resin paint (7), phenolic resin paint (2), and polyester paint (3). These articles reported 128 sets of air samples (Table VI). ANOVA

for transformed concentrations showed that no significant differences were found among paint types. (Paint making was not analyzed, and phenolic paint was not included in the analysis, both due to too few observations.)

Comparison of Benzene Air Concentrations by Reported Effectiveness of Workplace Ventilation

Seventy-seven articles provided information about the status of ventilation at the workplace. "Poor ventilation" (P) denoted that adequate mechanical ventilation facility was not present, but included simple electric fans (e.g., floor fans) or "natural" ventilation. These accounted for most of the articles;

TABLE V. Mean Benzene Concentration (mg/m³) for Different Job Activities

Job Activity	Historical Period	Mean	N	Median	Maximum	Minimum
Spray	1956–1978	509.95	20	280.30	3212.30	20.30
	1979–1989	201.42	46	88.46	1827.50	0.00
	1990–2001	79.76	102	24.78	1758.10	0.00
	2002–2005	101.72	27	8.15	991.50	0.00
	All years	156.65	195	43.90	3212.30	0.00
Brush	1956–1978	220.00	3	200.00	285.00	175.00
	1979–1989	194.87	14	51.70	885.00	0.00
	1990–2001	319.20	18	119.05	3373.50	0.00
	2002–2005	29.43	7	5.33	153.20	1.25
	All years	222.37	42	58.20	3373.50	0.00
Mixing	1990–2001	59.45	12	56.44	139.40	1.00
	2002–2005	23.82	3	9.37	56.70	5.38
	All years	52.33	15	53.58	139.40	1.00
Immersion	1956–1978	106.80	1	106.80	106.80	106.80
	1979–1989	115.56	8	52.70	461.80	2.15
	1990–2001	129.79	7	17.13	540.00	1.15
	All years	121.24	16	27.38	540.00	1.15
Paint manufacturing	1956–1978	267.00	2	267.00	344.00	190.00
	1979–1989	45.78	10	36.21	127.50	13.22
	1990–2001	14.05	50	12.06	82.00	1.00
	All years	27.32	62	15.08	344.00	1.00

Benzene exposure levels for different job activities were summarized. The exposure levels were broken down for different historical periods within each job category. Comparison between groups was conducted for *All years* data, not by historical period subgroups. The mean benzene exposure levels (all years) for each job activity were significantly different as determined by ANOVA on transformed data ($p = 0.0111$). The result was confirmed by Kruskal-Wallis test, and pair-wise comparisons between groups were adjusted for multiple comparisons using Tukey's method. Mean benzene concentration was significantly lower in paint manufacturing than spray painting, but the rest of the categories did not show a significant difference. N refers to number of source data sets and does not add to 407 due to missing data from source reports.

TABLE VI. Mean Benzene Concentration (mg/m³) for Different Types of Paint

Paint Type	Mean	N	Std. Dev.	Median	Maximum	Minimum
Nitrocellulose	215.76	29	315.64	59.30	965.00	0.00
Alkyd resin	25.89	14	22.53	21.93	86.92	0.00
Amino resin	28.43	4	11.01	24.55	44.61	20.00
Polyester	15.82	9	23.35	5.10	56.80	0.38

The mean benzene exposure levels for different types of paint were not significantly different as determined by ANOVA on transformed data ($p = 0.3537$). The result was confirmed by Kruskal-Wallis test. N refers to number of source data sets and does not add to 407 due to missing data from source reports.

78% (60/77). “Good ventilation” (G), indicating that adequate mechanical ventilation system (e.g., air exhaust hood and mechanical fan) was present, accounted for only 22% (17/77) of the articles. Summary data are shown in Table VII. A t-test was conducted on transformed data for reported workplace ventilation effectiveness. Mean benzene concentration was significantly lower for reports with good ventilation effectiveness for the paint-using groups.

Industry Type and Benzene Exposure

Ninety articles identified the specific type of industries in which paint or coatings were used. According to the *Classification Standard of National Economy*,⁽⁹⁾ the relevant industries and/or occupations were grouped into four categories with standard codes as: (1) construction, including civil engineering and household reconstruction; (2) transport vehicle manufacturing, including shipbuilding, aircraft, automobile, and locomotive vehicles; (3) stationery, sports equipment, handicrafts, and toy manufacturing; and (4) machinery equipment manufacturing, including electric engines, valves, lathes, abrasion wheels, plus paint making (Table VIII). ANOVA and Kruskal-Wallis tests both indicated that no significant differences were

found among industry types and benzene concentration for the paint-using groups. (Paint making was not analyzed.)

DISCUSSION

Trend of Benzene Workplace Air Concentrations in Paint/Coatings Industry in China

This report summarizes occupational benzene exposure data from the Chinese literature for the period 1956–2005. Four hundred twenty-eight data sets were extracted from 204 reports in 51 Chinese journals. (The total numbers in each analysis would not add to 428 due to missing values or exclusion.) After data transformation, ANOVA was used to detect associations between benzene exposure and several workplace factors. The published benzene exposure data ranged from undetectable to very high benzene concentrations (over 100 times the China occupational exposure limit for each historical period). In general, the mean benzene concentration for each historical period followed a downward trend, though the last two periods had similar mean concentrations.

It was neither the intent nor design of this report to assess compliance with the China OEL. However, it was interesting

TABLE VII. Mean Benzene Concentration (mg/m³) for Different Workplace Ventilation Effectiveness

Workplace Ventilation	Job Activity	Mean	N	Median	Maximum	Minimum
Poor	Spray	226.68	30	73.51	3212.30	0.00
	Brush	465.57	11	90.10	3373.50	1.25
	Mixing	36.43	8	26.05	120.06	1.00
	Immersion	203.12	3	68.20	540.00	1.15
	Paint manufacture (unspecified)	31.51	20	17.60	127.50	12.06
	Total	250.99	7	130.32	800.00	7.00
Good	Total	192.53	79	49.50	3373.50	0.00
	Spray	82.82	21	6.21	991.50	0.01
	Brush	—	0	—	—	—
	Mixing	105.50	4	111.65	139.40	59.30
	Immersion	9.63	3	5.60	20.20	3.10
	Paint manufacture	613.62	2	613.62	1180.00	47.23
	Total	113.91	30	18.61	1180.00	0.01

Mean benzene concentrations for workplaces were sorted by reported ventilation effectiveness and job activity. Comparison between groups was conducted for Total data, not by job activity subgroups. Benzene concentrations for poor ventilation (total) were significantly different from those for good ventilation (total) as determined by Wilcoxon test ($p = 0.0439$). The result was confirmed by t-test on transformed data. N refers to number of source data sets and does not add to 407 due to missing data from source reports. Workplace ventilation as reported by authors of the source reports: “Poor ventilation” included simple electric fans (e.g., floor fans) or “natural” ventilation; “Good ventilation” indicated that adequate mechanical ventilation system (e.g., air exhaust hood and mechanical fan).

TABLE VIII. Mean Benzene Concentration (mg/m³) for Different Types of Industry

Industry	Historical Period	Mean	N	Median	Maximum	Minimum
Construction	1956–1978	.	0	.	.	.
	1979–1989	151.26	5	52.40	600.00	6.50
	1990–2001	326.53	18	110.81	3373.50	1.35
	2002–2005	53.86	15	5.38	406.05	0.38
	All years	195.84	38	51.00	3373.50	0.38
Vehicle	1979–1989	129.92	9	115.00	243.60	8.57
	1990–2001	167.07	16	22.50	1758.10	0.81
	2002–2005	18.63	5	5.33	44.61	0.00
	All years	131.18	30	35.09	1758.10	0.00
Craft	1956–1978	157.27	3	165.00	200.00	106.80
	1979–1989	49.21	2	49.21	68.20	30.21
	1990–2001	78.74	19	54.50	300.00	0.98
	2002–2005	36.37	4	26.34	89.61	3.20
	All years	78.99	28	56.90	300.00	0.98
Machinery	1956–1978	423.75	11	285.00	1225.00	20.30
	1979–1989	184.73	29	97.00	1104.70	2.15
	1990–2001	22.55	35	15.73	171.66	0.01
	2002–2005	37.50	1	37.50	37.50	37.50
	All years	142.70	76	37.15	1225.00	0.01
Paint making	1956–1978	267.00	2	267.00	344.00	190.00
	1979–1989	45.78	10	36.21	127.50	13.22
	1990–2001	14.05	50	12.06	82.00	1.00
	All years	27.32	62	15.08	344.00	1.00

The benzene exposure levels from different types of industry were summarized. The exposure levels broken down for different historical periods within each industry were also shown. There was no significant differences among the mean benzene exposure levels (all years) for these industries (not including paint making) as determined by ANOVA on transformed data ($p = 0.9518$). The result was confirmed by Kruskal-Wallis test. N refers to number of source data sets and does not add to 407 due to missing data from source reports. *Construction* includes civil engineering and household reconstruction; *Vehicle* includes transport vehicle manufacturing, including shipbuilding, aircraft, automobile, and locomotive vehicles. *Crafts* includes stationery, sports equipment, handicrafts, and toy manufacturing. *Machinery* includes equipment manufacturing, including electric engines, valves, lathes, abrasion wheels.

to observe from Table II that mean benzene air concentrations were higher than the national OELs in effect at the time for each historical period. Even for the most recent time period, mean exposure was 81.73 mg/m³ exceeding the current OEL (6 mg/m³ time-weighted average, TWA) and the old OEL of 50 mg/m³ in effect from the 1950s until the late 1970s. (Until 2002, the OELs in China were defined as maximum allowable concentrations in workplace air.)⁽¹⁰⁾

Factors Affecting Benzene Exposure Levels

Job Activities

The job activity seemed to be an important determinant affecting benzene exposure level in the paint/coatings industry. As shown in Table V, benzene exposure levels by work activity were characterized as: brush painting > spray painting > paint making. Paint-making exposures were significantly lower than spray painting exposures.

Type of Paint/Coatings

As shown in Table IX, 17 categories of paint/coatings have been commonly used in China nationwide since the early 1980s.⁽¹¹⁾ Meanwhile, a variety of new products of paint/

coatings were derived from these primary categories. Information about the precise type of paint/coatings reported in the literature was limited. In this report, no significant differences were found among paint types and benzene concentration for the paint-using groups.

Status of Ventilation

The overall benzene levels at workplaces subjectively characterized as having good ventilation effectiveness were associated with lower benzene air concentrations than those with poor ventilation effectiveness. As suggested from Table VII, exposures above the OEL were commonly reported even for facilities with ventilation effectiveness judged “good” by the authors of the reports. Reliable prevention of overexposure to benzene in the painting industry can require costly and carefully designed and maintained ventilation systems,⁽¹²⁾ which was not commonly implemented until the passage of the Occupational Disease Prevention and Control Act in 2002.

Type of Industries using Paint/Coatings

There were no significant differences in mean benzene concentration by industry type or type of paint or coating. However, there was large dispersion in the data, and all industries

TABLE IX. Categories of Coatings in China

Coating Type	Benzene Potential?	Solvents/Thinners Commonly Used ^(11,16-19)
Oil-based coatings	Yes	200 solvency gasoline (petroleum distillate with a boiling range of 140–200°C) containing certain amount of aromatic hydrocarbons; mainly but not purely xylene and toluene
Natural resin coatings	No	Combination of natural oils and resins such as shellac
Phenolic resin coatings	Yes	Solid phenolic resin is soluble in most polar organic solvents and aromatic-oxygenated solvent mixtures
Bituminous coatings	Yes	(1) 200 solvency gasoline containing certain amount of aromatic hydrocarbons, mainly but not purely xylene and toluene; and (2) “heavy benzene”+ kerosene
Alkyd resin coatings	Yes	200 solvency gasoline containing certain amount of aromatic hydrocarbons, mainly but not purely xylene and toluene
Amino resin coatings	Yes	Xylene, butyl alcohol, ethyl acetate in proportion of 80:10:10
Nitro-cellulose coatings	Yes	“Xiangjiaoshui,” a solvent may contain as high as 20–40% benzene
Cellulosic coating	No	
Vinyl per-chloride coatings	Yes	Esters, ketones, and solvents containing benzene, toluene, or xylene
Alkene-based resin coatings	Uncertain	
Epoxy resin coatings	No	Cyclohexanone, xylene, butyl alcohol
Polyester coatings	Yes	Likely to be naphtha or mineral spirits
Acrylic resin coatings	Yes	Most acrylics require strong solvents; esters, alcohols, and benzene, toluene, or xylene are commonly used
Polyurethane coatings	No	xylene, butyl acetate, cyclohexanone
Elemental organic coatings	No	
Rubber coatings	Yes	
Other types of coatings	Varies	

had reported exposure measurements substantially higher than the OEL.

Solvent Composition

The decreasing OELs for benzene during the period of this review, and recognition of the health impact of benzene, led to the current controls on benzene in solvents in China. Benzene content in adhesives and coatings have been regulated as less than 0.5% (i.e., <5g/kg) since 2001.⁽¹³⁾

Outlook

Several actions in China offer hope for future reduction in benzene exposure in the painting industry including:

- More stringent environmental regulations set for paint/ coatings products, such as VOCs ≤ 200 g/L and benzene $\leq 0.5\%$ ⁽¹³⁾
- Adoption of an indoor air quality limit for benzene of 0.11 mg/m³⁽¹⁴⁾
- Improvement of occupational health services after the passage of the Occupational Disease Prevention and Control Act in 2002 and the reduced occupational exposure limits for benzene (personal exposure ≤ 6 mg/m³ TWA and ≤ 10 mg/m³ STEL).⁽¹⁰⁾

Strengths and Limitations of This Review

Strengths of this review included:

- The computer and manual literature searches yielded 204 papers of benzene poisoning case reports, industrial hygiene surveys, and other reports (toxicological studies and article reviews) published in 51 Chinese medical journals or other sources from 1956 to 2005.
- The collected data covered 24 provinces, municipalities, and autonomous regions representing 77% of the 31 administrative regions in China.
- Available exposure data were translated from Chinese, tabulated, and summarized, and additional information on the paint/coatings industry in China (online Appendix Tables A-VII through A-IX) were identified to improve the understanding of historical exposures involving paint/coatings in China.

Some of the limitations associated with the published information and the analyses currently presented include:

- Consistent with industrial hygiene practice in China, most of the literature data represented short-term (1-min grab) personal breathing zone or area (often unspecified which) samples from the work environment (Table I). Construction of a task TWA to estimate full-shift exposure was not undertaken as part of this review, in part, because the literature reports generally did not provide task duration and task frequency information.

- The relative accuracy and precision of the sampling and analytical methods used over the years in China has not been established.
- The current analysis relied predominately on two types of data: industrial hygiene surveys, and case reports. Case reports had higher average concentrations than IH surveys (Table III). It was uncommon for the purpose of the industrial hygiene surveys to be reported—they were commissioned for a variety of reasons and were not necessarily targeted at the situations with benzene poisoning or high benzene exposures.

SUMMARY AND CONCLUSIONS

The objective of this review was to summarize the Chinese literature on benzene exposure in industries using or manufacturing paint/coatings in China for the period 1956–2005.

The literature survey included both online and manual searching and resulted in 204 papers of benzene poisoning case reports, industrial hygiene surveys, and other reports (toxicological studies and article reviews) published in 51 Chinese medical journals or other sources. The collected data covered 24 provinces, municipalities, and autonomous regions, representing 77% of the 31 administrative regions in China.

Most of the reports included air sampling approaches that represented relatively short-term samples, typically from workers' breathing zones, for comparison with the Chinese maximum allowable concentration standard. The accuracy and precision of the sampling and analytical methods were not reported. The final analysis was based on 407 sets of benzene concentration values representing more than 5500 reported air samples. These data showed a skewed distribution and was transformed for subsequent analysis. The published benzene exposure data ranged from undetectable to very high benzene concentrations (over 100 times the China occupational exposure limit for each of four historical periods). In general, the mean benzene concentration for each historical period followed a downward trend, though the last two periods had similar mean concentrations. Mean benzene exposure was significantly lower for paint manufacturing than paint spraying. No significant differences were found among paint types and mean benzene concentration for the paint-using groups. Benzene exposure was significantly higher in workplaces judged to have poor ventilation. No significant differences were found in benzene exposure as a function of industry type.

From 1956 to 2001, the China OEH for benzene was expressed as a maximum allowable concentration (without a specified averaging time) and compliance was assessed by short-term (1–10 min) samples. With the passage of the Occupational Disease Prevention and Control Act of 2002, the permissible concentration for benzene was reduced to 6 mg/m³ as an 8-hr TWA exposure; 10 mg/m³ as a 15-min STEL. Most of the recent data summarized here were short-term

measurements by charcoal tube against the STEL, rather than TWA measurements. Even though substantially lower when compared with levels in the past, recent benzene concentration measurements suggested that many facilities in the paint/coatings industries in China still have benzene task concentrations above the current China OEL for benzene (STEL or TWA).

The information presented here is not adequate by itself for quantitative estimation of long-term average benzene exposure because most of the data were short-term samples, and information on task duration and frequency was not provided by the authors of the source reports. Without information on the accuracy and precision of the Chinese sampling and analytical methods, comparison with Western data is problematic. With these limitations, the data do allow identification of primary correlates of exposure that can be potentially useful in relative ranking of exposure in this industry.

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