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Lead levels in new enamel household paints from Asia, Africa and South America ☆

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ABSTRACT

In 2006 a report on the analysis for lead in 80 new residential paints from four countries in Asia revealed high levels in three of the countries (China, India and Malaysia) and low levels in a fourth country (Singapore) where a lead in paint regulation was enforced. The authors warned of the possible export of lead-painted consumer products to the United States and other countries and the dangers the lead paint represented to children in the countries where it was available for purchase. The need for a worldwide ban on the use of lead in paints was emphasized to prevent an increase in exposure and disease from this very preventable environmental source. Since the earlier paper almost 300 additional new paint samples have been collected from the four initial countries plus 8 additional countries, three from Asia, three from Africa and two from South America. During the intervening time period two million toys and other items imported into the United States were recalled because the lead content exceeded the United States standard. High lead paints were detected in all 12 countries. The average lead concentration by country ranged from 6988 (Singapore) to 31,960 ppm (Ecuador). One multinational company sold high lead paint in one country through January 2007 but sold low lead paint later in 2007 indicating that a major change to cease adding lead to their paints had occurred. However, the finding that almost one-third of the samples would meet the new United States standard for new paint of 90 ppm, suggests that the technology is already available in at least 11 of the 12 countries to produce low lead enamel paints for domestic use. The need remains urgent to establish effective worldwide controls to prevent the needless poisoning of millions of children from this preventable exposure.

1. Introduction and background

Although lead poisoning of children is widely recognized as a major public health problem in many parts of the world, very little attention has been given in many countries to the role of leaded paints. There have been a number of studies on the impact of the former widespread use of lead additives in gasoline. It is recognized that improper battery recycling is a major health problem where it occurs. Many of these operations appear to have few if any environmental and occupational exposure controls in place. In 2008 there were reports of very high exposures to lead in children, with blood lead levels up to 345 μg/dL in the city of

Abbreviations: AA, atomic absorption; ln, natural logarithm; ppm, parts per million; ≥, greater than or equal to; <, less than; μg/dL, micrograms per deciliter of blood; #, number

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Thiaroye Sur Mer (WHO, 2008, 2009), Senegal from exposures at a site where lead had been recovered from batteries. Several hundred residents were poisoned and 17 fatalities were reported. Meyer et al. (2003) emphasize that global efforts to prevent childhood lead poisoning must involve identifying and reducing all possible sources of lead including paint. Fewtrell et al. (2004) have estimated that 20% of all children have blood lead levels above 10 μg/dL and that most of these children live in developing countries.

In the United States major national efforts have been underway since the early 1990s to reduce exposures from older houses that were painted with high lead paint prior to the ban on the use of lead in new paints in 1978 (Wilson et al., 2006). In the United States the percentages of housing containing lead-based paint increases with increasing age of the housing (Jacobs et al., 2002). Lead-based paint has been shown to be a major contributor to lead-contaminated dusts, which represent a major pathway of exposure to children (Lanphear et al., 1998).

In one of the few published reports of the lead level in existing housing in Africa, a study in Johannesburg, South Africa by Montgomery and Mathee (2005) found that 60% of the suburbs built in 1948–1978 and from 1979 to the present contained at least one home containing lead-based paint ($\geq$0.5% lead by weight (5000 ppm)) compared to 50% for the 1901–1947 suburbs. The mean paint lead concentration followed the same pattern: 0.305% (3050 ppm) in the 1901–1947 houses, 0.545% (5450 ppm) in the 1948–1978 suburbs and 0.594% (5940 ppm) in the newest suburbs. The highest concentration (29.00% (290,000 ppm)) was found in one of the newest suburbs. These findings suggest that lead-based paints continue to be used in housing in Johannesburg. The authors state that their preliminary studies indicate that some colors of new enamel paint contain lead levels in excess of 5000 μg/g (5000 ppm).

In India, lead-based paint was found in the homes of three of ten children with blood lead levels of at least 40 μg/dL (Kuruvilla et al., 2004). In a report on dust lead levels in Delhi, India, homes Kumar and Clark (in press) reported that 31% of the floor dust lead level exceeded the current US limit of 40 $\mu g/ft^2$ and 14% of the window sill sample exceeded the current US limit of 250 $\mu g/ft^2$. Over 60% of the housing occupied by a population in Venezuela with elevated blood lead was found to have lead paint levels above the regulatory limit (Rojas et al., 2003).

Lin et al. (2008) reported that even though there are regulatory limits on the levels of lead in new paints in China 29 of 58 (50%) of new enamel paints tested contained lead greater than or equal to 600 ppm, the current limit in China for total lead in new paint. The lead concentration of almost one-fourth (24%) of the samples was greater than or equal to 5000 ppm. Ninety percent of the samples that failed the total lead limit also failed the “soluble” lead limit and 79% that met the total lead limit of 600 ppm also met the “soluble” limit of 90 ppm. National paint companies tended to have higher exceedance rates for both limits than local paint companies. Lin et al. (2008) found a statistically significant difference in lead level by color with the highest levels found in yellow, green and red paints. Lin et al. (2008) also collected samples of existing paint from a stratified random sampling of 12 kindergartens and 12 primary schools. Of the total of 28 samples collected from walls, furniture and toys, 57% had lead levels greater than or equal to 600 ppm and 21% had levels greater than or equal to 5000 ppm; these percentages are about the same as for the new paints.

In the first report of the lead content of new paints in Africa, Adebamowo et al. (2007) determined the lead content of five samples of different colors (blue, green, red, white and yellow) from each of five different manufacturers in Nigeria. Ninety-six percent (24 of 25 samples) had lead concentrations exceeding 600 ppm. The mean lead level was 14,500 ppm and the median was 15,800 ppm. Lead levels were found to vary by color ($p = 0.003$) with yellow paint concentrations the highest.

Table 1
Examples of limits on the concentration of lead (ppm) in new paints for household use.

Country/ region	Limit
China	600 ppm (total) and 90 ppm (leachable) (GAQSC, 2001, 2003)
India	1000 ppm (total)—voluntary (BIS, 2004)
Singapore	600 ppm (total) (NEA, 2004)
South Africa	600 ppm (total) (DOH, 2008)
United States	90 ppm (total)—effective August 14, 2009 (prior limit 600 ppm (total)) (CPSIA, 2008)

In what may be the first report of lead in new enamel paint in India, Van Alphen (1999) found that 4 of 24 paints produced contained in excess of 0.5% lead (5000 ppm), 3 exceeded 1% lead (10,000 ppm) with the highest containing 20.19% lead (201,900 ppm).

Sixty-six percent of new enamel paints from China, India and Malaysia were reported to contain 5000 ppm or higher concentrations of lead and 78% contained 600 ppm or more (Clark et al., 2006). In contrast, the comparable percentages in paints from Singapore were 0% and 9%. Paints from some brands had high concentrations in some countries and low in another. One company had low levels in all countries where it was obtained.

Kumar and Gottesfeld (2008) analyzed 38 new latex and 31 new enamel paint samples from India for lead content and found low levels in the latex paints, well below 600 ppm and high levels in five of the six brands of enamel paints. The arithmetic average level in the enamel paints was 26,100 ppm and the maximum was 40,000 ppm. The range of concentrations was said to be consistent with those in Clark et al. (2006).

Where limits on the lead content of new household paints exist, they vary from 90 to 1000 ppm total lead (Table 1). The new limits in the United States were enacted in 2008 in the Consumer Product Safety Commission Reform Act, in part as a response to concerns raised over the import and subsequent recall of millions of toys contaminated with lead-based paint.

This report will include the findings of our analysis of new enamel paints, which include almost 300 additional new paint samples collected since our 2006 study (Clark et al., 2006). The expanded database includes samples from the four initial countries plus 8 additional countries, three from Asia, three from Africa and two from South America. These results will be compared with those from studies in India and China, which have been published since our earlier paper.

2. Methods

New enamel household paints were collected from a total of 12 countries in Africa, Asia and South America and analyzed for lead in the Hematology and Environmental Laboratory (H & E) at the University of Cincinnati. The samples were collected from retail shops accessible to the public. Each paint sample was stirred and applied by brush to individual unused wood blocks. Each stirring utensil and paint brush was used only once. In the H & E Laboratory the paint was carefully removed from a measured area of the wood surface using a clean sharp paint scraper, using care not to remove portions of the wood. The paint scrapings were extracted using nitric acid and hydrogen peroxide according to the method: Standard Operating Procedures for Lead in Paint by Hotplate or Microwave-based Acid Digestions and Atomic Absorption of Inductively Coupled Plasma Emission Spectroscopy, EPA, PB92-114172, September 1991 (US EPA, 2001). Extracts were analyzed by flame atomic absorption spectroscopy using a Perkin-Elmer 5100 spectrometer. The H & E Laboratory is accredited by the American Industrial Hygiene Association as an industrial hygiene laboratory and an environmental lead laboratory under the National Lead Laboratory Accreditation Program. The laboratory participates in the Proficiency Analytical Testing (PAT) and Environmental Lead Proficiency Analytical Testing (ELPAT) proficiency programs. Strict quality control procedures are maintained according to the accreditation guidelines. The laboratory is also a recognized facility through the National Environmental Laboratory Accreditation Conference and participates in the New York proficiency program for environmental sample analytes including lead.

Lead concentration data were analyzed by country where collected, color, paint company and purchase price. Data from one country, from which only three samples were collected from three different paint companies, are not used in the analyses by country but are used in other analyses. Where available, data from paint brands that were sampled in multiple countries were compared as well as data from the same brand over time in a particular country. Statistical methods of analysis used are analysis of variance, and Scheffe's test for comparison of data pairs. Lead paint concentration data from our study in Nigeria (Adebamowo et al., 2007) were included in the multi-country analysis reported in this study.

3. Results

3.1. New paint lead concentration by country

Results of the lead determination from 337 new household enamel paint samples from eleven countries, with at least ten results from each, were available for analyses. Data presented in Table 2 are the number of samples analyzed in each country, the average, geometric mean, median and percentage of samples equal to or greater than 90 ppm and equal to or greater than 600 ppm. Lead concentrations varied widely among the countries. The lowest average concentrations were for the paints from Singapore (6988 ppm) and the highest from Ecuador, 31,960 ppm. New paints from Singapore and China had the lowest percentage of samples equal to or greater than 90 ppm (43.8% and 43.9%, respectively, and the lowest percentage of samples equal to or exceeding 600 ppm, 36.6% and 32.8%, respectively. There is a significant difference in lead paint levels by country (analysis of variance, $p<0.0001$). Four pairs of countries which have significantly different levels are indicated by superscripts in the table. Samples were also collected from two other countries but were not included in these analyses because of the very small number of samples available.

3.2. Lead concentration by color

A summary of the lead concentration data by color is presented in Table 3. The color found to have the lowest lead concentrations (ppm) was white and the colors found to have the highest concentrations are yellow and orange, followed closely by green and red. The concentration of most of the samples was greater than or equal to the level of 600 ppm, the current limit for new paint in a number of countries. There is a significant difference in lead concentration by color (analysis of variance, $p<0.0001$). Seven pairs of colors that have significant differences (Scheffe's Test, alpha = 0.05) are indicated by superscripts in Table 3. Data from twelve countries are included in this analysis, including one that was not included in the analysis by country because of small sample size.

Table 2
Lead concentrations of new enamel household paints by country and percentages equal to or exceeding 90 and 600 ppm, dry weight ($n = 371$).

Country	# of samples	Average	Geometric mean	Median	%≥90	%≥600
Singapore[a,b]	41	6988	163	55	43.9	36.6
Peru	10	11,550	3259	5711	90.0	80.0
Indonesia	11	14,770	2642	3474	81.8	72.7
China[c,d]	64	15,070	169	34	43.8	32.8
Nigeria[a,c]	25	15,750	7341	5760	96.0	96.0
Thailand	18	19,410	7281	15,170	100.0	88.9
Malaysia	72	24,510	769	614	59.7	50.0
Seychelles	28	24,880	1167	2527	67.9	60.7
Egypt	20	26,200	1338	4717	65.0	65.0
India[b,d]	72	29,660	4801	9630	87.5	81.9
Ecuador	10	31,960	2178	13,460	70.0	60.0

[a,b,c,d] Countries with the same letter superscript have significantly different concentrations (Scheffe's test, alpha=0.05).

Table 3
Lead concentrations (ppm dry weight) of new enamel household paints by color and percentages equal to or exceeding 90 and 600 ppm ($n = 372$).

Color	# of samples	Average	Geometric mean	Median	%≥90	%≥600
White[a,b,c,d]	57	1547	101	53	45.6	33.3
Blue[e,f]	50	2650	338	825	64.0	52.0
Black	19	4059	503	428	68.4	47.4
Brown	16	9228	208	67	43.8	37.5
Red[d]	66	17,540	2089	4765	78.8	74.2
Green[b,c]	50	21,660	4195	19,180	78.0	78.0
Orange[a]	9	42,840	17,520	35,280	88.9	88.9
Yellow[c,f]	100	47,250	3633	38,960	73.0	66.0

[a,b,c,d,e,f] Colors with the same letter superscript have significantly different concentrations (Scheffe's test, alpha = 0.05).

Table 4
Comparison of price of 1 L cans of paint and lead concentration (ppm dry weight) of major paint companies in India.

Company ID[a]	Average lead level ppm[b]	Average price of 1 L (rupees)[c]
1	31,500	167
2	48,400	152
3[a]	7	155
4	28,700	159

[a] Paint from Company #3 had significantly lower lead concentration than each of the other three companies (analysis of covariance $p<0.001$).
[b] There was a significant difference in lead concentration by color of paint ($p<0.0074$) with white paint having significantly lower concentrations than green and yellow.
[c] Price and ln (paint lead concentration) were moderately correlated (Pearson correlation coefficient $r = 0.34$, $p = 0.14$) but were not related after controlling for company and color ($p = 0.69$).

3.3. Concentration of lead and cost

Two approaches were used to examine the possible relationship between the lead concentration of new paint and the retail cost of purchase: (1) analyze cost of 1 L of paint of various colors from several large paint companies in India and (2) analyze the cost of various sized paint cans collected from multiple countries and its relationship to lead concentration.

The retail price of 1 L cans of paint was compared for five colors from each of four of the top five paint companies in India. The average lead concentration and price per liter for each of these brands (Table 4) shows a 7000-fold range in lead concentration while the highest average price per liter is only about 10% higher than the lowest price. Each of these paints was produced by companies that also marketed paint in other countries. One of the paint brands (#3) was found by analysis of covariance to have significantly lower lead concentration than each of the other three companies ($p<0.001$). There was a significant difference in lead concentration by color of paint ($p<0.0074$) with white paint having significantly lower concentrations than green and yellow. Price and ln (paint lead concentration) are moderately correlated (Pearson correlation coefficient $r = 0.34$, $p = 0.14$) but were not related after controlling for company and color ($p = 0.69$).

For 265 of the new enamel paint samples from the eleven countries, price per container of paint purchased was available.

However, since the paint containers varied from 50 mL to 4 L, it was necessary to calculate a per liter price. Since the price per liter of a small-sized can of paint is generally much higher than that of a 1 L can, this calculation introduced an uncertainty in the accuracy of the data. In order to have a common scale for the cost of the paint cans purchased in different currencies, the paint cost data were standardized according to the observed mean and standard deviation calculated for each country. A z-score was created for each can of paint by deviating the cost per liter of each can of paint purchased in a country from the mean cost of a liter of paint in that country and this result divided by the standard deviation in this country's cost of a liter of paint. Regression analysis of the relationship between the ln of the lead concentration in ppm and the standardized price for each paint sample did not reveal a significant relationship ($p = 0.1788$). If country and color were used along with z-price in an analysis of covariance, there was a significant relationship with price ($p<0.02$). A 10% increase in price would result in a reduction in lead concentration that varies between 5 and 1972 ppm, depending on the country where the paint was purchased.

3.4. Lead levels by paint companies and country

The number of paint companies whose paint samples have been collected is shown by country in Table 5 and by the number of companies with at least one sample with very high lead and the number with at least one sample greater than or equal to 600 ppm. Sixty-nine percent of the companies had at least one sample exceeding 10,000 ppm and 73% had at least one sample exceeding 600 ppm.

Table 5
Number of companies with enamel paint sampled, by country, with one or more samples with lead content greater than or equal to 10,000 and 600 ppm lead (dry weight).

Country	Number of paint companies sampled	Number with at least one sample with lead ≥10,000 ppm	Number with at least one sample with lead greater than or equal to 600 ppm
China	19	10	10
Ecuador	2	2	2
Egypt	4	4	4
India	9	6	7
Indonesia	4	2	2
Malaysia	14	11	11
Nigeria	5	5	5
Peru	2	2	2
Seychelles	2	2	2
Singapore	7	2	4
Taiwan	3	3	3
Thailand	7	5	5
Total	78	54 (69%)	57 (73%)

3.5. Lead levels for paints from companies available in multiple countries

A total of 28 samples from multinational Company A were analyzed from three countries—India, Nigeria and Singapore (Table 6). Results are much lower in samples collected in Singapore than in those from India and Nigeria. Thirteen of the 23 samples from India and Nigeria had lead concentrations exceeding 10,000 ppm with the highest level in India of 187,200 and the highest in Nigeria of 38,018 while in Singapore the highest concentration was 1328 ppm.

None of the 13 samples from Company B exceeded 10,000 ppm and only 2 of the 13 reached 90 and 600 ppm (Table 7). Two samples from Singapore exceeded the 600 ppm; the highest concentration was 3505 ppm.

A total of 27 samples from Company C were obtained from four Asian countries. The lead concentration by color and country (Table 8) were all consistently low with the highest concentrations found in yellow samples from Malaysia and Singapore, 134 and 151 ppm, respectively.

Paint levels in samples from Company D collected during the period 2003–2006 were low in China (highest concentration 18 ppm) and in Singapore where 6 of 7 samples contained less than 90 ppm lead and the highest contained 3245 ppm. A major difference in concentration in samples from this company was detected between samples from Malaysia collected up through January 2007 compared with those collected in October 2007. During the former period 5 of the 9 samples contained in excess of 10,000 ppm lead with the highest level of 113,300 ppm. All 5 samples collected in October 2007 contained less than detectible levels of lead (Table 9).

3.6. Comparison of results with other studies

Results from the current study for new enamel paints from China, compared with those in the study by Lin et al. (2008), are presented in Table 10. For the paints of colors collected in both studies the percent of the samples greater than or equal to 600 ppm was 54% in the Lin et al. (2008) study compared to 29% in the current study. For these same colors the percent of samples with lead concentrations greater than or equal to 5000 ppm was similar in each study, 27% in Lin et al (2008) and 25% in the

Table 6
Lead concentrations (ppm dry weight) in new enamel paints from Company A in three countries.

Country	# Samples	% (#) ≥90 ppm	% (#) ≥600 ppm	% (#) ≥10,000 ppm	Maximum
India	18	100 (18)	94 (17)	61 (11)	187,200
Nigeria	5	80 (4)	80 (4)	40 (2)	38,018
Singapore	4	50 (2)	25 (1)	0	1328

Table 7
Lead concentration (ppm dry weight) in new enamel paints from Company B in four countries.

Country	# Samples	% (#) ≥90 ppm	% (#) ≥600 ppm	% (#) ≥10,000 ppm	Maximum
Indonesia	1	0 (0)	0 (0)	0 (0)	Below detection
Malaysia	7	0 (0)	0 (0)	0 (0)	40
Singapore	4	50 (2)	50 (2)	0 (0)	3505
Thailand	1	100 (1)	0 (0)	0 (0)	103

Table 8
Lead levels (ppm dry weight) in new enamel paints from Company C collected in four countries.

Color (# samples)	China	India	Malaysia	Singapore	Range by color (#)
Black (2)	No sample	Below detection	Below detection	No sample	Below detection (2)
Blue (3)	33	Below detection	Below detection	No sample	Below detection to 33 (3)
Brown (3)	No sample	Below detection	Below detection	Below detection	Below detection (3)
Green (4)	Below detection	Below detection	No sample	Below detection (2 samples)	Below detection (4)
Red (2)	Below detection	No sample	Below detection	Below detection	Below detection (3)
White (4)	Below detection	Below detection	Below detection	Below detection	Below detection to 6 (4)
Yellow (9)	Below detection	No sample	Below detection (2), 6 and 134	Below detection (2), 9 and 151	Below detection to 151 (9)
Range by country (#)	Below detection to 33 (5)	Below detection (5)	Below detection to 134 (9)	Below detection to 151 (9)	Below detection to 151 (27)

Table 10
Comparison of lead concentration (ppm) in new Chinese enamel paints study of Lin et al. (2008) with current study.

Color	N	Max	Min	Median	% (#)≥600 ppm	% (#)≥5000 ppm	No.	Max	Min	Median	% (#) ≥600 ppm	% (no) ≥5000 ppm
Black	7	2640	4.0	218	43 (3)	0	4	402	4.5	126	0	0
Blue	5	2980	0.8	139	20 (1)	0	6	529	4.5	16	0	0
Gray	2	178	23	100	0	0	1	0	4.5	4.5	0	0
Green	5	27,600	5.220	8950	100 (5)	100 (5)	8	52,500	4.5	27,900	62 (5)	62 (5)
Red	16	153,000	0.8	752	56 (9)	13 (2)	11	31,300	4.5	145	36 (4)	18 (2)
White	8	1020	1.0	21	13 (1)	0	12	185	4.5	8	0	0
Yellow	9	58,000	795	17,600	100 (9)	78 (7)	17	207,000	4.5	30	47 (8)	47 (8)
All of above samples	52	153,000	0.8	776	54 (28)	27 (14)	59	207,000	4.5	36	29 (17)	25 (15)
Additional color(s)	6*	2350	1.0	3.0	17 (1)	0	5**	50,300	4.5	6040	80 (4)	60 (3)
Overall	58	153,000	0.8	552	50 (29)	24 (14)	64	207,000	4.5	164	33 (21)	28 (18)

* Silver ** blue-green, brown, orange-red, and orange.

Table 9
Lead levels (ppm dry weight) in new enamel paints from Company D collected in three countries.

Color	Singapore 2003	China Aug/ Sept 06	Malaysia May 04 to Jan 07	Malaysia Oct 07
Blue	48	<10	31	<10
Green	35	<10	8526; 4039; 24,166	<10
Red	<10	18	48,520; 102,560	<10
White	No samples	<10	109	<10
Yellow	87: <10; 32 (2006); 3245 (2006)	<10	113,300; 90,240	<10

Table 11
Comparison of average lead concentrations (ppm dry weight) of new enamel paints in India from study by Kumar and Gottesfeld (2008) with current study.

Color	Kumar and Gottesfeld (2008) ($n=31$)	Current study ($n=66$)[a]
Black	3619	8050
Blue	5600	4610
Green	21,250	28,200
Orange	4000	79,700
Red	6538	30,600
White	992	1330
Yellow	90,000	85,000
Average	26,130	33,000

[a] Six additional samples of other colors, average 10,800 ppm, are not included in this table.

current study. The maximum levels were 153,000 for a red paint in the Lin et al. (2008) study and 207,000 for a yellow paint in the current study.

The results for new enamel paints from India that were analyzed in the current study, when compared with those from Kumar and Gottesfeld (2008) (Table 11), reveal similar levels with the average concentration highest for the yellow paints 85,000 and 80,000 ppm, respectively; and lowest for white paints, 1330 and 992 ppm, respectively. Lead concentrations in the orange and red paints were much higher in the current study than in Kumar and Gottesfeld (2008).

4. Discussion

The findings of Montgomery and Mathee (2005) that older housing in Johannesburg, South Africa did not have higher lead paint levels than the newest housing, is opposite to the findings in the United States where the percent of housing units with lead-based paint hazards was 3% for units built in the period 1978–1988, 8% for 1960–1977, 43% for 1940–1959 and 68% for units built before 1949. Their finding suggests that lead-based paint is still being used in the Johannesburg housing in contrast to the United States where the lead paint ban in 1978 effectively stopped the practice of lead paint use in housing.

Lead levels in new enamel paints in India and China reported in the current study, and in the 2006 report, have been generally corroborated by findings reported by Kumar and Gottesfeld (2008) and Lin et al. (2008).

Similar lead concentrations in paints from Singapore and China reported in the current study are in contrast to the earlier paper (Clark et al., 2006) where lead concentrations in the 22 paints from Singapore were generally very low (median 9 ppm and maximum 3500 ppm) and concentrations were much higher in the 9 samples from China (median 3280 ppm and maximum 73,400 ppm). The primary reason for this difference is that additional paint companies were included in the current analyses. The new paint companies sampled in Singapore tended to have high lead concentrations (median concentration of 5330 ppm, maximum of 75,600 ppm) while 33 of the 46 additional samples from China were from companies with paint containing below detection levels of lead.

Two of the five paint samples purchased at a large US-owned retail store in China contained very high levels of lead, 28,800 and 57,900 ppm.

A comparison of the results of the determination of total lead and "soluble" lead in the paper by Lin et al (2008) revealed rates of exceeding of the standards of 600 and 90 ppm, respectively, that are essentially equivalent. It would be of interest to compare results side-by-side for individual paint colors.

Over 50 years ago the lead content of painted toys purchased in an Ohio city and manufactured in the United States and Europe was determined and although the average contents were, for example an average 107,400 pm for orange, 34,900 for red and 400 ppm for white, many of the toys painted with colored paints had lead content of 100 ppm (Kehoe, 1957). The author stated that the findings "removes the last remnant of support for any claim which might be made by a manufacturer of paint that he cannot provide satisfactory colors for children's toys without using lead compounds". It is ironic that more than 50 years later a similar situation prevailed in the United States but with the source of the toys being primarily from China rather than the US and Europe.

The paints from one of the large multinational companies from which samples were collected in multiple countries had generally low levels of lead in China and Singapore and high levels in Malaysia in samples collected through January 2007; the highest level in Malaysia was 113,300 ppm. However, the five samples collected in October 2007 in Malaysia each had below detection levels of lead. The paints purchased in October were mixed at the time of the sale to obtain the desired color while those obtained earlier were pre-mixed, indicating a major technology change that resulted in eliminating the addition of lead to their paints.

In China Lin et al. (2008) reported that there was no significant correlation between lead concentration and price for the 58 samples in their study. In the current study there was a similar finding for paints from India for 1 L containers of paint. In an analysis using the prices derived from different sized cans, there was a significant relationship between concentration and price.

Since the publication of the 2006 paper, there have been important developments in efforts to achieve a worldwide ban on the use of lead in paints. At its November 2007 annual meeting, the American Public Health Association adopted a resolution that "…urges a worldwide ban on the continued use of lead in residential and outdoor paints, children's products and all non-essential uses in consumer products to avoid future public health problems". The Association also recommended that "this ban be carried out through all trade agreements between US and overseas corporations and all trade agreements completed by the World Trade Organization" (APHA, 2007).

At its meeting in Dakar, Senegal in 2008, the International Forum on Chemical Safety (IFCS) proposed consideration by the Strategic Approach to International Chemicals Management (SAICM) of a global partnership addressing lead in paint. This partnership would help to implement one of the goals of the Johannesburg Plan of Implementation of the 2002 World Summit on Sustainable Development (WSSD): the phasing out of lead in lead-based paints. The IFCS has developed terms of reference for such a global partnership for consideration at the second meeting of the International Conference on Chemical Management (ICCM-2) in Geneva Switzerland in May 2009. A resolution calling for the establishment of a global partnership to promote the phase out of the use of lead in paints was adopted at the Geneva meeting of SAICM and ICCM-2.

5. Conclusions

The average concentration of lead in new enamel household paints in the countries in this study ranged from 6988 to 31,960 ppm. The percentage of samples that were equal to or exceeded the limit of 600 ppm ranged from 33% (China) to 96% (Nigeria). The finding of high lead in new enamel paints for domestic use in India and China were generally corroborated by the recent studies of Kumar and Gottesfeld (2008) and Lin et al. (2008)

The average lead concentration by color ranged from 1547 (white) to 47,250 ppm (yellow). White, blue, black and brown paints had the lower concentrations and the bright colors red, green, orange and yellow had the higher. The percent of paints with lead concentration equal to or exceeding the limit of 600 ppm ranged from 33% (white) to 89% (orange).

The examination of whether there was a relationship between lead concentration and cost is complicated by the fact that a wide range of paint can sizes were purchased for this study and the price per liter generally is higher when the paint is sold in smaller cans. Regression analysis of price and concentration alone did not reveal a significant relationship but when country and color were used in analysis of covariance a significant relationship resulted ($p<0.02$). A 10% increase in price would result in a lead concentration increase ranging from 5 to 1972 ppm depending on the country where the paint was purchased. An analysis of the price of 1 L cans of various color paints from four major brands in India did not reveal a significant relationship of concentration and price.

An average of 73% of the paint brands tested in the various countries had at least one sample with a lead concentration that was at least 600 ppm. Only a slightly smaller percentage had at least one sample with a much higher concentration, 10,000 ppm. Fifty-four percent of the paints tested in Singapore and China had concentrations less than 90 ppm indicating that the technology is available in these countries to produce low lead paints that would meet the new limit for new paints in the United States. Three multinational companies whose samples were analyzed were found to produce paint with lead levels at or below the detection limit. The observation that one of these companies changed from a high paint lead producing company to one producing very low lead paint during the course of this study is documentation that technologies can be changed to attain such a goal. Results from this study suggest that the achievement of a worldwide ban on the use of lead in paints has been shown to be technically achievable.

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