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Volatile Organic Compound Emissions from Surface Coating Facilities: Characterization of Facilities, Estimation of Emission Rates, and Dispersion Modeling of Off-Site Impacts

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ABSTRACT

Surface coating facilities are major sources of volatile organic compounds (VOCs) in urban areas. These VOCs can contribute to ground-level ozone formation, and many are hazardous air pollutants (HAPs), including xylene, ethylbenzene, and toluene. This project was conducted in order to provide information for updating the Texas Commission on Environmental Quality (TCEQ), USA, permit by rule for Surface Coating Facilities. Project objectives were: 1) To develop a database of information regarding surface coating facilities in Texas; 2) To estimate maximum emission rates for various VOC species from surface coating facilities in Texas; 3) To conduct dispersion modeling to estimate off-site impacts from surface coating facilities. The database was developed using 286 TCEQ permit files authorizing surface coating facilities in Texas during 2006 and 2007. The database was designed to include information important for estimating emission rates, and for using as inputs to the dispersion model. Hourly and annual emissions of volatile organic compounds (VOCs), particulate matter (PM), and exempt solvents (ES) were calculated for each permitted entity/company in the database, according to equations given by TCEQ. Dispersion modeling was then conducted for 3 facility configurations (worst-case stack height, good practice stack height, and fugitive emissions), for urban and rural dispersion parameters, for 8-hour and 24-hour operating scenarios, and for 1-hour, 24-hour, and annual averaging times, for a total of 36 scenarios. The highest modeled concentrations were for the worst-case stack height, rural dispersion parameters, 24-hour operation scenario, and 1-hour averaging time. 108 specific chemical species, which are components of surface coatings, were identified as candidates for further health impacts review.

Keywords: Volatile Organic Compounds; Hazardous Air Pollutants; Surface Coating Facilities; Emissions; Dispersion Modeling

1. Introduction

Surface coating facilities apply decorative or protective coatings (paints, varnishes, lacquers) to substrates, which can include metals, wood, paper, plastic, and others. The coatings, in liquid or powder form, can be applied by a variety of methods, such as brushing, rolling, spraying, dipping and flow coating. After the coating is applied, the surface is air and/or heat dried to remove the volatile solvents from the coated surface [1]. Types of surface coating facilities include automobile refinishing shops and industrial facilities that apply coatings to products such as appliances, furniture, boilers, furnaces, pipes, cans, computers, and aircraft [2].

Surface coating facilities are major sources of volatile organic compounds (VOCs) in urban areas [3-5]. Surface coating facilities release VOCs when organic solvents in the coatings evaporate [6,7]. These VOCs can contribute to ground-level ozone formation, and many are hazardous air pollutants (HAPs) according to the US Clean Air Act, including xylene, ethylbenzene, and toluene.

Several studies have evaluated the contribution of surface coating facilities to regional emission inventories [8-11]. In addition, a number of studies have examined methods of reducing emissions from surface coating facilities [6,12-17]. Wadden *et al.* (1995) estimated VOC emissions for a sheetfed offset printing facility [18]. McCarthy and Senser (2006) developed a numerical model for paint transfer and deposition in electrostatic air sprays [19]. No previous work, to our knowledge, has developed a comprehensive database to characterize surface coating facilities or conducted dispersion modeling to systematically characterize off-site impacts.

The work was performed for the Texas Commission on Environmental Quality (TCEQ), in order to provide information for updating the TCEQ permit by rule for Surface Coating Facilities. Project objectives were:

1) To develop a database of information regarding surface coating facilities in Texas;

2) To estimate maximum emission rates for various VOC species from surface coating facilities in Texas;

3) To conduct dispersion modeling to estimate off-site impacts from surface coating facilities.

2. Methodology

2.1. Development of Surface Coating Facilities Database

Data was collected from almost 300 TCEQ permit files authorizing surface coating facilities in Texas during 2006 and 2007. Surface coating permits by rule (PBRs) and new source review permits (NSRs) were reviewed for projects that were completed between 9/1/06 and 8/31/07. This period was chosen as a fairly recent time, but one which would allow permit files to be complete/closed. Projects were retained in the database that involved actual surface coating of items; projects involving abrasive blast alone, manufacture of coatings, making objects from a mold but not surface coating them, and printing alone were not included. The final databases thus contained 190 PBRs and 96 NSRs, for a total of 286 permits. The database included physical specifications of the surface coating facilities (stack parameters and building dimensions); facility location information; hours of operation; spray, drying, and air pollution control technology information; and coatings information (amount and type of coatings used, coating composition). The database was designed to include information important for estimating emission rates, and for using as inputs to the dispersion model.

2.2. Estimation of Maximum VOC Emission Rates

Emissions were calculated for each permitted entity/company in the database. Hourly and annual emissions were calculated for volatile organic compounds (VOCs), particulate matter (PM), and exempt solvents (ES), according to equations given by TCEQ in "Painting Basics and Emission Calculations for TCEQ Air Quality Permit Applications" [20]. PM and ES were included, since some emissions from surface coating facilities occur in the form of particulates or solvent which are organics but have been excluded from the regulatory definition of VOCs. Emissions calculations accounted for transfer efficiency, overspray filter efficiency, PM fallout, and solvent flash off, as appropriate.

2.3. Dispersion Modeling

To estimate surface coating facility off-site impacts, dispersion modeling was conducted using the Gaussian dispersion model ISCST3 (ISC-AERMOD View, Lakes Environmental Version 5.1). Inputs to ISCST3 are discussed below.

2.3.1. Source Information

Three emission configurations were modeled, as listed in **Table 1**. These configurations were based on an evaluation of information contained in the database, as will be discussed later.

All sources were co-located at the origin of radial receptor grid (0, 0), to provide a worst-case scenario. The stacks were modeled as point sources exiting vertically, with velocity 53 ft/sec and ambient temperature, based on information from the database. BPIP (Building Profile Input Program) was run to account for building downwash for the worst-case stack.

Fugitive emissions were modeled as 5 circular area sources, 25' in diameter at heights of 5', 10', 15', 20', and 25'. All 5 circular area sources were modeled simultaneously, to represent emissions emanating from building doors, windows, and other openings of various heights. Information about specific locations and dimensions of building doors, windows, and other openings was not available in the permit files. The fugitive scenario was also used to represent outdoor facilities.

An emission rate of 1 lb/hr was used for each source.

Table 1. Emission configurations modeled.

Building Configuration	Building Dimensions	Paint Booth Stack	Fugitives
1	Circular building, 25' dia × 25' height	Worst-case stack, 30' high, 1' diameter	None
2	Circular building, 25' dia × 25' height	Good practice stack, 40' high, 1' diameter	None
3	Circular building, 25' dia × 25' height	None	X

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Model output values were later multiplied by factors to account for actual emission rates of specific chemical compounds. Both 8-hour (8 a.m. to 4 p.m.) and 24-hour operating scenarios were modeled.

2.3.2. Meteorological Data

- The meteorological data had wind direction aligned with the receptor radials. Directions ranged from 0˚ to 350˚ at 10˚ increments.
- Five years of hourly meteorological data was provided by TCEQ staff.

2.3.3. Receptor Grid/Terrain Elevations

- Receptor locations were based on an origin of (0, 0).
- Receptors were located in radials from 0˚ to 350˚ at 10˚ increments.
- The spacing of receptors in the radial direction was 100 feet (30.5 m).
- The extent of the receptors was from 100 - 1000 feet (30.5 m to 304.8 m).
- The elevation of the receptors was set to 0 meters.

2.3.4. Other Model Options

- 1-hour and annual averaging times were used to facilitate comparison with TCEQ short-term and long-term Effects Screening Levels (ESLs), respectively. A 24-hour averaging time was also modeled.
- Regulatory default mode was used.
- Runs were conducted using rural and urban dispersion parameters.
- It was assumed that no significant removal occurs due to wet deposition, dry deposition, chemical reaction (exponential decay), or gravitational setting.
- The PLOTFILE option was selected for each source group and averaging times.

3. Results and Discussion

3.1. Summary of Surface Coating Facility Characterization Data

As mentioned above, the database included 286 surface coating facility permits. The number of values for various parameters varied, since some permits contained incomplete data. This section summarizes surface coating facility information collected from the database.

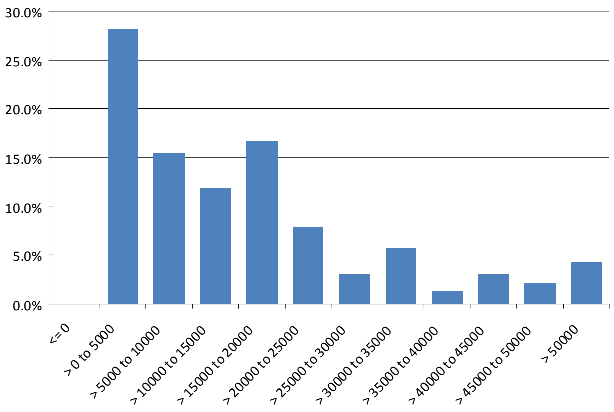

Figure 1. Summary of stack flow rates (ft^3/min) (n = 227).

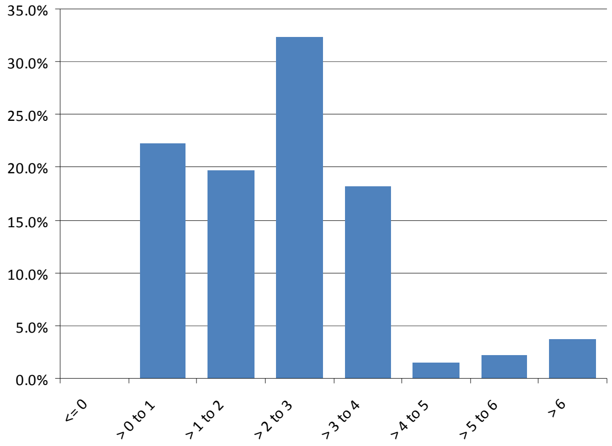

Figure 2. Summary of stack diameters (ft) (n = 269).

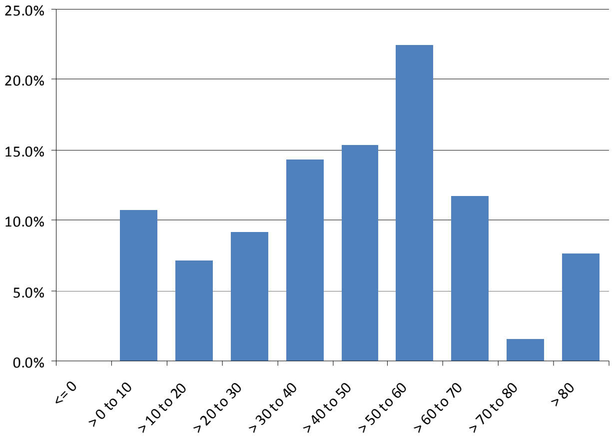

Figure 3. Summary of stack velocities (ft/sec) (n = 196).

3.1.1. Stack Parameters

Figures 1-6 summarize stack flow rate, diameter, velocity, height, temperature, and stack height-to-building height ratio values. The n value in parentheses after each figure caption indicates the number of values of that parameter that were found in the database, and used to create the histogram. Verbal summaries of the stack parameter data are provided below:

- *Stack flow rate*: The histogram peak for stack flow rate occurs in the 0 - 5000 ft^3/min category, representing 28% of facilities. Over 70% of facilities have a stack flow rate of 20,000 ft^3/min or less.
- *Stack diameter*: The largest number of facilities (32%)

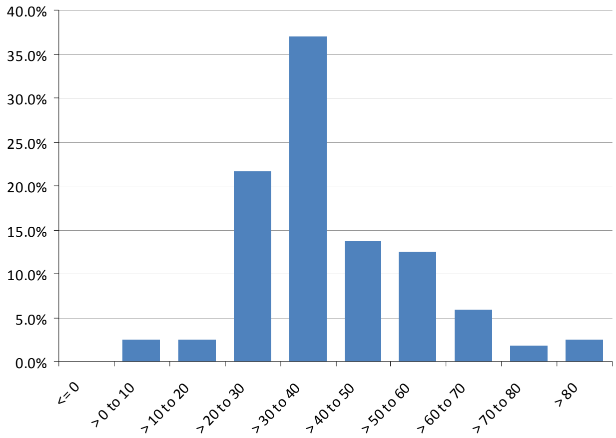

Figure 4. Summary of stack heights (ft) (n = 440).

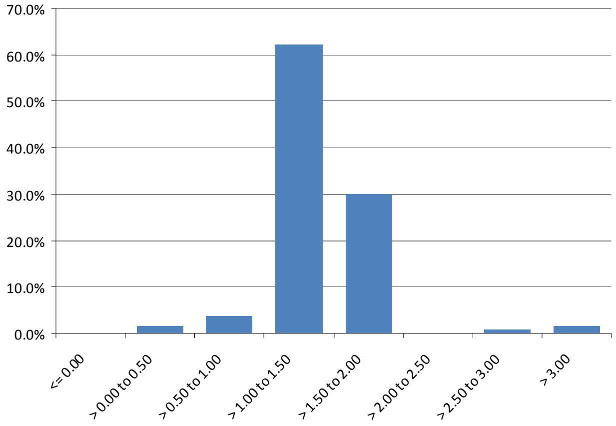

Figure 5. Summary of stack height to building height ratios (n = 130).

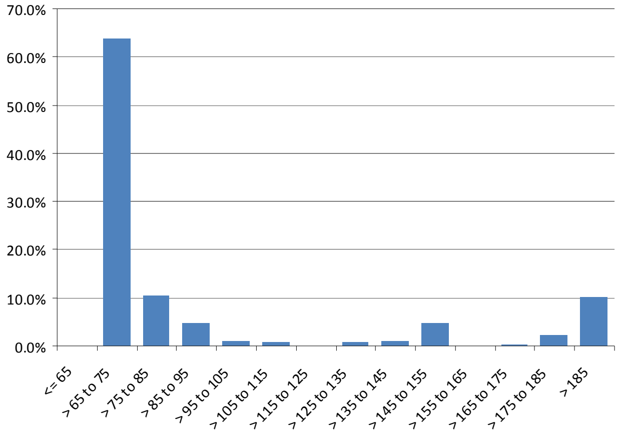

Figure 6. Summary of stack exit temperatures (˚F) (n = 276).

have stacks in the >2 - 3 foot range, with around 20% of stacks falling in each of the 0 - 1, >1 - 2, and >3 - 4 foot categories. 83% of the stacks have diameters 1 foot or greater.

- *Stack velocity*: The peak of the velocity histogram occurs at 50 - 60 ft/sec (22% of facilities).
- *Stack height*: The peak of the stack height histogram occurs in the >30 - 40 ft range, representing 37% of facilities. The average stack height is 41 ft.
- *Stack height to building height ratio*: 92% of the facilities have a stack height/building height ratio of 1.2 or greater. Good practice stack height is at least 1.5 times the building height to prevent building downwash. The average stack height to building height ratio was 1.51.
- *Stack temperature*: 70% of facilities operate approximately at ambient temperatures of 68˚F - 80˚F. All other facilities operate at higher temperatures, likely representing use of a drying oven.
- *Number of stacks*: Of the facilities for which stack information was available, 78 (52%) had one stack, 32 (21%) had 2 stacks, and 41 (27%) had 3 or more stacks.

Ground-level concentrations tend to increase as plume rise decreases. Since most surface coating facilities release emissions at ambient temperatures, their plume rise is dominated by momentum, not buoyancy. Momentum plume rise decreases when stack diameter and velocity decrease, since it is proportional to $(V_sD_s)^{2/3}$ for stable meteorological conditions, and V_sD_s for unstable/neutral meteorological conditions. Thus, a worst-case stack would have a small diameter and velocity.

83% of the stacks had diameters 1 foot or greater. A 1-ft diameter thus represents a conservative worst-case likely to occur. The histogram peak for stack flow rate occurs in the 0 - 5000 ft^3/min category, representing 28% of facilities. Choosing a flow rate value of 2500 ft^3/min in the middle of the category, along with a 1 foot diameter stack, gives a calculated velocity of 53 ft/sec, which is within the histogram peak for stack velocity.

92% of the facilities had a stack height/building height ratio of ≥1.2. Thus, a stack height/building height ratio of 1.2 seems to be a worst case that is reasonably likely to occur. Since the building height was chosen to be 25’, a 30’ stack was chosen as a worst-case stack height.

Good practice stack height is ≥1.5 times the building height to prevent building downwash. The average stack height to building height ratio was 1.51. Since the building height was chosen to be 25’, a stack height of 1.5 × 25’ = 40’ (rounded up to the nearest tens of feet) was chosen for good practice/typical stack height.

In summary, based on the above information, it was decided that 2 cases would be modeled: a worst-case stack with height 30 feet; and good practice/typical stack with height 40 feet. Both stacks would have diameter 1 ft, flow rate 2500 ft^3/min, and resulting velocity 53 ft/sec.

The stacks were placed at the center of the building at

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(0,0). The stacks were modeled as point sources exiting vertically. From the data summary, virtually all stacks for which information was available exited vertically. In only isolated cases (4) was there a stack that was capped or exited horizontally.

For the case with worst-case stack height, building downwash needed to be considered. BPIP (Building Profile Input Program) was used to calculate values needed as inputs to the building downwash algorithm.

3.1.2. Building Dimensions and Configurations

Figures 7-9 summarize building height, length, and width values from the database. 48% of buildings have a height between 20 - 30 ft, with an average height of 27 feet. The histogram peaks for both building length and width occur in the 0 - 50 ft category, representing 23% and 31% of facilities, respectively. Of the buildings with dimensions that fall in the 0 - 50 foot range, the average building lengths and widths are 28.5 ft and 25.3 ft, respectively.

A previous TCEQ study showed that worst case downwash occurs when all three building dimensions are equal. Instead of modeling a cubic building, we modeled a cylindrical building with equal diameter and height, so that the projected length/width of the building is the same in all directions. Based on the database building dimension information, a circular building 25' in diameter with 25' height was chosen for modeling.

Table 2 summarizes emission release configuration information obtained from the database.

Together, the one stack/no fugitives and one stack with fugitives configurations represent 52% (78 of 151) of the facilities in the database for which building configuration information was available.

Two of the facilities in the table above with 2 or more stacks also had ovens. Since no facilities with one stack had ovens, and only 2 facilities with 2 or more stacks had ovens, modeling a separate building configuration with an oven stack was not warranted.

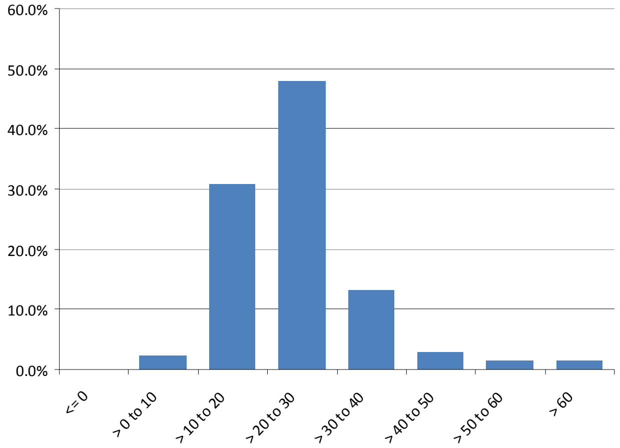

Figure 7. Summary of building heights (ft) (n = 136).

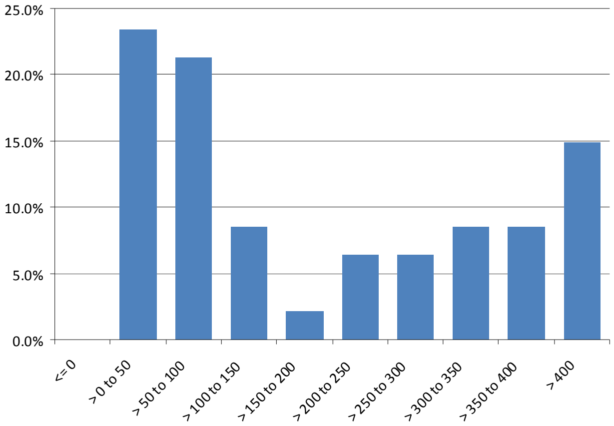

Figure 8. Summary of building lengths (ft) (n = 47).

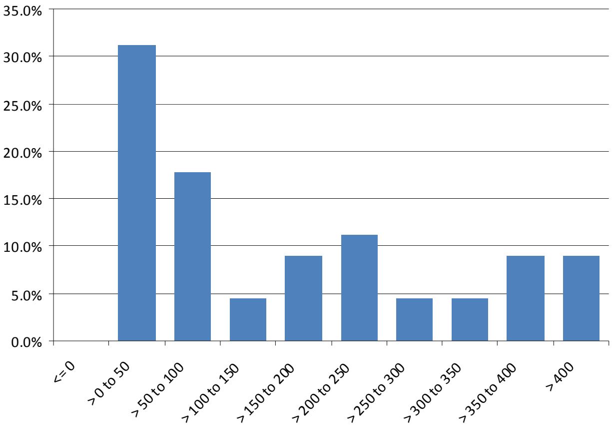

Figure 9. Summary of building widths (ft) (n = 45).

Table 2. Summary of emission release configurations.

Emission Release Configuration			Total
1 stack	no oven	no fug	76
1 stack	oven	no fug	NA
1 stack	no oven	fug	2
1 stack	oven	fug	NA
2 stacks	no oven	fug	11
> 2 stacks	no oven	fug	11
2 stacks	no oven	no fug	21
> 2 stacks	no oven	no fug	30
		Total	151

Based on information from **Table 2**, 2 emission release configurations were chosen for modeling: a building with one stack, and the same building with fugitives.

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3.1.3. Hours of Operation

As shown in **Figure 10**, 44% of facilities are permitted to operate 24 hours a day. Another 20% of facilities operate 6 - 9 hours a day, representing the histogram category with the second highest peak. Within the 6 - 9-hour category, most of the facilities operate 8 hours. Thus, both 24-hour and 8-hour operating scenarios were chosen for modeling.

3.1.4. Distance to Property Line and Nearest Off-Site Receptor

As shown in **Figure 11**, only 14% of facilities have a distance to the property line 50 feet or less. Almost a third of facilities have a distance to the property line in the range >50 - 100. These distances could be used in conjunction with dispersion modeling output, discussed later, to determine whether health impacts are likely to occur past the property line.

As shown in **Figure 12**, 28% of facilities have a distance to the nearest off-site receptor of ≤250 ft. Almost a third of facilities have a distance to the nearest off-site receptor >250 - 500 ft. These distances could be used in conjunction with dispersion modeling output to determine whether health impacts are likely to occur at nearby receptors.

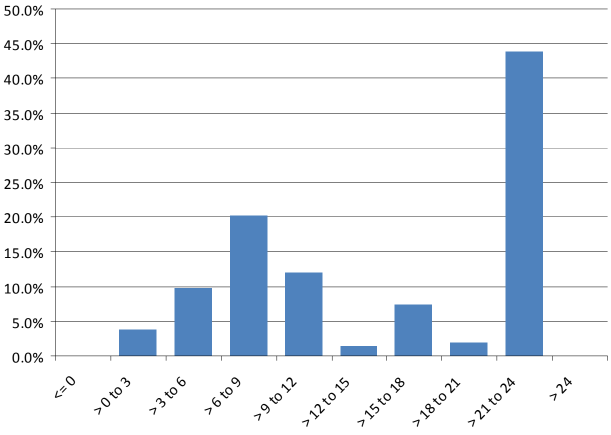

Figure 10. Summary of hours of operation (n = 217).

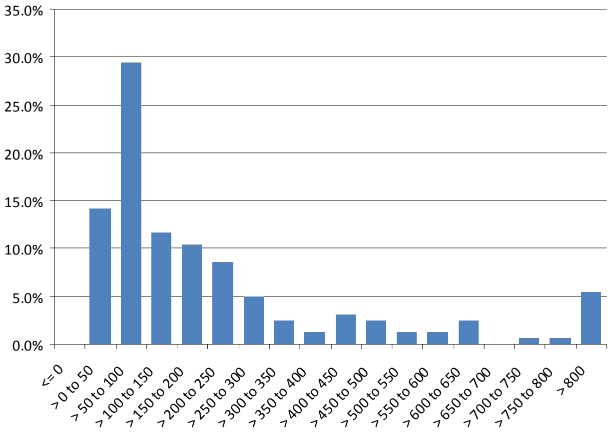

Figure 11. Summary of distance to nearest property line (ft) (n = 163).

3.1.5. Spray Information

Tables 3 and **4** summarize spray type and object shape information obtained from the database. This information was used in the emission calculations discussed in the next section.

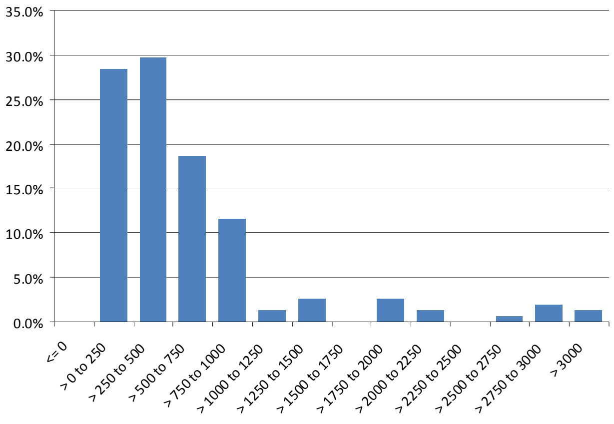

Figure 12. Summary of distance to nearest offsite receptor (ft) (n = 155).

Table 3. Summary of spray type information (n = 220).

Spray Type	Usage Frequency-Percent
Aerosol & Air Atomized Spray	3.2
Airless Spray	17.7
HVLP	20.5
Brush	1.4
Dip	6.4
Electrostatic Air Atomized	1.8
Air Assisted	0.9
Flow Coat	0.5
Misc./Unspecified Spray	45.5

Table 4. Summary of object shape information (n = 235).

Object Shape	Frequency (%)
Flat Surface	43.8
Table Leg	23.0
Bird Cage	7.2
Two or Three Shapes	12.3
Miscellaneous	13.6

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Figures 13-15 summarize spray time, max. hourly spray rate, and number of application station information.

3.1.6. Drying Information

Figures 16 and **17** summarize database values of time in drying booth and drying oven heat input values, respectively. Only 1 time on conveyer value was available (0.5 min), and only 3 time in oven values were available (90 min, 180 min, and 180 min). This information was used in the emission calculations discussed later.

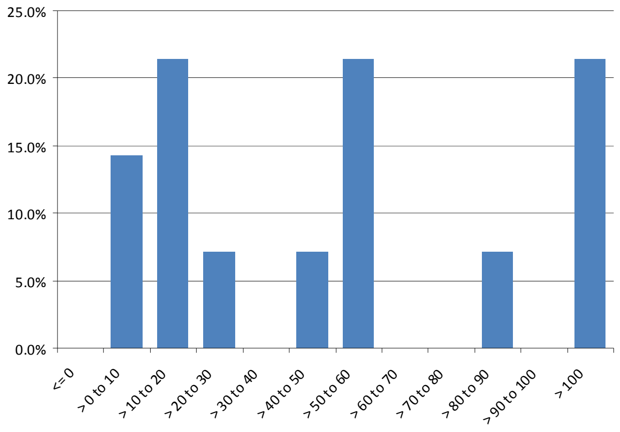

Figure 13. Summary of spray times (min) (n = 14).

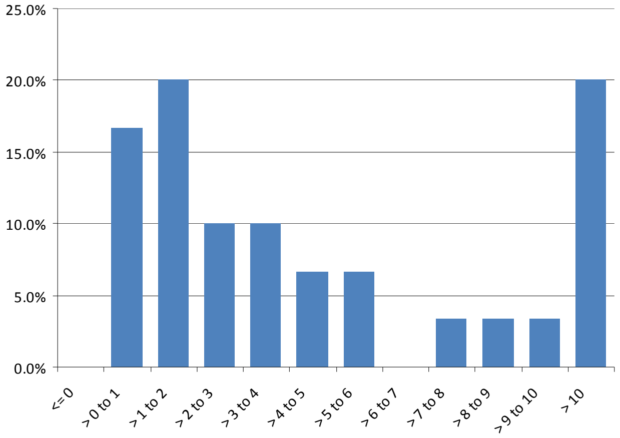

Figure 14. Summary of max. hourly spray rates (gal/hr) (n = 30).

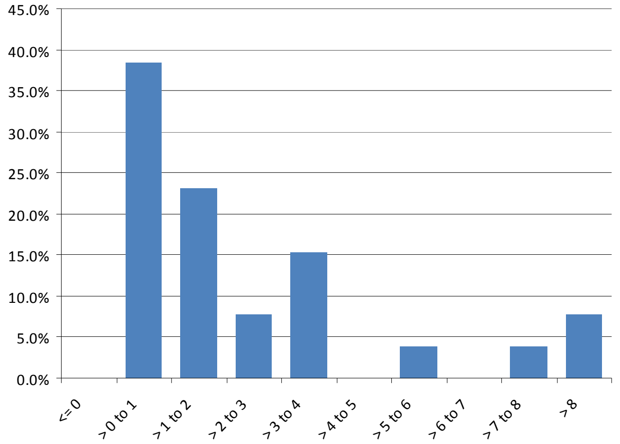

Figure 15. Summary of no. of application stations (n = 26).

Only one time on conveyor value was available from the database (0.5 min), and only 3 time in oven values were available (90 min, 180 min, and 180 min).

3.1.7. Control Information

Figures 18-20 summarize parameters related to filters used to control particulate emissions: minimum face velocity, dry filter efficiency, and dry filter face velocity. In addition, 6 facilities are shown in the database as using water wash/wet scrubber systems. This information was used in the emission calculations discussed later.

3.1.8. Solvent Information

Figures 21-23 summarize solvent information used in

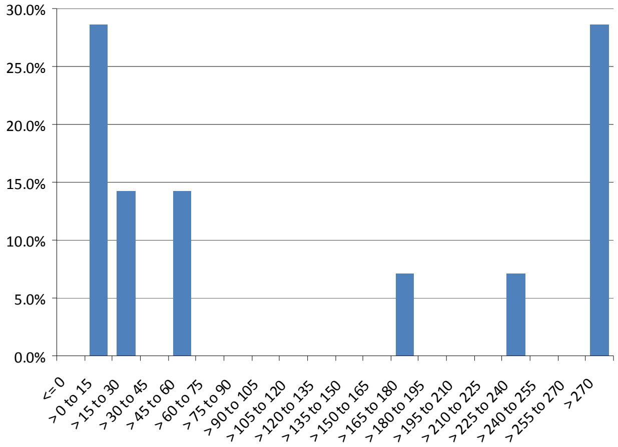

Figure 16. Summary of time in booth, min (n = 14).

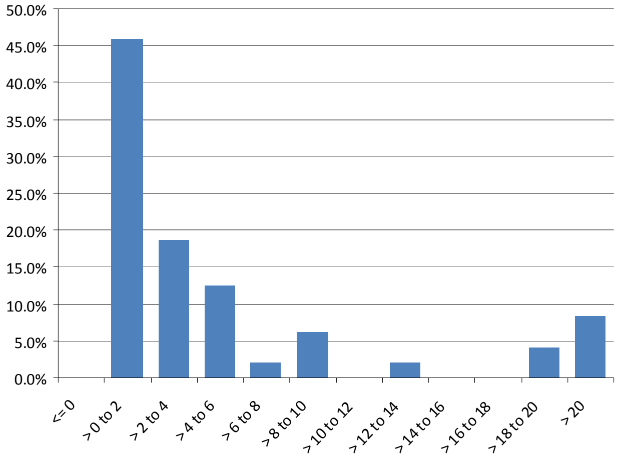

Figure 17. Summary of maximum heat input, MMBtu/hr (n = 48).

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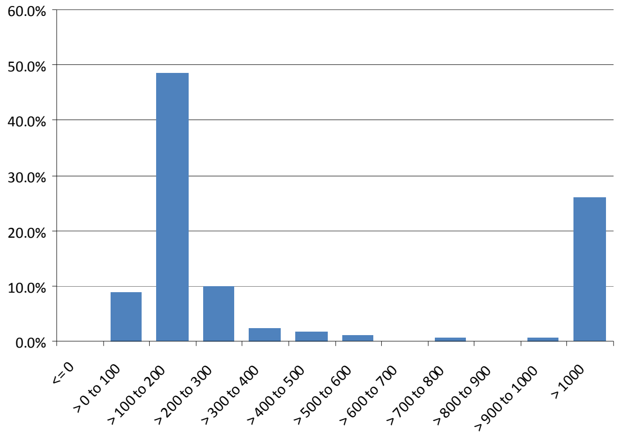

Figure 18. Summary of minimum face velocity, ft/min (n = 169).

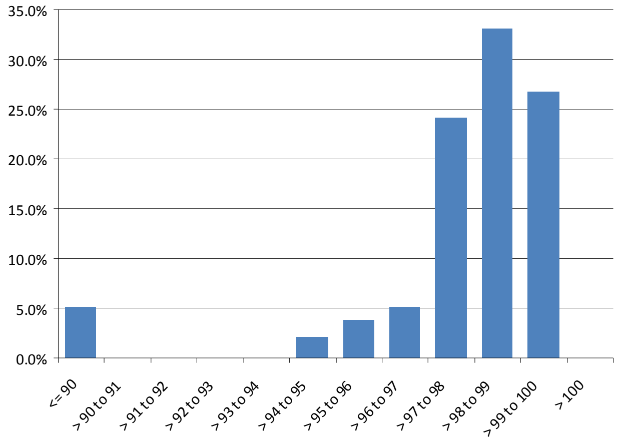

Figure 19. Summary of dry filter efficiency (n = 236).

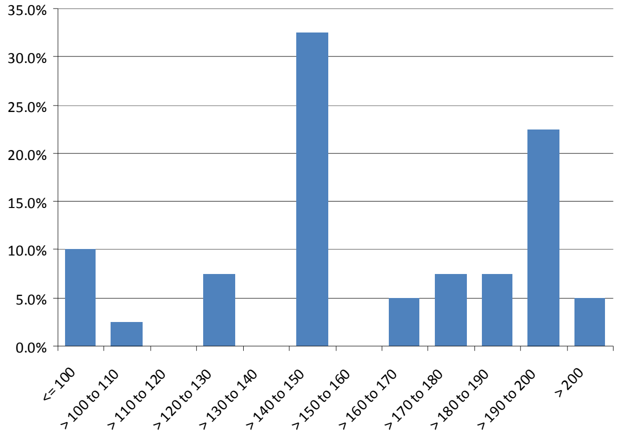

Figure 20. Summary of dry filter face velocity, ft/min (n = 40).

emission calculations.

Table 5 shows the 20 components used at the most facilities. As shown, xylene is the component used at the most facilities.

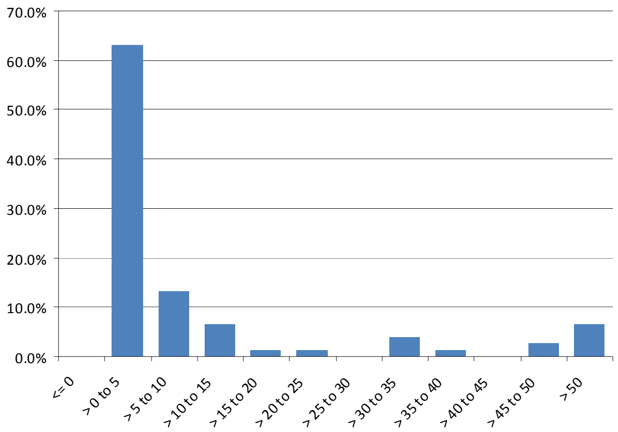

Figure 21. Summary of hourly coating use, gal/hr (n = 76).

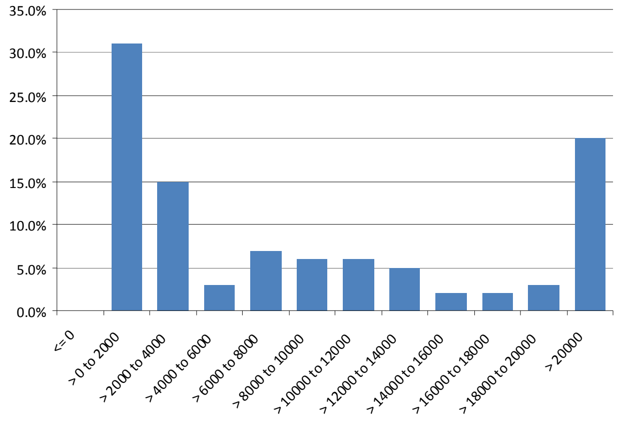

Figure 22. Summary of annual coating use, gal/yr (n = 100).

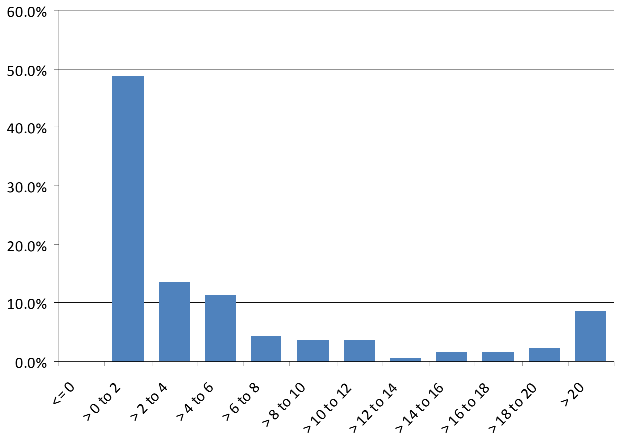

Figure 23. Summary of number of coatings/solvents used per project (n = 185).

3.2. Maximum VOC Emission Rates

Of the 199 coating/solvent components identified in the database, the 21 chemicals with the maximum ratios of emissions to short-term (1-hour) effect screening levels (ESLs) are shown in **Table 6**. These are likely to be the

Table 5. Number of facilities using each component.

Component	No. of facilities
Xylene	87
Ethylbenzene	78
Toluene	61
Titanium dioxide	58
Methyl isobutyl ketone	52
Magnesium silicate	49
Methyl n-amyl ketone	46
n-tateebutyl aB	45
Quartz	43
yl ethyl ketoneMeth	43
Acetone	42
Glycol Ether	41
1-Butanol	39
Light aromatic hydrocarbons	38
1,2,4-Trimethylbenzene	38
Carbon black	36
1-Methoxyl-2-propanol acetate	34
Isopropyl alcohol	34
Naphtha	29
V. M. & P. Naphtha	28

N/A Not applicable.

chemicals of most concern in terms of health impacts; this must be confirmed taking into account emission configurations (paint booths emissions typically emitted via a stack, and conveyor emissions released as fugitives) via dispersion modeling, as discussed in the next section. The TCEQ uses ESLs in their air permitting process to evaluate air dispersion modeling's predicted impacts. If modeled concentrations of a pollutant do not exceed the screening level, adverse health or welfare effects are not expected. If modeled concentrations of a pollutant exceed the screening levels, it does not necessarily indicate a problem but rather triggers a more in-depth review.

3.3. Dispersion Modeling Results

3.3.1. Pollution Concentration Isopleths

Dispersion modeling was conducted for the 3 configurations (worst-case stack height, good practice stack height, and fugitive emissions), for urban and rural dispersion parameters, for 8-hour and 24-hour operating scenarios, and for 1-hour, 24-hour, and annual averaging times, for a total of 2 × 3 × 2 × 3 = 36 scenarios. All 36 concentration isopleths are available from the authors. **Figures 24-26** show plots with the highest concentrations for each configuration. The plots show the maximum 1-hour concentrations at each receptor over the 5 years of meteorological data modeled. Vertical and horizontal axes have units of m.

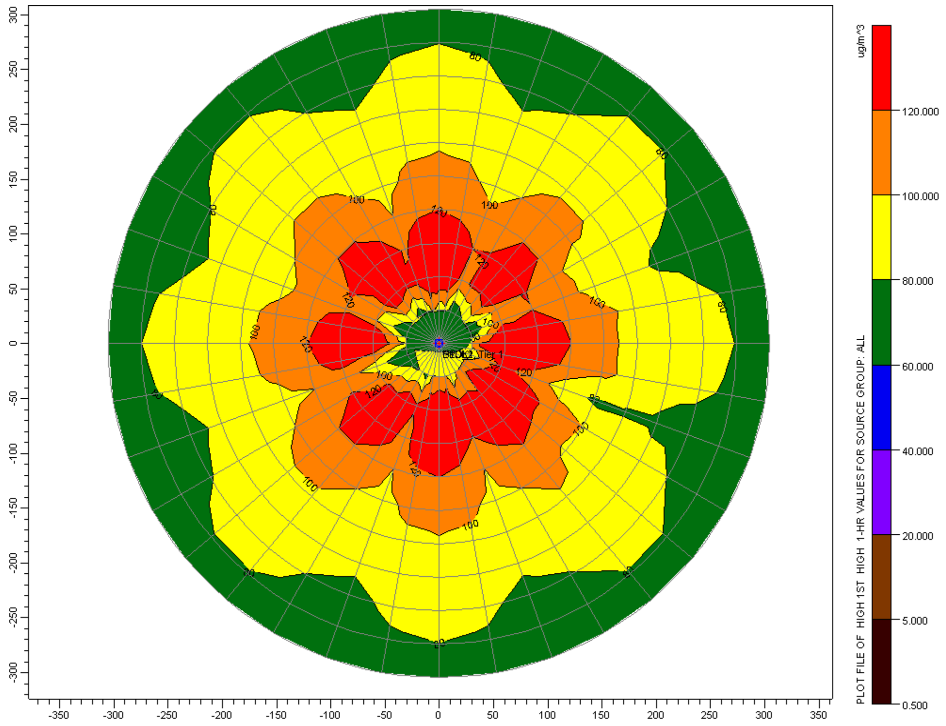

Figure 24. Concentrations for worst-case stack configuration, rural dispersion parameters, 24-hour operation, 1-hour averaging time.

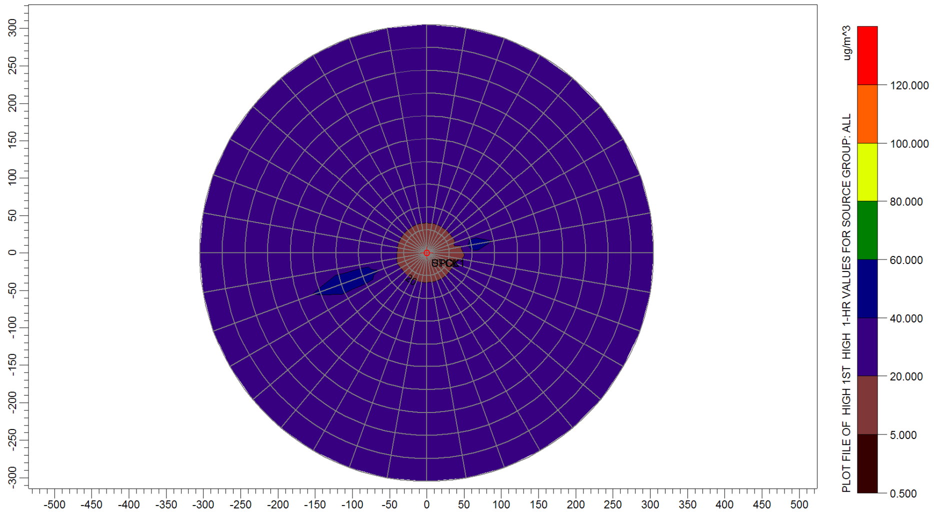

Figure 25. Concentrations for good practice stack configuration, urban dispersion parameters, 24-hour operation, 1-hour averaging time.

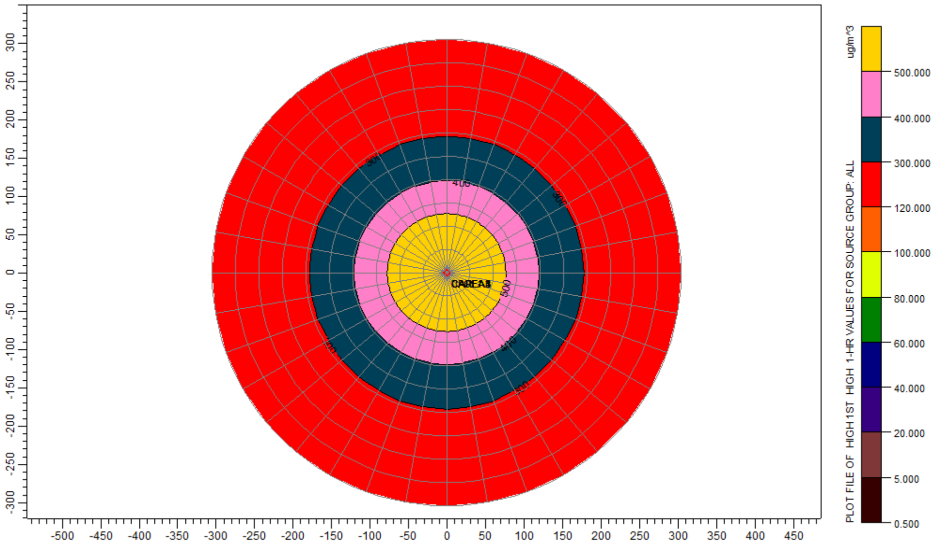

Figure 26. Concentrations for fugitive configuration, rural dispersion parameters, 24-hour operation, 1-hour averaging time.

The impact of building configuration, averaging time, operating scenario, and rural vs. urban terrain on ground-level concentrations are discussed below.

Building configuration. As expected, the worst-case stack produced higher ground-level concentrations than the good practice stack. The fugitive configuration produced higher ground-level concentrations than either stack configuration, most likely because the fugitive source is located nearer the ground.

Averaging time. As expected, 1-hour average concentrations were higher than 24-hour average concentrations, which were in turn higher than annual average concentrations. Variations in wind direction produce lower concentrations as averaging time increases.

Operating scenario. The 24-hour operating scenario gave higher concentrations than the 8-hour operating scenario for the worst-case stack; for the good-practice stack and fugitive building configurations, however, both operating scenarios produced the same concentrations. The fact that the 8-hour and 24-hour operating scenarios produced the same concentrations indicates that meteorological conditions producing worst-case concentrations occurred from 8 a.m.-4 p.m., during 8-hour operation. We believe that the 8-hour and 24-hour operating scenarios gave different concentrations for the worst-case stack configuration because this was the only configuration for which the building downwash program BPIP was run.

Rural vs. urban terrain. For the stack configurations, at some receptor locations urban dispersion parameters

Table 6. Coating/solvent components with highest emission to effect screening level ratios.

Component	Maximum Emission Rate E, lb/hr		Short-Term ESL, μg/m³	E/ESL	
	Paint Booth	Conveyor		Paint Booth	Conveyor
Quartz	56.09	N/A	10	5.61	N/A
4,4'-diphenylomethane diisocyanate	2.55	0.56	0.5	5.1	1.12
Diphenylmethane diisocyanate polymer	10.22	N/A	3	3.41	N/A
Hexamethylene diisocyanate	10.44	N/A	4	2.61	N/A
Talc	37.19	N/A	20	1.86	N/A
Zinc dust	91.88	N/A	50	1.84	N/A
Hydrated iron oxide	76.34	N/A	50	1.53	N/A
Clay (kaolin)	18.98	N/A	20	0.95	N/A
Bisphenol A diglycidyl ether	12.99	N/A	14	0.93	N/A
C18 unsaturated dimers, polymer w/BPA	38.04	N/A	50	0.76	N/A
Potassium silicate	37.72	N/A	50	0.75	N/A
Phenol novalac	36.43	N/A	50	0.73	N/A
Butyl acetate	25.5	9.09	36	0.71	0.25
Tremolite (non-asbestiform)	12.99	N/A	20	0.65	N/A
Barium sulfate	31.09	N/A	50	0.62	N/A
Methyl n-amyl ketone	19.58	4.54	32	0.61	0.14
Paraffin waxes, hydrocarbon waxes	11.59	N/A	20	0.58	N/A
Epoxy resin	26.65	N/A	50	0.53	N/A
Chromium oxide	0.53	N/A	1	0.53	N/A
p-Toluenesulfonyl isocyanate	0.53	N/A	1	0.53	N/A
Chromium III (as Cr)	0.53	N/A	1	0.53	N/A

N/A: Not applicable.

gave higher concentrations, and in some cases rural gave higher. For the fugitive configuration, rural dispersion parameters gave higher concentrations. When worst-case stack concentrations were added to fugitive concentrations, rural dispersion parameters gave higher maximum values for each pollutant, as shown in **Table 7**. However, when good-practice stack concentrations were added to fugitive concentrations, urban dispersion parameters gave higher maximum values for each pollutant.

3.3.2. Coating Component Species Warranting Further Review

To determine which pollutants would warrant a more in-depth health impacts evaluation, pollutant specific emission rates (E) and effects screening levels (ESLs) were applied in the form of E/ESL on a source-by-source basis to the unit concentration at each receptor; then the contribution from each source at each receptor was summed. In other words, the following sum was evaluated for each chemical species i at each receptor location j:

$$\begin{aligned}\mathrm{SUM} = \left(E_{\mathrm{i\ paintbooth}}\right)\Big/\mathrm{ESL}_{\mathrm{i}} * \left(C_{\mathrm{j\ paintbooth\ max}}\right) \\ + \left(E_{\mathrm{i\ conveyor}}\right)\Big/\mathrm{ESL}_{\mathrm{i}} * \left(C_{\mathrm{j\ fugitives\ max}}\right)\end{aligned} \quad (1)$$

where

$C_{\mathrm{j\ paintbooth\ max}}$ is the maximum modeled 1-hour concentration for the worst-case or good-practice stack configuration at receptor location j.

$C_{\mathrm{j\ fugitives\ max}}$ is the maximum modeled 1-hour concentration for the fugitive configuration at receptor location j.

$\mathrm{ESL}_{\mathrm{i}}$ is the short-term (1-hour) effect screening level for pollutant i,

$E_{\mathrm{i\ paintbooth}}$ is the maximum stack emission of pollutant i,

$E_{\mathrm{i\ conveyor}}$ is the maximum fugitive emission of pollutant i.

Only concentrations for the 1-hour averaging time

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Table 7. Maximum SUM values for worst-case stack + fugitives.

Compound	Short-Term ESL, mg/m^3	Rural 8-hour operation		Rural 24-hour operation		Urban 24-hour operation	
		Max. Sum of (E/ESL)*C, lb/hr	No. of Sum Values > 1	Max. Sum of (E/ESL)*C, lb/hr	No. of Sum Values > 1	Max. Sum of (E/ESL)*C, lb/hr	No. of Sum Values > 1
1,3,5-Trimethylbenzene	1250	1.5	128	1.5	163	1.5	37
2,4-pentanedione	40	4.7	360	5.1	360	4.5	360
2-Butoxy ethanol	210	14.4	360	14.9	360	14.1	360
2-Butoxyethyl acetate	310	6.0	360	6.3	360	5.9	360
4,4’-diphenylomethane diisocyanate	0.5	1287	360	1342	360	1255.4	360
Acrylic polymer A	50	12.2	360	13.2	360	11.6	360
Alkyl phthalate	50	16.6	360	17.9	360	15.8	360
Aluminum flakes	50	9.9	360	10.6	360	9.4	360
Aluminum oxide	50	5.4	360	5.8	360	5.1	360
Aluminum silicate	50	24.0	360	25.9	360	22.9	360
Anthophyllite (non-asbestiform)	20	3.1	353	3.3	360	2.9	360
Antigorite	20	17.4	360	18.8	360	16.6	360
Barium chromate	0.1	13.3	360	14.4	360	12.7	360
Barium metaborate hydrate	50	9.3	360	10.0	360	8.81	360
Barium sulfate	50	84.6	360	91.3	360	80.6	360
Benzyl alcohol	500	3.0	342	3.1	360	2.9	360
Bisphenol A diglycidyl ether	14	126.2	360	136.2	360	120.3	360
Butoxyethoxyethanol	1060	2.8	330	3.0	360	2.7	218
Butyl acetate	36	230.1	360	237.7	360	225.8	360
Butyl alcohol	610	5.4	360	5.5	360	5.33	360
C18 unsaturated dimers, polymer w/BPA and ech	50	103.5	360	111.7	360	98.6	360
Calcium carbonate	50	28.8	360	31.1	360	27.5	360
Calcium magnesium carbonate	50	9.9	360	10.6	360	9.4	360
Ceramic metals and wares	50	31.9	360	34.4	360	30.4	360
Chromium III (as Cr)	1	72.1	360	77.8	360	68.7	360
Chromium oxide	1	72.1	360	77.8	360	68.7	360
Clay	50	26.9	360	29.0	360	25.6	360
Clay (kaolin)	20	129.1	360	139.3	360	123.0	360
Clay 68911-87-5	100	6.6	360	7.1	360	6.3	360
Cyclic amine epoxy polymer	50	30.8	360	33.2	360	29.3	360
Cyclohexanone	480	6.2	360	6.4	360	6.0	360
Diacetone alcohol	960	2.2	231	2.2	288	2.1	108
Diaminocyclohexane	470	2.9	340	3.1	360	2.74	237
Dibasic esters	100	8.1	360	8.3	360	7.9	360
Diethylenetriamine	40	19.4	360	20.1	360	19.1	360

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Continued

Diisodecyl phthalate	50	14.0	360	15.1	360	13.3	360
Diisodecyl phyhalate	50	4.7	360	5.1	360	4.5	360
Diphenylmethane diisocyanate polymer	3	463.4	360	500.2	360	441.6	360
Epoxy resin	50	72.5	360	78.3	360	69.1	360
Epoxy resin 25036-25-3	50	67.4	360	72.7	360	64.2	360
Ethyl 3-ethoxypropionate	400	3.3	360	3.6	360	3.2	290
Ethyl silicate	850	1.2	21	1.2	89	1.2	36
Ethyl silicate polymer (as ethyl silicate)	50	25.3	360	27.3	360	24.1	360
Ethylbenzene	2000	1.2	61	1.3	108	1.2	36
Hansa yellow	50	12.0	360	13.0	360	11.5	360
Heptane	3500	1.4	16	1.56	164	1.37	74
Hexamethylene diisocyanate	4	355	360	383.2	360	338.3	360
High flash naphtha	1250	1.1	5	1.23	60	1.08	36
Hydrated iron oxide	50	207.7	360	224.2	360	197.9	360
Hydrotreated light naphha	3500	1.2	5	1.26	72	1.11	39
Iron oxide	50	17.6	360	19.0	360	16.8	360
Iron oxide (red) (as fe fume)	50	2.48	287	2.67	360	2.36	182
Iron phosphide	50	40.7	360	43.9	360	38.8	360
Isobutanol	1520	4.2	360	4.35	360	4.1	360
Isophorone diamine	100	6.7	360	7.3	360	6.4	360
Lead	1.5	15.4	360	16.6	360	14.7	360
Light aliphatic solvent naphtha	3500	1.3	7	1.4	126	1.25	72
Light hydrotreated distallate	1000	5.0	360	5.4	360	4.80	360
Medium aromatic hydrocarbons	2560	2.2	244	2.3	308	2.2	108
MEKP	15	14.8	360	16.0	360	14.1	360
Methyl ethyl ketone	3900	2.4	266	2.5	360	2.3	109
Methyl isoamyl ketone	60	20.5	360	21.2	360	20.1	360
Methyl isobutyl ketone	2050	3.2	360	3.3	360	3.1	360
Methyl n-amyl ketone	32	158.4	360	165.0	360	154.6	360
Methyl silicate	60	1.1	2	1.2	45	1.04	35
Mica	30	47.2	360	50.9	360	44.9	360
Modified aliphatic polyamine	420	1.4	10	1.5	142	1.3	74
Naphthalene	440	1.2	12	1.2	81	1.1	36
Nonyl phenol	400	1.8	90	2.0	323	1.8	110
Nonylphenol	400	2.3	244	2.5	358	2.2	181
Odorless petroleum naphtha	3500	1.2	5	1.3	79	1.13	39
Organic yellow pigment	50	12.0	360	13.0	360	11.5	360

Continued

Organophilic clay	50	28.8	360	31.1	360	27.5	360
Paraffin waxes, hydrocarbon waxes	20	78.8	360	85.1	360	75.1	360
Pentyl propionate	230	6.5	360	7.0	360	6.1	360
Phenol	150	3.0	348	3.2	360	2.83	253
Phenol novalac	50	99.1	360	107.0	360	94.5	360
Phenolic polymer	30	32.4	360	35.0	360	30.9	360
Polyamide	50	37.6	360	40.6	360	35.9	360
Polyamide resin	50	37.7	360	40.7	360	36.0	360
Polyamine	180	9.9	360	10.7	360	9.5	360
Polyamine adduct	50	7.9	360	8.6	360	7.5	360
Polyester resin	50	52.0	360	56.2	360	49.6	360
Polysilicate	10	23.1	360	25.0	360	22.0	360
Polystyrene	50	2.2	191	2.3	356	2.1	146
Potassium hydroxide	20	23.1	360	25.3	360	22.4	360
Potassium silicate	50	102.6	360	110.8	360	97.8	360
Propylene Glycol Methyl Ether Acetate	660	5.9	360	6.1	360	5.7	360
Propylene glycol mono methyl ether	3700	1.2	16	1.2	84	1.16	36
p-Toluenesulfonyl isocyanate	1	72.1	360	77.8	100	68.7	360
Quartz	10	762.9	360	823.5	0	727.1	360
Quaternary ammonium compounds, benzyl-C12-16-alky	100	1.7	60	1.9	273	1.65	110
Rheology additive	50	6.8	360	7.3	360	6.4	360
Strontium chromate	0.1	13.6	360	14.7	360	13.0	360
Talc	20	252.9	360	273	360	241	360
Tetraethylenepentamine	400	1.3	7	1.4	126	1.25	73
Titanate	10	1.1	2	1.2	45	1.04	35
Titanium dioxide	50	46	360	50	360	43.8	360
Toluene	640	6.0	360	6.1	360	5.8	360
Tremolite (non-asbestiform)	20	88.3	360	95.4	360	84.2	360
Triethylene tetramine	240	1.3	7	1.4	103	1.2	51
Trimethyl benzene	1250	1.1	3	1.14	61	1.08	36
Trimethyl borate	13	13.0	360	13.4	360	12.7	360
Xylene	350	30.1	360	30.7	360	29.7	360
Zinc chloride	10	1.1	2	1.2	45	1.04	35
Zinc dust	50	250.0	360	269.8	360	238.2	360
Zinc oxide	50	25.1	360	27.1	360	23.9	360
Zinc phosphate	50	19.5	360	21.0	360	18.5	360

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Table 8. Maximum SUM values for good practice stack + fugitives.

Compound	Short-Term ESL, mg/m^3	Rural 24-hour operation		Urban 24-hour operation	
		Max. Sum of (E/ESL)*C, lb/hr	Number of Sum Values > 1	Max. Sum of (E/ESL)*C, lb/hr	Number of Sum Values > 1
1,3,5-Trimethylbenzene	1250	1.02	69	1.03	36
2,4-pentanedione	40	1.21	6	1.95	252
2-Butoxy ethanol	210	9.0	360	9.1	360
2-Butoxyethyl acetate	310	2.9	360	2.96	252
4,4'-diphenylomethane diisocyanate	0.5	658.4	360	666.1	360
Acrylic polymer A	50	3.1	324	5.0	360
Alkyl phthalate	50	4.2	324	6.8	360
Aluminum flakes	50	2.5	288	4.1	360
Aluminum oxide	50	1.4	16	2.2	288
Aluminum silicate	50	6.14	324	9.9	360
Anthophyllite (non-asbestiform)	20	0.8	0	1.3	3
Antigorite	20	4.5	324	7.2	360
Barium chromate	0.1	3.4	324	5.5	360
Barium metaborate hydrate	50	2.4	288	3.8	324
Barium sulfate	50	21.6	324	34.9	360
Benzyl alcohol	500	1.8	252	1.8	73
Bisphenol A diglycidyl ether	14	32.3	324	52.1	360
Butoxyethoxyethanol	1060	0.7	0	1.16	3
Butyl acetate	36	142.8	360	144	360
Butyl alcohol	610	3.9	360	3.94	148
C18 unsaturated dimers, polymer w/BPA and ech	50	26.5	324	42.8	360
Calcium carbonate	50	7.4	324	11.9	360
Calcium magnesium carbonate	50	2.5	288	4.1	360
Ceramic metals and wares	50	8.2	324	13.2	360
Chromium III (as Cr)	1	18.4	324	29.8	360
Chromium oxide	1	18.4	324	29.8	360
Clay	50	6.9	324	11.1	360
Clay (kaolin)	20	33.0	324	53.3	360
Clay 68911-87-5	100	1.7	215	2.7	324
Cyclic amine epoxy polymer	50	7.9	324	12.7	360
Cyclohexanone	480	3.7	360	3.8	216
Diacetone alcohol	960	1.3	145	1.3	37
Diaminocyclohexane	470	0.74	0	1.2	3
Dibasic esters	100	4.9	360	4.9	288

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Continued

Diethylenetriamine	40	11.8	360	11.9	360
Diisodecyl phthalate	50	3.6	324	5.8	360
Diisodecyl phyhalate	50	1.2	6	1.96	252
Diphenylmethane diisocyanate polymer	3	118.5	357	191.4	360
Epoxy resin	50	18.5	324	30.0	360
Epoxy resin 25036-25-3	50	17.2	324	27.8	360
Ethyl 3-ethoxypropionate	400	0.85	0	1.4	4
Ethyl silicate	850	0.7	0	0.73	0
Ethyl silicate polymer (as ethyl silicate)	50	6.5	324	10.5	360
Ethylbenzene	2000	0.84	0	0.84	0
Hansa yellow	50	3.1	324	5.0	360
Heptane	3500	0.37	0	0.6	0
Hexamethylene diisocyanate	4	90.8	324	146.7	360
High flash naphtha	1250	0.29	0	0.47	0
Hydrated iron oxide	50	53.1	324	85.8	260
Hydrotreated light naphha	3500	0.3	0	0.5	0
Iron oxide	50	4.5	324	7.3	360
Iron oxide (red) (as fe fume)	50	0.63	0	1.02	1
Iron phosphide	50	10.4	324	16.8	360
Isobutanol	1520	2.55	360	2.6	112
Isophorone diamine	100	1.72	231	2.8	324
Lead	1.5	3.9	324	6.4	360
Light aliphatic solvent naphtha	3500	0.34	0	0.54	0
Light hydrotreated distallate	1000	1.3	10	2.10	252
Medium aromatic hydrocarbons	2560	1.34	145	1.35	37
MEKP	15	3.8	324	6.1	360
Methyl ethyl ketone	3900	1.2	109	1.2	37
Methyl isoamyl ketone	60	12.4	360	12.5	360
Methyl isobutyl ketone	2050	1.83	254	1.85	74
Methyl n-amyl ketone	32	83.0	360	83.9	360
Methyl silicate	60	0.28	0	0.45	0
Mica	30	12.1	324	19.5	360
Modified aliphatic polyamine	420	0.36	0	0.6	0
Naphthalene	440	0.7	0	0.71	0
Nonyl phenol	400	0.5	0	0.76	0
Nonylphenol	400	0.6	0	0.96	0
Odorless petroleum naphtha	3500	0.3	0	0.49	0

Continued

Organic yellow pigment	50	3.1	324	5.0	360
Organophilic clay	50	7.4	324	11.9	360
Paraffin waxes, hydrocarbon waxes	20	20.2	324	32.6	360
Pentyl propionate	230	1.7	188	2.7	324
Phenol	150	0.76	0	1.2	3
Phenol novalac	50	25.3	324	40.9	360
Phenolic polymer	30	8.3	324	13.4	360
Polyamide	50	9.6	324	15.5	360
Polyamide resin	50	9.7	324	15.6	360
Polyamine	180	2.5	288	4.1	360
Polyamine adduct	50	2.0	288	3.3	324
Polyester resin	50	13.3	324	21.5	360
Polysilicate	10	5.9	324	9.6	360
Polystyrene	50	0.55	0	0.9	0
Potassium hydroxide	20	6.0	324	9.7	360
Potassium silicate	50	26.2	324	42.4	360
Propylene glycol methyl ether acetate	660	3.0	360	3.1	216
Propylene glycol mono methyl ether	3700	0.7	0	0.7	0
p-Toluenesulfonyl isocyanate	1	18.4	324	29.8	360
Quartz	10	195.1	360	315	360
Quaternary ammonium compounds, benzyl-C12-16-alky	100	0.44	0	0.7	0
Rheology additive	50	1.7	249	2.8	324
Strontium chromate	0.1	3.5	324	5.6	360
Talc	20	64.7	324	104.5	360
Tetraethylenepentamine	400	0.34	0	0.5	0
Titanate	10	0.28	0	0.45	0
Titanium dioxide	50	11.8	324	19	360
Toluene	640	3.8	360	3.8	183
Tremolite (non-asbestiform)	20	22.6	324	36.5	360
Triethylene tetramine	240	0.32	0	0.5	0
Trimethyl benzene	1250	0.67	0	0.67	0
Trimethyl borate	13	7.9	360	7.9	360
Xylene	350	22.9	360	23	360
Zinc chloride	10	0.28	0	0.45	0
Zinc dust	50	63.9	324	103.3	360
Zinc oxide	50	6.4	324	10.4	360
Zinc phosphate	50	5.0	324	8	369

were included in the SUM, to correspond to the 1-hour averaging time of the short-term ESLs. Although TCEQ also provides long-term (annual) effect screening levels, short-term ESLs generally result in more stringent permit limits than long-term ESLs. Thus, only short-term ESLs were considered. Concentrations were calculated for both urban and rural dispersion parameters, because depending on the receptor location, either could be higher for the stack configurations.

SUMS were calculated for all 360 receptor locations. If SUM < 1 is for a given species for all receptor locations, that pollutant would not warrant in-depth health review. For those pollutants where SUM > 1, further analysis may be required through pollutant specific modeling analyses.

Table 7 lists maximum SUM values for the 108 (out of 181) pollutants with SUM > 1 for the worst-case stack + fugitives for the 24-hour operation scenario for rural and urban dispersion parameters, as well as the 8-hour operation scenario for rural dispersion parameters is also presented for comparison. **Table 8** lists the maximum SUM values for the good-practice stack + fugitives. As seen in **Tables 7** and **8**, the worst-case stack + fugitives 24-hour operation scenario with rural dispersion parameters gave the highest concentrations. This was anticipated because worst-case stack gave higher concentrations than the good-practice stack, the 24-hour operation scenario gave higher concentrations than the 8-hour operation scenario for the worst-case stack, and the rural dispersion parameters gave higher fugitive concentrations.

The pollutants listed in **Tables 7** and **8** warrant a more in-depth health impacts evaluation.

4. Summary

A database was developed using 286 TCEQ permit files authorizing surface coating facilities in Texas during 2006 and 2007. The database includes information important for estimating emission rates, and for using as dispersion model inputs.

Hourly and annual emissions of volatile organic compounds (VOCs), particulate matter (PM), and exempt solvents (ES) were calculated for each permitted entity/ company in the database, according to equations given by TCEQ. Dispersion modeling was then conducted for 3 facility configurations (worst-case stack height, good practice stack height, and fugitive emissions), for urban and rural dispersion parameters, for 8-hour and 24-hour operating scenarios, and for 1-hour, 24-hour, and annual averaging times, for a total of 36 scenarios. The highest modeled concentrations were for the worst-case stack height, rural dispersion parameters, 24-hour operation scenario, and 1-hour averaging time. 108 specific chemical species, which are components of surface coatings, were identified as candidates for further health impacts review.

5. Acknowledgements

We would like to acknowledge the Texas Commission on Environmental Quality for providing funding for this project. The paper does not, however, necessarily represent the opinions or positions of TCEQ.

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