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A Validation of the Emissions Model from EPA's Metal Finishing Facility Risk Screening Tool - MFFRST

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A paper presented at the 2000 AESF/EPA conference provided a comparison of MFFRST-predicted emissions from stacks with those reported in the Toxics Release Inventory (TRI) data base. While predictions of some of the organic solvent emissions (TCE, e.g.) were similar to reported quantities, there was apparently a large discrepancy between predicted and reported emissions of metals. MFFRST was predicting emissions two orders of magnitude and more lower than were reported in TRI. This paper continues the testing of the emissions model. Twelve stack test reports from chrome plating facilities in California were used in a model validation exercise. All pertinent parameters (tank size, initial concentrations, current density, ventilation rates and others) were extracted and values assigned. Model predictions of chromium (Cr^{+6} and total chromium) emissions were compared against measured emissions. Initial testing showed an r^2 correlation of 0.59, between predicted and observed emissions. The model mostly underpredicted emissions by an average of about a factor of 6. This is much less than the underprediction of MFFRST compared to TRI emissions. Causes for this model underprediction will be explored and described in the paper.

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Introduction

MFFRST is a "user-friendly" tool that enables anyone to perform a screening characterization of health risks to worker and neighbors of metal finishing facilities. It was developed by the U.S. Environmental Protection Agency (EPA) under the Common Sense Initiative (CSI) Metal Finishing Sector. This tool focuses on human health impacts from inhaling chemicals emitted from metal finishing facilities. The tool has three major modules that are combined to calculate health risks. The first module characterizes atmospheric emissions from process tanks in metal finishing shops based on operating parameters (e.g., the concentration of chemicals in electroplating baths). *It is this module only that will be discussed in this report.* The second module models the movement (i.e., fate and transport) of the process tanks emissions to human receptors both in the metal finishing shop as well as to local neighbors external to the shop. The third module then calculates the level of exposure from those emissions. The third module also calculates the carcinogenic and non-carcinogenic risks from that level of exposure.

MFFRST was first introduced in January, 1999 at the AESF/EPA Conference for Environmental Excellence (Lorber, et al., 1999; Schwartz and Lorber, 1999). At that time, the proposed methodology and input data for MFFRST had been developed, but not installed into the software tool. The fully installed tool was completed and available in time for display at the June, 1999 SURF/FIN® Conference. Based on public comments sought and received at both conferences from experts in the metal finishing industry, federal government (EPA, OSHA), state agencies, non-government organizations, consultants, and others, MFFRST was updated for presentation at the January, 2000 AESF/EPA Conference for Environmental Excellence (Lorber, et al., 2000; Schwartz and Lorber, 2000). Subsequent to the January, 2000 presentation, additional comments were sought and received, and incorporated into the latest version of MFFRST. These comments and responses to comments are discussed in a companion paper to this one (Lorber, et al., 2001).

The primary purpose of this paper is to test MFFRST emissions estimates (i.e., the output of the first module) against actual field sampling data. As discussed below, MFFRST model predictions of chromium emissions very closely matched measurements of chromium emissions, for both controlled and uncontrolled emissions testing.

MFFRST Procedures and Input Data

The first module of MFFRST predicts emissions from dozens of metal finishing operations in terms of contaminant concentration and also in terms of daily mass emissions. Specifically, the MFFRST user can choose any combination of 17 different metal finishing lines (e.g., hard chromium electroplating, acid copper electroplating, chromium conversion, sulfuric acid anodizing) from which to estimate emissions. Each metal finishing line in MFFRST consists of a number of different tanks from which atmospheric emissions are generated (e.g., the hard chromium electroplating line consists of an alkaline cleaner, and electrocleaner, an acid etch, and a chromium plating tank). The emissions from each of the tanks in each of the lines are calculated in MFFRST by using default input operating parameters. For example, for the chromium plating tank in the hard chromium electroplating line, the default input data are: tank surface area of 20 square feet, chromium concentration of 160 grams/liter, current density of 1.5 amperes/sq.in., cathode efficiency of 15%, and a ventilation rate of 340 cubic feet per minute/square foot of tank surface area (or 6,800 cubic feet per minute for the default 20 sq.ft. tank). In addition, default control efficiencies are given for 12 types of emission controls (e.g., a packed bed scrubber is estimated to be 99.27% efficient).

MFFRST also allows the user to design his/her own metal finishing line (i.e., change the number and type of tanks in a line, as compared to the default line), and/or change any of the default input operating parameters (e.g., the user may have a 40 sq.ft. tank instead of the default 20 sq.ft. tank) or emission control efficiencies.

For testing MFFRST, EPA compared actual emissions sampling data for chromium emissions from chromium electroplating tanks from 14 different hard chromium electroplating lines (Refs. 5 - 15) to predictions made by MFFRST. Table 1 summarizes the sampling data.

Most of the data are for controlled emissions only. However, the Hawker Pacific data also include emission results from uncontrolled emissions. All data are for total chromium emissions, except for the Department of Defense (DOD) data, which are hexavalent chromium. MFFRST conservatively assumes that all chromium emissions are in the form of hexavalent chromium. The emission controls used for each set of tests were a variety of scrubbers, HEPA filters, and mist eliminators, with a variety of different exhaust configurations. In addition to a scrubber, Kwikset also controlled its emissions with a fume suppressant. Canyon Precision Plating and Grinding used fume suppressants and polymer balls in addition to mist eliminators and a HEPA filter. Grant Piston Rings used a fume suppressant and polymer balls, as well as a scrubber. For the DOD electroplating facilities only uncontrolled emissions data were available. The types of emission controls are noted on Table 1, column 2.

As noted earlier, MFFRST input data for a hard chromium electroplating tank include the current density, tank surface area, chromium concentration, and cathode efficiency. Some of the tests in Table 1 gave data for chromium concentration and for tank surface area. None of the tests gave data for current density or for cathode efficiency. Where data were not supplied MFFRST used default data, which were noted above (current density equal to 1.5 amps/in^2, etc.).

Tank surface area (which is essentially determined by the size of the articles being electroplated) is used in MFFRST to calculate the rate of emission (in cubic feet per minute - cfm). For those tests where the surface area was given (9 controlled and 2 uncontrolled tests), MFFRST calculated the predicted ventilation rate. For those tests where ventilation rate was supplied, even if the surface area was also given, the measured ventilation rate was used instead of the predicted ventilation rate.

TABLE 1
CHROMIUM PLATING EMISSIONS VERIFICATION DATA

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Name of Facility (references in parenthesis)	**Air Pollution Control Device***	**Controlled Chromium Emissions (mg/day)**					**Bath Conc. (g/l Cr-t)**		**col.9/ col.8**	**Tank Surf. Area (sq.ft.)**	**Air Flow (1000 cfm)**		**col.13/ col.12**
		Predicted	**Actual**	**col.4/col.3**	**Log(Predicted)**	**Log(Actual)**	**Predicted**	**Actual**			**Predicted**	**Actual**	
Electronic	ME,	6.30E+01	6.14E+02	9.7	1.80	2.79			166.0	56.4	22.0	0.39	Chrome
Accu Crome Plating (6)	Scrubber	5.59E+03	4.05E+03	0.7	3.75	3.61				89.0	30.3	3.5	0.12
Canyon Precision Plat.&Grind. (7)	PB, FS, ME, HEPA	2.18E+01	8.20E+01	3.8	1.34	1.91	160	105	0.66	116.0	39.4	11.6	0.29
Multichrome (8)	Scrubber	8.43E+02	1.86E+03	2.2	2.93	3.27				118.0	40.1	9.4	0.23
Grant Piston Rings (9)	PB, FS, Scrubber	2.15E+02	9.12E+02	4.2	2.33	2.96				18.9	6.4	2.4	0.38
US Chrome Corp. of California (10)	ME, HEPA	3.40E+01	7.40E+01	2.2	1.53	1.87				117.0	39.8	12.0	0.30
Chrome Crankshaft (Scrubber#3) (11)	Scrub., ME, HEPA	2.90E+01	1.42E+02	4.9	1.46	2.15	160	132	0.83	40.0	13.6	12.2	0.90
Chrome Crankshaft (Scrubber#1) (12)	Scrub., ME, HEPA	3.20E+01	3.00E+02	9.4	1.51	2.48	160	164	1.03	40.0	13.6	11.0	0.81
Hawker Pacific (low load) (13)	Scrubber	5.94E+03	< 487	<0.082	3.77	2.69	160	109	0.68	60.0	20.4	5.4	0.26
Hawker Pacific (high load) (13)	Scrubber	5.46E+01	<1,100	<0.20	3.74	3.04	160	104	0.65				
Kwikset (14)	FS	5.10E+01	6.83E+02	13.4	1.71	2.83	160	150	0.94	73.5	25.0	16.0	0.64
Kwikset (14)	FS, Scrubber	5.80E+00	1.03E+02	17.8	0.76	2.01							
		Aver. of Actual / Predict.=		**5.7**			**Aver. % of Predic. for Cr Conc. =**		**80**		**Aver. % of Pred. for Air Flow =**		**43**
		UNcontrolled Chromium Emissions (mg/day)											
Hawker Pacific (13)													
Tank 2 - (low load)	N/A	2.64E+05	1.41E+05	0.53	5.42	5.15	160	109	0.68			1.8	
Tank 4 - (low load)	N/A	1.65E+05	8.45E+03	0.05	5.22	3.93	160	109	0.68			1.1	
Tank 5 - (low load)	N/A	2.49E+05	3.19E+04	0.13	5.40	4.50	160	109	0.68			1.7	
Tank 2 - (high load)	N/A	2.32E+05	2.71E+06	11.7	5.37	6.43	160	104	0.65			1.6	
Tank 4 - (high load)	N/A	1.45E+05	1.84E+05	1.3	5.16	5.27	160	104	0.65			1.0	
Tank 5 - (high load)	N/A	2.15E+05	2.21E+05	1.0	5.33	5.34	160	104	0.65			1.5	
DOD Facility 1 (averg	N/A	7.51E+05	5.28E+05	0.70	5.88	5.72	160	105	0.66	21.0	7.1	5.2	0.73. of
DOD Facility 2 (averg	N/A	2.82E+06	1.16E+05	0.04	6.45	5.06	160	115	0.72	26.8	9.1	7.4	0.81. of

MFFRST Emissions Predictions Versus Actual Field Testing

Table 1 compares several MFFRST-predicted data versus actual data, where actual data were available. Specifically:

1. Plating bath concentrations (grams/liter) of chromium (columns 8 through 10). These columns compare the actual chromium concentrations with the MFFRST default concentration.
2. Tank exhaust rate in thousand cubic feet per minute (cfm) (column 12 through 14). These columns compare the actual ventilation with what MFFRST would predict given the tank surface area.
3. Rates of emission (milligrams/day) for both controlled and uncontrolled emissions (columns 3 through 5). The emission rates are the principal output from the tank emission algorithms in MFFRST.

The top section of Table 1 is for controlled emissions (the method of control being shown in column 2). The bottom section is for uncontrolled emissions.

The predicted ventilation rates are compared to the actual rates in columns 12 and 13 respectively. The ratios of the two rates are displayed in column 14, showing that on the average, for those tests with emission controls, the actual emission volumes were only 43% of those predicted by MFFRST. If these test data are representative, it would mean that MFFRST could be overpredicting chemical emissions by a factor of about 2.3 (the inverse of 0.43), since MFFRST calculates mass emissions rates as directly proportional to ventilation rate.

Only two uncontrolled emissions tests, for the DOD facilities, supplied data for surface area and ventilation rate. In those cases, the actual ventilation rates were 73% and 81% of the predicted rate.

MFFRST default electroplating bath concentrations are compared with actual test concentrations (columns 8 and 9 respectively). The ratios of the actual versus the default concentrations are displayed in column 10, showing that on the average for those tests with emission controls, the actual chromium concentrations were about 80% of those supplied as default values in MFFRST. This too would suggest that MFFRST could be slightly overpredicting emissions by a factor of about 1.25, since MFFRST calculates emissions as directly proportional to bath concentration.

Both DOD uncontrolled emissions tests supplied plating bath concentration. (Actually, all sets of uncontrolled emissions tests supplied bath concentration data, but the set from Hawker Pacific is the same as for their controlled emissions data.) The data from the DOD tests showed actual bath concentrations of 66% and 72% of the MFFRST default parameter assignment.

After supplying the input data and/or using the model defaults, as described above, MFFRST predicts emissions in units of mass per day. It is important to note that the input parameter values taken from the emissions tests for this model testing exercise include the measured bath concentration and ventilation air flow (which are shown in columns 9 and 13 of Table 1). In other words, the maximum amount of provided information useful for developing the independent model inputs to MFFRST were used, and where the information was unavailable, MFFRST default values were used. In this way, the capability of MFFRST to predict emission rates is evaluated by comparing the predicted emission rates with the measured emission rates. Uncontrolled emissions are predicted as well as emissions that are controlled with a variety of air pollution control devices. Table 1 shows a comparison of these predicted emissions to actual emissions in columns 3 and 4 respectively. Twelve complete sets of predicted versus actual controlled emissions data are available. It should be noted that, due to analytical sensitivity, the set from Hawker Pacific has only "less than" values for their actual controlled emissions. These "less than" values have been used as though they did not have the "less than" symbol. The ratio of actual to predicted emissions is given in column 5. The average of all the ratios is 5.7, suggesting that MFFRST underpredicts emissions by a factor of well under 10, not even one order of magnitude.

Uncontrolled emission data from Hawker Pacific (bottom of Table 1) are difficult to evaluate because various current densities were used in the three low-load tests used, but these current densities were not stated. Likewise, three different current densities were used in the high-load tests, and again they were not stated. To determine emissions, MFFRST could only use the one default current density input value of 1.5 amp/in^2 (for all 6 tests), which of course would result in only one predicted output value. The predicted values shown in Table 1 were derived from this default current density input value, and using actual ventilation rates and plating bath chromium concentrations given for each of the tests.

For the two DOD uncontrolled emissions tests, the ratios of actual to predicted emissions are 0.70 and 0.04 respectively, an average overprediction of about 2.7.

Theoretically, it should be much easier to predict uncontrolled emission using MFFRST as opposed to controlled emissions. This is because there are almost an infinite number of air pollution control scrubber and mist eliminator designs, as well as infinite combinations of air pollution control devices and combinations of devices. Further, there are numerous fume suppressants, and concentrations of suppressants, plus numerous sizes and distribution densities for polymer balls. To complicate matters further, there is no way of knowing the current state of maintenance of any control device. MFFRST limits its controlled emission predictions to 12 specific air pollution control devices and combination of devices, for which it assumes control efficiencies based on literature information. However, the MFFRST user may override the 12 choices and enter any numerical control efficiency.

As an example of the diversity of air pollution control devices, we note that MFFRST has a "packed bed scrubber" (PBS) default control efficiency of 99.3%. Hawker Pacific's "PBS" has a control efficiency of 99.2% when used at "low load", and 99.9% when used at high load, based on the data in Table 1. (Average of low load uncontrolled values is 6.0 x 10^4 mg/day versus the low load controlled value of 487 mg/day. Average high load uncontrolled values is 1.0 x 10^6 mg/day versus the high load controlled value of 1,100 mg/day.)

Data Correlation

To assist in determining the ability of MFFRST to accurately predict controlled emissions, the actual versus predicted data from Table 1 were plotted. Because the predicted and actual data span several orders of magnitude (5.80×10^0 to 5.94×10^3 mg/day), the logarithms of the data were calculated. They are shown in columns 6 and 7 of Table 1 for the predicted and actual data respectively. The plot of these logarithmic data are shown on Figure 1. The log data were subject to a regression analysis, and plotted on the graph, as shown. The regression has a correlation coefficient of 0.77 (and an r^2 value of 0.59). As shown on Figure 1, the regression analysis indicates that the best-fit equation relating predicted (p) to actual (a) data is:

$$\log(p) = 1.40(\log(a)) - 1.65$$

or

$$\log(a) = 0.71(\log(p)) + 1.18$$

For reference, Figure 1 also contains a line showing what the plot would look like if the predicted values equaled the actual values. The predicted controlled emissions appear to be less than an order of magnitude below actual emissions (as can be seen by comparing the two lines on Figure 1). This difference could easily be explained by merely having an air pollution control device that is only 99.5 percent efficient instead of one that is predicted to be 99.95 percent efficient. Such a drop in efficiency might be the result of less than optimum operating and/or maintenance practices. Or, the difference might be a result of not having the myriad combinations and permutations of control devices available in MFFRST.

Conclusions

These results are very encouraging for use of MFFRST in a predictive mode. The actual values for the bath concentration of chromium average 80% of the default value, and the actual value for the tank ventilation flow rates are about 43% of the default value. Most importantly, the predicted air concentrations of chromium are within a factor of 5.7 of measured air concentrations of chromium. In general, this is a good modeling result, but it has to be considered particularly successful given the point made just above regarding pollution control device - the difference could be explained by an actual control efficiency of 99.5% instead of a modeled control efficiency of 99.95%.

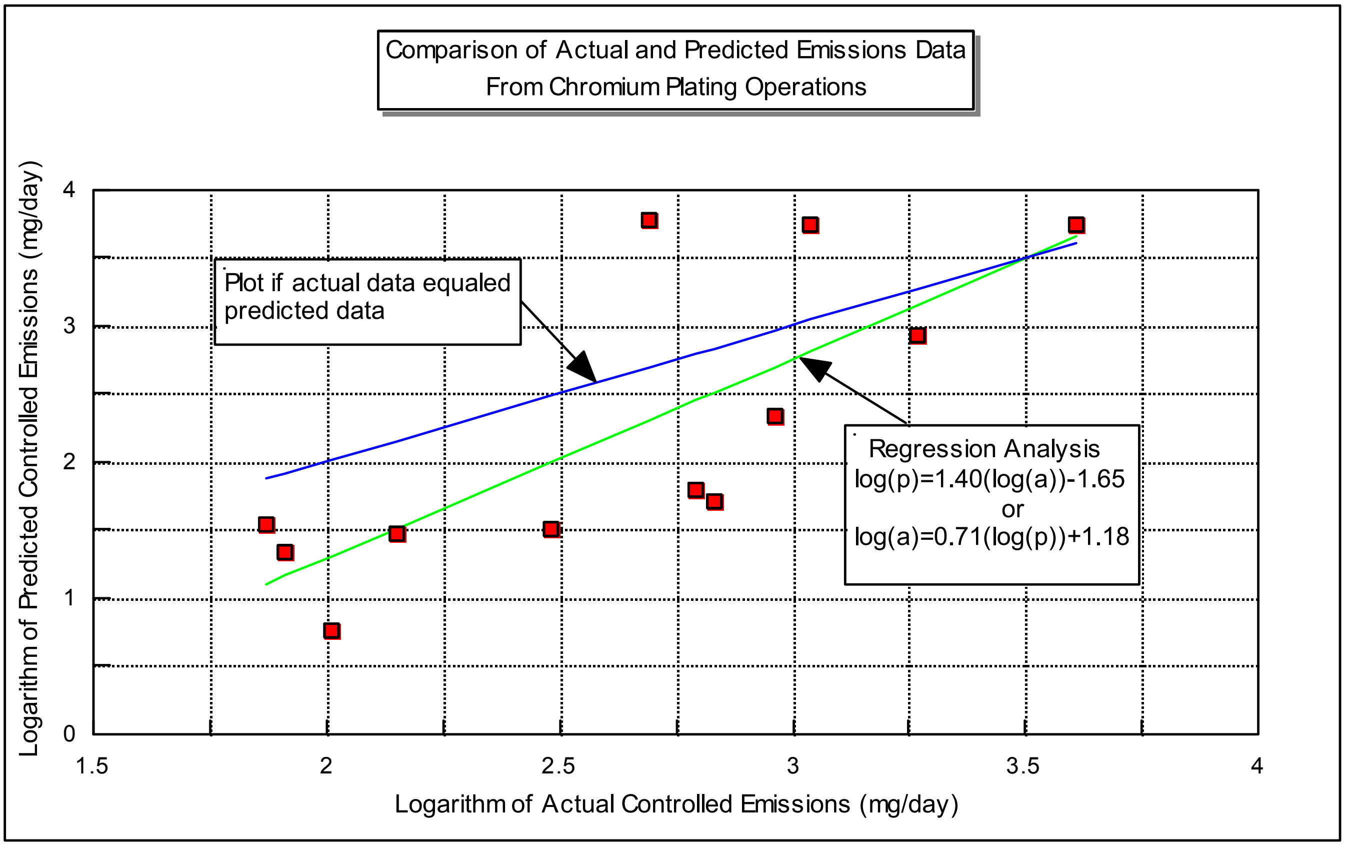

Figure 1. *Comparison of Actual and Predicted Emissions Data from Chromium Plating Operations.*

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