STATE OF CALIFORNIA

PETE WILSON, Governor

AIR RESOURCES BOARD
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August 27, 1993

Craig Anderson
San Diego Air Pollution Control District
9150 Chesapeake Drive
San Diego, CA 92123-1096

Dear Mr. Anderson:

Air Toxics Emission from Welding Operations

Per your request, we have reviewed the San Diego Air Pollution Control District's method for estimating metal emissions from welding operations and several references on metal emissions from welding operations that you previously sent us. In general, the District has taken a very positive approach in proposing an emission factor to estimate metal emissions from arc welding operations. Depending on the size of operations, these processes can result in significant metal emissions. Your method is useful in calculating a conservative estimate of metal emissions from metal arc welding processes when there are no data regarding a facility's specific types of welding operations.

I also asked Chris Nguyen of my staff to review the scientific literature for additional references on arc metal welding processes and their associated emissions with the intent of refining emission estimation techniques for these processes. Chris has reviewed data from the American Welding Society study and a paper submitted at the 86th Annual Meeting & Exhibition of the Air & Waste Management Association in 1993 (AWS, 1979; and AWMA, 1993). We are recommending two methods for estimating emissions from metal arc welding operations when more facility specific data are available.

As you know, metal emissions from arc welding operations depend on the types of welding processes (e.g. Shield Metal Arc Welding and Gas Metal Arc Welding) and the types of electrodes used. Fume generation rate (FGR) is a major component of the metal emissions from metal arc welding. Major factors affecting the fume generation rate include the type of welding processes, metal contents in the electrode, voltage and current, and the shielding gas applied during the welding operations. Thus, a single emission factor will not accurately characterize all emissions from a facility with a variety of welding operations.

The basic equation for calculating emission factors from welding processes is provided below:

$$EF = FGR * C_i \qquad (1)$$

Where

EF : Emission factor, unit mass of metal/unit mass of electrode
FGR : Fume generation rate, dimensionless
C_i : Concentration of metal in the electrode, unit mass of metal per unit mass of electrode

Method 1 - When the type of welding is known but the type of electrode is not:

For the purpose of establishing a general method to estimate metal emissions from arc welding and to be conservative, we recommend using a FGR of 0.02 for Shield Metal Arc Welding (SMAW) and a FGR of 0.01 for Gas Metal Arc Welding (GMAW), when data on these types of welding processes are available. These values are based upon reviewed data for FGRs for these two welding operations. Data on other types of welding operations such as Flux-Cored Arc Welding and Gas Tungsten-Arc Welding are extremely limited. However, based on limited data, the FGR for Flux-Cored Arc Welding is similar to SMAW and the FGR for Gas Tungsten-Arc Welding is similar to GMAW.

Please note that for metals with relatively high melting points, such as chromium and nickel, using the concentration of metal in the electrode, C_i, to estimate emissions will probably result in a conservative estimate of emissions. Conversely, it may underestimate emissions for low melting point metals such as cadmium.

Method 2 - When the type of welding and electrode are known:

When more specific data are available on the welding operations, we recommend using emission factors based on the data in the references we have reviewed. Tables 1 and 2 summarize specific metal emission factors for different types of electrodes. The fume generation rates (FGRs) in lbs of fume per 100 lbs of electrode and the concentrations of metals in the fume were published in the AWS and AWMA studies. The chromium content of the electrode and the hexavalent chromium concentrations in the fume were AWS unpublished data and were taken from a National Steel and Shipbuilding Company's (NASSCO) report. Thus, in Table 1, chromium emission factors were calculated by ARB staff from published data. Hexavalent chromium emission factors were calculated from unpublished data. From both AWS and AWMA studies, the currents applied during the tests range from 130 amperes to 230 amperes for SMAW and from 165 amperes to 345 amperes for GMAW. These ranges were considered to be typical operating conditions in metal arc welding operations. Note that data in Table 1 show the averaged percentages of hexavalent chromium to total chromium for the SMAW is approximately 63 percent while it is approximately 5 percent for GMAW.

Additionally, data in Table 1 and 2 show that the concentrations of metals in the fume are relatively higher for electrodes with higher metal contents. Also, we believe it is reasonable to assume that the concentrations of the metal in the fume are relatively higher for lower melting point metals.

If you have any questions regarding this letter, please contact Chris Nguyen of my staff at (916) 322-7141.

Sincerely,

Richard Bode, Manager
Special Pollutants
Emission Inventory Section
Technical Support Division

Attachment
cc: Chris Nguyen

TABLE 1: SUMMARY OF CHROMIUM EMISSION FACTORS

Source	Welding Process	Rod Type	%Cr in elect	lbs fume per 100 lbs elect	%CR in fume	%Cr6 in fume	%Cr6/Cr in fume	EMFAC (lbs metal/lbs electrode) %Cr	EMFAC (lbs metal/lbs electrode) %Cr6
AWS (1979)	SMAW	E316-15	18.7	0.71	5.8	3.949	68.08	4.12E-04	2.80E-04
"	"	E316-16	18.7	0 60	6.5	3.949	60.75	3.90E-04	2.37E-04
"	"	E9018B3(17)	N/A	1.22	1.6	-	-	1 95E-04	-
"	"	Inconel 625	21.5	0.70	5.9	3.949	66.93	4.13E-04	2.76E-04
"	"	Haynes C-276	16.0	0.98	2.5	-	-	2.45E-04	-
"	"	Haynes 25	20.0	0.65	6.9	3.949	57.23	4.49E-04	2.57E-04
AWMA (1993)	"	E308-16	<15	0.64	6.2	-	-	3.97E-04	-
AWS (1979)	"	E8018C3(14)	N/A	1.30	0.1	-	-	1.30E-05	-
AWMA (1993)	"	E6010(A)	N/A	2.27	0.018	-	-	4.09E-06	-
"	"	E6010(B)	N/A	2.05	0.011	-	-	2.26E-06	-
"	"	E6011	N/A	3.84	0.012	-	-	4.61E-06	-
"	"	E6013	N/A	1.36	0.03	-	-	4.08E-06	-
"	"	E7018	0.03	1.57	0.024	-	-	3.77E-06	-

AVERAGE OF THE ABOVE VALUES 63.25

Source	Welding Process	Rod Type	%Cr in elect	lbs fume per 100 lbs elect	%CR in fume	%Cr6 in fume	%Cr6/Cr in fume	EMFAC (lbs metal/lbs electrode) %Cr	EMFAC (lbs metal/lbs electrode) %Cr6
AWS (1979)	GMAW	316-L	18.7	0.84	12.5	0.62	4.96	1.05E-03	5.21E-05
"	"	Inconel 625	21.5	0.08	15.4	0.62	4.03	1.23E-04	4.96E-06
"	"	Haynes C-276	16.0	0.69	8.2	0.62	7.56	5.66E-04	4.28E-05
"	"	Haynes 25	20	0.13	14.9	0.62	4.16	1.94E-04	8.06E-06
		ERNiCu-7	N/A	0.20	0.01	-	-	2.00E-07	-
AWMA (1993)	"	E308LSi	20	0.54	6.0	-	-	3.24E-04	-
"	"	E70S-3	N/A	0.86	0.02	-	-	1.72E-06	-
"	"	E70S-6	N/A	0.79	0.015	-	-	1.19E-06	-

AVERAGE OF THE ABOVE VALUES 5.18

Notes:

SMAW : Shield Metal Arc Welding

GMAC : Gas Metal Arc Welding

%Cr in the electrode and %Cr6 in fume were AWS unpublised data obtained from a NASSCO report.

With the exception of electrode 316-L, there seems to be a trend in chromium emission factors. The higher the chromium content in the electrode, the higher the chromium emission factors.

1. AWS (1979). Fume and Gases in the Welding Environment. Edited by Speiht, F.Y. et al (1979). American Welding Society, Miami, Fl.

2. AWMA (1993). Emission Factors for Arc Welding. Gerstle, R.W. et al. Presented at the 86th Annual Meeting & Exhibition of the Air & Waste Management Association. Denver, Co.

TABLE 2: SUMMARY OF OTHER METALS EMISSION FACTORS

Source	Welding Process	Rod Type	lbs fume per 100 lbs elect	%Mn in fume	%Ni in fume	%Cu in fume	EMFAC (lbs metal/lbs electrode) Mn	Ni	Cu
AWS (1979)	SMAW	E6010(11)	3.56	3.4	-	-	1.21E-03	-	-
"	"	E6010(1)	2.48	3.0	-	-	7.44E-04	-	-
"	"	E6010(2)	2.19	3.4	-	-	7.45E-04	-	-
"	"	E6013(3)	1.80	4.1	-	-	7.38E-04	-	-
"	"	E6013(4)	1.65	5.1	-	-	8.42E-04	-	-
"	"	E6013(6)	1.01	5.5	-	-	5.56E-04	-	-
"	"	E7018(5)	1.60	4.5	-	-	7.20E-04	-	-
"	"	E7018(10)	1.54	3.6	-	-	5.54E-04	-	-
"	"	E7018(12)	1.64	4.1	-	-	6.72E-04	-	-
"	"	E7024(7)	0.67	5.3	-	-	3.55E-04	-	-
"	"	E7024(8)	0.67	5.6	-	-	3.75E-04	-	-
"	"	E7024(9)	0.63	7.8	-	-	4.91E-04	-	-
"	"	E8018(14)	1.30	7.2	0.3	-	9.36E-04	3.90E-05	-
"	"	E9018(17)	1.22	5.9	0.1	-	7.20E-04	1.22E-05	-
"	"	E316-15(22)	0.73	7.7	1.1	-	5.62E-04	8.03E-05	-
"	"	E316-16(20)	0.73	8.8	1.5	-	6.42E-04	1.10E-04	-
"	"	E410-16(21)	0.96	5.2	0.1	-	4.99E-04	9.60E-06	-
"	"	ENi-CI	1.22	0.3	6.9	0.10	3.66E-05	8.42E-04	1.22E-05
"	"	ENiCu-2	0.74	2.1	4.2	6.20	1.55E-04	3.11E-04	4.59E-04
"	"	Inconel 625	0.70	-	4.6	0.70	-	3.22E-04	4.90E-05
"	"	Haynes C-276	0.98	0.3	1.1	-	2.94E-05	1.08E-04	-
"	"	Haynes 25	0.65	4.6	1.8	-	2.99E-04	1.17E-04	-
AWMA (1993)	"	E6010(A)	2.27	3.9	0.026	0.26	8.85E-04	5.90E-06	5.90E-05
"	"	E6010(B)	2.05	4.4	0.008	0.033	9.02E-04	1.64E-06	6.77E-06
"	"	E6011	3.84	2.6	0.014	0.014	9.98E-04	5.38E-06	5.38E-06
"	"	E6013	1.36	4.1	0.018	0.16	5.58E-04	2.45E-06	2.18E-05
"	"	E308-16	0.64	3.8	0.82	0.10	2.43E-04	5.25E-05	6.40E-06
"	"	E7018	1.57	3.9	0.012	0.072	6.12E-04	1.88E-06	1.13E-05

AVERAGE OF THE ABOVE VALUES: 1.44

Source	Welding Process	Rod Type	lbs fume per 100 lbs elect	%Mn in fume	%Ni in fume	%Cu in fume	EMFAC (lbs metal/lbs electrode) Mn	Ni	Cu
AWS (1979)	GMAW	E70S-3(A2 02)	0.53	5.57	-	1.29	2.95E-04	-	6.84E-05
"	"	E70S-3(A9 CO2)	0.73	4.6	-	0.99	3.36E-04	-	7.23E-05
"	"	E70S-3(CO2)	0.32	5.5	-	1.2	1.76E-04	-	3.84E-05
"	"	E70S5	0.41	5.8	-	1.75	2.38E-04	-	7.18E-05
"	"	Inconel 625	0.08	-	27.2	0.69	-	2.18E-04	5.52E-06
"	"	Haynes C-276	0.69	1.0	32.5	-	-	2.24E-03	-
"	"	Haynes 25	0.13	15.4	7.1	-	-	9.23E-05	-
"	"	ERCuAl-A2	0.79	-	-	70.5	-	-	5.57E-03
"	"	ERCu	0.47	-	-	66	-	-	3.10E-03
"	"	ERNiCu-7	0.20	1.1	22.1	44.4	2.20E-05	4.42E-04	8.88E-04
AWMA (1993)	"	E70S-3	0.86	6.7	0.0072	0.65	5.76E-04	6.19E-07	5.59E-05
"	"	E70S-6	0.79	10.4	0.014	0.44	8.22E-04	1.11E-06	3.48E-05
"	"	E308LSi	0.54	6.4	3.4	0.5	3.46E-04	1.84E-04	2.70E-05

AVERAGE OF THE ABOVE VALUES: 0.53

1. AWS (1979). Fume and Gases in the Welding Environment. Edited by Speiht, F.Y. et al (1979). American Welding Society, Miami, Fl.
2. AWMA (1993). Emission Factors for Arc Welding. Gerstle, R.W. et al. Presented at the 86th Annual Meeting & Exhibition of the Air & Waste Management Association. Denver, Co.
3. Average of the FGR for GMAW also includes data from electrode 316-L in Table 1.