EASTERN RESEARCH GROUP, INC.

MEMORANDUM

TO: Jim Eddinger, U.S. Environmental Protection Agency, OAQPS (C439-01)

FROM: Roy Oommen, Eastern Research Group (ERG), Morrisville

DATE: October 2002

SUBJECT: Methodology for Estimating Control Costs for the Industrial, Commercial, and Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants

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1.0 INTRODUCTION

The purpose of this memorandum is to document the algorithms and inputs used to estimate capital and annual costs of control options considered for the industrial, commercial, and institutional boilers and process heaters NESHAP. Cost impacts were calculated for add-on control technologies and operating practices. The costs to comply with testing and monitoring requirements of the proposed rule were also discussed. The following sections are included within this memorandum:

2.0 Cost Algorithms and Inputs for Add-on Technologies
3.0 Cost Algorithms and Inputs for Operating Practices
4.0 Testing and Monitoring Costs
5.0 References
Appendices - Detailed Cost Algorithms and Inputs

2.0 COST ALGORITHMS AND INPUTS FOR ADD-ON CONTROL TECHNOLOGIES

Add-on control techniques are those technologies that are applied to the vent gas stream of the boiler or process heater to reduce emissions. The boiler and process heaters population database includes information on all control techniques that are applied to industrial, commercial, institutional boilers and process heaters. Generally, they can be grouped into PM control or acid gas control. The most common technologies, and the ones analyzed for the impacts analysis, include fabric filters, ESP's, packed scrubbers, venturi scrubbers, and spray dryers. In addition, when add-on technologies are used, the cost of ductwork and associated equipment also needed to be considered. The discussion of the algorithms used to calculate capital and annual costs of these devices and the inputs to the algorithms are presented in this section.

Components of capital cost incorporated into the algorithms include:

- purchased equipment cost of the primary device and auxiliary equipment,
- instrumentation,
- sales tax and freight, and
- installation costs. Installation costs include foundations and support, handling and erection, electrical, piping, insulation, and painting, engineering, construction and field expenses, contractor fees, start-up, performance tests, and contingencies.

Components of annual cost include:

- raw materials (lime, caustic, etc.)
- utilities (electricity, fuel, steam, air, water),
- waste treatment and disposal,
- labor (operating, supervisory, maintenance),
- maintenance materials,
- replacement parts,
- overhead,
- property taxes,
- insurance,

- administration charges, and
- capital recovery costs.

For this analysis, costs were estimated in 1998 dollars. Capital recovery was calculated assuming 7 percent interest rate over the life of the equipment.

The cost algorithms for the control devices were obtained from previous EPA studies, primarily the EPA's OAQPS Control Cost Manual (OCCM).[1] The OCCM contains the detailed cost procedures and algorithms for each control device. The appendices include cost algorithms reduced/simplified to basic equations from the EPA studies. Inputs for the algorithms used in the impacts analysis are also presented. The inputs associated with different model units, such as flue flow rate, flue gas temperature, and moisture content, are included in the model units memorandum.

2.1 Fabric filter

The algorithms used to estimate capital and annual costs of fabric filters were obtained from Chapter 5 of the OCCM.[1] Algorithms were provided for 4 types of fabric filters: shaker, reversed air, pulse-jet modular, and pulse-jet common. The cost algorithms for estimating capital costs reduced to basic equations for each are provided in Appendix A-1. For the cost calculations, the algorithms and inputs for the pulse-jet common were used as representative of typical fabric filters. The only equipment costed are the fabric filters themselves. Capital costs are based on the gross cloth area of the fabric filter, which is a function of the gas inlet flow rate. Algorithms for calculating annual costs are provided in Appendix A-2. Annual costs include dust disposal, electricity, maintenance, labor, bag replacement, maintenance labor, compressed air, capital recovery costs, overhead, administrative, property taxes, and insurance. Appendix A-3 presents the values for the inputs used in this analysis and the reasons for their use.

2.2 Electrostatic Precipitator

The algorithms used to estimate capital and annual costs of ESPs were obtained from Chapter 6 of the OCCM.[1] Capital costs are based on the total collection plate area, which is calculated from the gas inlet flow rate and the required removal efficiency. The cost algorithms for estimating capital costs of ESPs reduced to basic equations are provided in Appendix B-1.

The only equipment costed are the ESP's themselves. Algorithms for calculating annual costs are provided in Appendix B-2. Annual costs include dust disposal, electricity, maintenance, labor, maintenance labor, capital recovery costs, overhead, administrative, property taxes, and insurance. Appendix B-3 presents the values for the inputs used in this analysis and the reasons for their use.

2.3 Venturi Scrubber

The algorithms used to estimate capital and annual costs of fabric filters were obtained from cost algorithms provided on EPA's website (http://www.epa.gov/ttncatc1/cica/cicaeng.html).[2] Capital costs include the cost of the venturi scrubber and a pump to provide motive force for the solvent. Capital costs are based on the gas flow rate and saturation temperature of the gas-solvent. The cost algorithms for estimating capital costs of each piece of equipment were reduced to basic equations in Appendix C-1. The cost algorithms for estimating annual costs were reduced to basic equations in Appendix C-2. Annual costs include wastewater disposal, solvent, electricity, maintenance, labor, maintenance labor, capital recovery costs, overhead, administrative, property taxes, and insurance. Appendix C-3 presents the values for the inputs used in this analysis and the reasons for their use.

2.4 Packed Bed Scrubber

The algorithms used to estimate capital and annual costs of packed bed scrubbers were obtained from Chapter 8 of the OCCM.[1] The capital costs are comprised of the scrubber tower, packing, and pumps. Capital costs are based primarily on gas flow rate and removal efficiency. The cost algorithms for estimating capital costs of packed scrubber equipment reduced to their basic equations for each are provided in Appendix D-1. The cost algorithms for estimating annual costs of packed scrubbers are provided in Appendix D-2 Annual costs include caustic, wastewater disposal, water, electricity, maintenance, labor, maintenance labor, capital recovery costs, overhead, administrative, property taxes, and insurance. Appendix D-3 presents the values for the inputs used in this analysis and the reasons for their use.

2.5 Spray Dryer

The algorithms used to estimate capital and annual costs of spray dryers were obtained from a previous EPA study on controls for municipal waste combustors.[3] Capital costs include the cost of the spray dryer and pumps. Capital costs are based on the gas flow rate. The cost algorithms for estimating capital costs of spray dryer equipment reduced to basic equations are provided in Appendix E-1. The cost algorithms for estimating annual costs for spray dryers are provided in Appendix E-2. Annual costs include lime, water, electricity, maintenance, labor, maintenance labor, capital recovery costs, overhead, administrative, property taxes, and insurance. Appendix E-3 presents the values for the inputs used in this analysis and the reasons for their use.

2.6 <u>Ductwork</u>

The algorithms used to estimate capital and annual costs of ductwork were obtained from Chapter 10 of the OCCM.[1] Capital costs include 500 feet of ductwork, elbows, and fans. The 500 feet of ductwork was based on engineering judgement and previous experience on the distance between emission points and control devices in chemical facilities and the availability of space for retrofitting controls. Costs are based on ductwork diameter, which is calculated from the gas flow rate. The cost algorithms for estimating capital costs and annual costs reduced to basic equations are provided in Appendix F-1. Annual costs include electricity, maintenance, maintenance labor, capital recovery costs, overhead, administrative, property taxes, and insurance. Required inputs to the ductwork algorithms are provided in the input tables provided in Appendices A-3, B-3, C-3, D-3, and E-3.

3.0 GOOD COMBUSTION PRACTICES

Few sources in the population database specifically reported using good combustion practices (GCP). Boilers and process heaters within each subcategory might use any of a wide variety of different work practices, depending on the characteristics of the individual unit.

Consequently, any uniform requirements or set of work practices that would meaningfully reflect the use of good combustion practices, or that could be meaningfully implemented across any subcategory of boilers and process heaters could not be identified.

Additionally, few of the GCP’s have been documented to reduce organic HAP emissions, and they could not be considered in the MACT analysis. One GCP that may effect organic HAP emissions is maintaining CO emission levels. CO is generally an indicator of incomplete combustion because CO will burn to carbon dioxide if adequate oxygen is available. Controlling CO emissions is a mechanism for ensuring combustion efficiency, and therefore may be viewed as a kind of GCP. [4]

Capital and annual costs for CO monitoring are presented in Appendix G. The costing information was obtained from a previous EPA study for medical waste incinerators.[5] Capital costs are comprised of the initial cost of the equipment. Annual costs include operating and maintenance costs, annual and quarterly checks, recordkeeping and reporting, taxes, insurance, administrative, and capital recovery costs. Capital recovery was calculated assuming an equipment life of 20 years and an interest rate of 7 percent.

4.0 TESTING AND MONITORING COSTS

The proposed industrial, commercial, and institutional boiler and process heater rule includes emission limits for HCl, PM, metallic HAP, and mercury and requires owners or operators to demonstrate compliance on an annual basis. Additionally, the rule allows sources to meet requirements by monitoring fuel content instead of emissions. Consequently, testing and monitoring costs of meeting the standards were incorporated into the cost estimates. Capital and annual costs for testing include stack tests for PM, HCl, and metals for fossil fuels, and materials and fuel analysis for biomass. Monitoring costs are included for opacity monitoring, and scrubber parametric monitoring. Monitoring costs include the capital cost of monitoring equipment, and the annual costs of capital recovery assuming the initial capital investment is annualized over a 20 year period at 7 percent interest. Annual monitoring costs also include operation and maintenance as well as other additional costs. Appendix G includes these costs. Information used to estimate testing and monitoring costs were obtained from a previous EPA study on medical waste incinerators.[5]

5.0 REFERENCES

1. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *OAQPS Control Cost Manual* Fifth Edition, EPA 453/B-96-001, Research Triangle Park, NC. February, 1996.

2. EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html

3. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Municipal Waste Combustors - Background Information for Proposed Standards: Cost Procedures*, EPA 453/3-89-270, August 1989.

4. Petroleum Environmental Research Forum. Project 92-19. The Origin and Fate of Toxic Combustion Byproducts in Refinery Heaters and Boilers.

5. Memorandum from Thomas Holloway, Midwest Research Institute, to Rick Copland, U.S. Environmental Protection Agency, *Revised Testing and Monitoring Options and Costs for Medical Waste Incinerators (MWI's) - Methodology and Assumptions*. March 17, 1997.

Appendix A

Fabric Filter Costing Algorithms and Inputs

Appendix A-1. Algorithms for Fabric Filter Total Capital Investment
(From OAQPS Control Cost Mannual, Chapter 5, Fifth Edition)

$TCI_{ff} = 2.5606\ EC_{ff}$	TCI_{ff} = Total capital investment of ff, \$ EC_{ff} = equipment cost of ff, \$
Type Shaker $EC_{ff} = 37{,}465 + 24{,}567(M) + [7.466 + CF_{bag-shak} + 0.335(I) + 4.699(M)](GCA)(GN_{ratio})$ Reverse Air $EC_{ff} = 30{,}383 + 13{,}631(M) + [7.812 + CF_{bag-ra} + 5.27(M)](GCA)(GN_{ratio})$ -------- -------- -------- -- Pulse-jet modular $EC_{ff} = 47{,}220 + 3{,}000(I) + 24{,}250(M) + [7.323 + CF_{bag-pjm} + 2.079(I) + 6.738(M)](GCA) + EC_{cage}$ Pulse-jet common $EC_{ff} = 9{,}688 + 1{,}428(I) + 10{,}489(M) + [5.552 + CF_{bag-pjc} + 0.0931(I) + 4.54(M)](GCA) + EC_{cage}$	M = factor for stainless steel $CF_{bag-shak}$ = cost factor for shaker bag, \$/bag CF_{bag-ra} = cost factor for RA bag, \$/bag I = insulation factor GN_{ratio} = Gross/net area rato, see below $CF_{bag-pjm}$ = cost factor for pjm bag, \$/bag $CF_{bag-pjc}$ = cost factor for pjc bag, \$/bag GCA = gross cloth area, acfm/ft^2 EC_{cage} = equipment cost of cages, \$

Shaker and Reverse Air

$$GCA = \frac{(G_i)}{(GF_a)(GF_b)(GF_c)}$$

Pulse-jet

$$GCA = \frac{G_i}{2.878\ (GC_m)(GC_{ap})(T)^{-0.255}(I_l)^{-0.06021}(0.7471\ +\ \ln(D_{dm}))}$$

G_i = gas flow rate, acfm
GF_a = G/C ratio factor
GF_b = G/C ratio factor
GFc = G/C ratio factor
GC_m = G/C ratio for material
GC_{ap} = G/C ratio for application
T = temperature of gas stream, ºF
I_l = inlet loading of pollutant, gr/ft^3
D_{dm} = dust median diameter, microns

Pulse Jet

$$EC_{cage} = \left[\frac{GCA}{A_B} + 1\right]\ [26.897(S_1) + 0.2137(A_b)(S_1) + 9.441(S_2) + 0.165(A_b)(S_2)]$$

A_b = area per bag, ft^2
S_1 = stainless steel cage factor 1
S_2 = stainless steel cage factor 2

Shaker and Reverse Air

GCA (≥ (ft^2)	GN_{ratio}
1	2.00
4001	1.50
12001	1.25
24001	1.17
36001	1.125
48001	1.110
60001	1.100
72001	1.09
84001	1.08
96001	1.07
108001	1.06
132001	1.05
180001	1.04

Appendix A-2. Algorithms for Fabric Filter Total Annual Cost
(From OAQPS Control Cost Mannual, Chapter 5, Fifth Edition)

$TAC_{ff} = C_{fixed} + C_{variable}$	C_{fixed} = fixed annual cost, \$/yr $C_{variable}$ = variable annual cost, \$/yr
$C_{fixed} = C_{ovhd} + C_{adm} + C_{prop} + C_{ins} + C_{cr}$	C_{ovhd} = overhead cost, \$/yr C_{adm} = administrative cost, \$/yr C_{prop} = property tax, \$/yr C_{ins} = insurance, \$/yr C_{cr} = capital recovery, \$/yr
$C_{ovhd} = 0.6\ (C_{lab} + C_{main})$ $C_{adm} = 0.02\ (TCI_{ff})$ $C_{prop} = 0.01\ (TCI_{ff})$ $C_{ins} = 0.01\ (TCI_{ff})$ $C_{cr} = CRF_{ff}\ (TCI_{ff})$	C_{lab} = labor cost, \$/yr C_{main} = maintenance cost, \$/yr TCI_{ff} = total capital investment, \$ CRF_{ff} = capital rec factor esp
$CRF_{ff} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$ $CRF_{bag} = \frac{[i\ (1+i)^{n_{bag}}]}{[(1+i)^{n_{bag}} - 1]}$	i = interest rate, fraction n = life of equipment, yrs CRF_{bag} = capital recovery factor bags n_{bag} = bag life, yrs
$C_{variable} = C_{dd} + C_{main} + C_{lab} + C_e + C_{ca} + C_{br}$	C_{dd} = cost of dust disposal, \$/yr C_{main} = cost of maintenance mat&lab, \$/yr C_{lab} = cost of labor (op., sup, coord), \$/yr C_e = cost of electricity, \$/yr C_{ca} = cost of compressed air, \$/yr C_{br} = cost of bag replacement, \$/yr
$C_{dd} = 0.00000429\ (è)(CF_{dd})(I_l)(G_i)$ C_e = See electricity costing sheet $C_{main} = 0.25\ (CF_{ml})(M_f)(è)$ $C_{lab} = 0.14375\ (è)(CF_{lab})(O_f)$ <u>Shaker or Reverse air</u> $C_{br} = (CRF_{bag})(GCA)\ [0.0297\ (CF_{ml}) + 1.08\ (CF_{bag\ -s/ra})\ ]$ <u>Pulse Jet</u> $C_{ca} = 0.00012(G_i)(CF_{ca})(è)$ $C_{br} = (CRF_{bag})(GCA)\ [0.01485\ (CF_{ml}) + 1.08\ (CF_{bag-pj})\ ]$	G_i = inlet gas flow rate, acfm I_l = pollutant inlet loading, gr/ft^3 è = operating hours/year CF_{dds} = cost factor for dust disposal, \$/ton CF_{lab} = cost factor for labor, \$/hr CF_{ml} = cost factor for maint. labor, \$/hr O_f = operating factor for ff M_f = maintenance factor for ff CF_{ca} = cost factor for comp. air, \$/1000 scf $CF_{bag-s/ra}$ = cost factor for repl.bags, \$/ft^2 CF_{bag-pj} = cost factor for repl.bags, \$/ft^2 GCA = gross cloth area, acfm/ft^2

Electricity Cost -- FF

<u>Cost of electricity</u> $C_e = CF_{elec\text{-}ff} (E_{fan})$	C_e = electricty cost, $\$$/yr CF_{elec} = cost factor for electricy, $\$$/kw-hr E_{fan}= electricity for fan use, kw
<u>Fans</u> $E_{fan} = \dfrac{(0.000117)(G_i)(\text{è})(P_g)}{(\text{å}_f)}$ $P_g = P_{ff} + P_d$ $P_d = 0.136(1/D_d)^{1.18} (u_t/1000)^{1.8} (L/100) + (L)(N_e/L_D)(k)(u_t/4016)^2$ Shaker or Reverse air $P_{ff} = (r_D)(G_i / GCA) + (D_r)(I_l/7000) [G_i / GCA]^2 (F_T)$ Pulse Jet $P_{ff} = 6.08(G_i / GCA)(C_p)^{-0.65} + (D_r)(I_l/7000) [G_i / GCA]^2 (F_T)$	P_g = pressured drop of gas, in.H_2O P_d = pressure drop through duct, in.H_2O P_{ff} = pressure drop through ff, in H_2O G_i = Gas flow rate, acfm u_t = gas transport velocity, ft/min L = length of ductwork N_e/L_D = # of elbows per length of duct k = friction loss factor for elbow å_f = efficiency of fan D_d = diameter of duct, ft r_D = fabric residual drag, in. H_2O/fpm C_p = cleaning pressure, psig D_r = dust resistance, in.H2O/fpm/lb/ft2 F_T = filtration time, minutes GCA = gross cloth area, ft^2

Appendix A-3. Inputs for Fabric Filter Algorithms

Variable	Description	Value	Source
Common Defaults/Ductwork Defaults			
I	interest rate	0.07	Current EPA default value
Ne/LD	# of elbows per length of duct	0.02	OCCM Chapter 10 default
L	length of ductwork	500	Engineering judgement
ut	gas transport velocity, ft/min	3000	OCCM chapter 10 default values
DEFAULTS- TOTAL ANNUAL COST -- FABRIC FILTER			
n	life of equipment, yrs	20	OCCM Chapter 5 default
I_l	pollutant inlet loading, gr/ft3	4	Emissions test database
è	operating hours/year	8400	Engineering judgement
CF_{ml}	cost factor for maintenance labor, $/hr	20.28	Chemical Engineering Magazine for 1998
M_f	maintenance factor for ff	1	Engineering judgement
n_{bag}	bag life, years	2	OCCM Chapter 5 default
CF_{ca}	cost factor for compressed air, $/1000 scf	0.16	OCCM chapter 5 and EPA webpage algorithms (http://www.epa.gov/ttncatc1/cica/cicaeng.html)
C_{dd}	cost factor for dust disposal, $/ton	20	
CF_{lab}	cost factor for labor, $/hr	18.44	Chemical Engineering magazine for 1998
DEFAULTS - ELECTRICITY - FABRIC FILTER			
CF_{elec}	cost factor for electricy, $/kw-hr	0.06	Chemical Engineering magazine for 1998
k	friction loss factor for elbow	0.35	OCCM chapter 10 default
r_D	fabric residual drag, in. H2O/fpm	1.1	OCCM chapter 5 default
C_p	cleaning pressure, psig	100	
D_r	dust resistance, in.H2O/fpm/lb/ft2	15	
F_T	filtration time, minutes	10	
å_f	efficiency of fan	0.7	Engineering judgement
DEFAULTS - DUCTWORK - FABRIC FILTER			
a	fan coefficient	22.1	OCCM chapters 8 and 10 default
b	fan exponent	1.55	
D_d	fan diameter, inches	36.5	
n_duct	life of equipment, yrs	20	
DEFAULTS -TCI - FABRIC FILTER			
M	factor for stainless steel	0	Engineering judgement
$CF_{bag-shak}$	cost factor for shaker bag, $/bag	0.743	OCCM chapter 5 and EPA webpage algorithms (http://www.epa.gov/ttncatc1/cica/cicaeng.html)
CF_{bag-ra}	cost factor for reverse air bag, $/bag	0.743	
I	Insulation factor	1	
$CF_{bag-pjm}$	cost factor for pulse jet modular bag, $/bag	1.14	
$CF_{bag-pjc}$	cost factor for pulse jet common bag, $/bag	1.14	
GF_a	G/C ratio factor	2	
GF_b	G/C ratio factor	0.9	
GF_c	G/C ratio factor	1	
GF_m	G/C ratio for material	9	
GF_{ap}	G/C ratio for application	0.8	
D_{dm}	dust median diameter, microns	7	
A_b	area per bag, ft2	13.417	
S_1	stainless steel cage factor 1	0	Engineering judgement
S_2	stainless steel cage factor 2	1	Engineering judgement
FFType	S, RA, PJM or PJC types of fabric filters S = 1, RA = 2, PJM = 3, PJC = 4	4	Engineering judgement

Appendix B

Algorithms and Inputs for ESP's

Appendix B-1. Cost Algorithms for ESP Total Capital Investment (From chapter 6 of OCCM)

Case 1 = special add-ons (This is the Case that was costed out) $TCI_{esp} = 3.8326(m)(EC_{esp})$ Case 2 = no special add-ons $TCI_{esp} = 2.6432(m)(EC_{esp})$	TCI_{esp} = Total capital investment of esp, \$ m = factor to convert from FRP to other mat. EC_{esp} = equipment cost of esp, \$
TCP < 50,000 $EC_{esp} = 614.55\ (TCP)^{0.6276}$ TCP > or = 50,000 $EC_{esp} = 57.87\ (TCP)^{0.8431}$	TCP = total collection plate area, ft^2
$$TCP = \left(\frac{G_i}{1000}\right)\left(\frac{-508\ \ln(1-ç)}{M_v}\right)(SCA_{ra})$$	G_i = Gas flow rate, acfm ç = efficiency of scrubber M_v = PM migration velocity cm/s SCA_{ra} = spec. Collect. Area ratio, see below

ESP efficiency	Sections	SCA_{ra}
80.00 - 96.49	2	2.60
96.50 - 98.90	3	2.65
99.00 - 99.79	4	2.89
99.80 - 99.89	5	2.96
≥ 99.90	6	3.09

Appendix B-2. Cost Algorithms for EPS Total Annual Cost
(From chapter 6 of OCCM)

$TAC_{esp} = C_{fixed} + C_{variable}$	C_{fixed} = fixed annual cost, $/yr $C_{variable}$ = variable annual cost, $/yr
$C_{fixed} = C_{ovhd} + C_{adm} + C_{prop} + C_{ins} + C_{cr}$	C_{ovhd} = overhead cost, $/yr C_{adm} = administrative cost, $/yr C_{prop} = property tax, $/yr C_{ins} = insurance, $/yr C_{cr} = capital recovery, $/yr
$C_{ovhd} = 0.6\ (C_{lab} + C_{main})$ $C_{adm} = 0.02\ (TCI_{esp})$ $C_{prop} = 0.01\ (TCI_{esp})$ $C_{ins} = 0.01\ (TCI_{esp})$ $C_{cr} = CRF_{esp}\ (TCI_{esp})$	C_{lab} = labor cost, $/yr C_{main} = maintenance cost, $/yr TCI_{esp} = total capital investment, $ CRF_{esp} = capital rec factor esp
$CRF_{esp} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs
$C_{variable} = C_{dd} + C_{main} + C_{lab} + C_e$	C_{dd} = cost of dust disposal, $/yr C_{main} = cost of maintenance mat&lab, $/yr C_{lab} = cost of labor (op., sup, coord), $/yr C_e = cost of electricity, $/yr
C_{dd} = 0.00000429 (è)(CF_{dd})(I_l)(G_i)(ç) C_e = See electricity costing sheet C_{main} = if TCP <50,000--> 4166.25 if TCP > or = 50,000--> 0.83325(TCP) C_{lab} = 0.1854 (è)(CF_{lab})(O_f) If TCP < 10,000-->O_f = 0 If TCP > or = 10,000 --> O_f = 1	G_i = inlet gas flow rate, acfm I_l = pollutant inlet loading, gr/ft^3 è = operating hours/year CF_{dds} = cost factor for dust disposal, $/ton CF_{lab} = cost factor for labor, $/hr O_f = operating factor for esp TCP = total collection plate area, ft^2

Electricity Cost--ESP

<u>Cost of electricity</u> $C_e = CF_{elec\text{-}esp}(E_{fan})$	C_e = electricty cost, \$/yr CF_{elec} = cost factor for electricy, \$/kw-hr E_{pump}= electricty for pump use, kw E_{fan}= electricity for fan use, kw
<u>Fans</u> $E_{fan\text{-}esp} = \dfrac{(0.000117)(G_i)(\text{è})(P_g)}{(\text{å}_f)} + 0.00194\,(TCP)(\text{è})$ $P_g = P_{esp} + P_d$ $P_d = 0.136(1/D_d)^{1.18}(u_t/1000)^{1.8}(L/100) + (L)(N_e/L_D)(k)(u_t/4016)^2$	P_g = pressured drop of gas, in.H_2O P_d = pressure drop through duct, in.H_2O P_{esp} = pressure drop through esp, in H_2O G_i = Gas flow rate, acfm TCP = total collection plate area, ft^2 è = operating hours/year u_t = gas transport velocity, ft/min L = length of ductwork N_e/L_D = # of elbows per length of duct k = friction loss factor for elbow å_f = efficiency of fan D_d = diameter of duct, ft

Appendix B-3. Inputs for EPS Algorithms

Var	Description	Value	Source
COMMON DEFAULTS- ESP			
I	interest rate	0.07	Current EPA default value
N_e/L_D	# of elbows per length of duct	0.02	OCCM Chapter 10 default
L	length of ductwork	500	Engineering judgement
u_t	transport velocity, ft/min	3000	OCCM chapter 10 default values
DEFAULTS- TOTAL ANNUAL COST -- ESP			
n	life of equipment, yrs	20	OCCM chapter 6
è	operating hours/year	8400	Engineering judgement
CF_{dds}	cost factor for dust disposal, $/ton	20	OCCM chapter 6 and EPA webpage algorithms (http://www.epa.gov/ttncatc1/cica/cicaeng.html)
CF_{lab}	cost factor for labor, $/hr	18.44	Chemical engineering magazine 1998
DEFAULTS - ELECTRICITY - ESP			
CF_{elec}	cost factor for electricy, $/kw-hr	0.06	Chemical engineering magazine 1998
P_{esp}	pressure drop through esp, in H2O	0.38	OCCM chapter 6 and EPA webpage algorithms (http://www.epa.gov/ttncatc1/cica/cicaeng.html)
k	friction loss factor for elbow	0.19	OCCM chapter 10 default
å$_f$	efficiency of fan	0.7	Engineering judgement
DEFAULTS - DUCTWORK - ESP			
a	fan coefficient	22.1	OCCM chapters 8 and 10 default
b	fan exponent	1.55	
D_d	fan diameter, inches	36.5	
n_duct	life of equipment, yrs	20	
DEFAULTS -TCI - ESP			
Fone	special add-on factor	1	Engineering judgement
Ftwo	no special add-on factor	0	Engineering judgement
m	Factor to convert from FRP to other mat.	1	Engineering judgement
Mv	PM migration velocity, cm/s	16	OCCM chapter 6 and EPA webpage algorithms (http://www.epa.gov/ttncatc1/cica/cicaeng.html)

Appendix C

Cost Algorithms and Inputs for Venturi Scrubbers

Appendix C-1. Cost Algorithms for Venturi Scrubber Total Capital Investment
(Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html)

$TCI_{venturi} = TCI_{vscrub} + TCI_{pump}$	$TCI_{venturi}$ = total cap. Inv. Venturi, \$ TCI_{vscrub} = total cap. Inv. Vscrub, \$ TCI_{pump} = total cap. Inv pump, \$
TCI_{vscrub} = $G_o < 19{,}000$, then TCI = 2.254 (m)[8,180 + 1.41(Go)] $G_o \geq 19{,}000$, then TCI = $189.787(m)(G_o)^{0.612}$	m = material of construction factor G_o = outlet gas flow rate, acfm
$$G_o = [0.9964(G_i)(1-h_m) + 29.044(SH)(G_i)(1-h_m)]\left[\frac{460+ST}{460+T}\right]$$	G_i = inlet gas flow rate, acfm h_m = inlet moisture content, mole fraction SH = saturation absolute humidity, lb/lb bda T = temperature of gas stream, ºF ST = saturation temperature, ºF
$$ST = \left(\frac{SH}{INTA}\right)^{\left(\frac{1}{SLOPB}\right)}$$	INTA = saturation temperature factor SLOPB = saturation temperature factor
$$TCI_{pump} = \frac{2.956(CF_{pump})(G_i)(h_m)}{T+460}$$	CF_{pump} = cost factor for pump, \$/gpm

Appendix C-2. Cost Algorithms for Venturi Scrubber Total Annual Cost
(Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html)

$TAC_{scrub} = C_{fixed} + C_{variable}$	C_{fixed} = fixed annual cost, \$/yr $C_{variable}$ = variable annual cost, \$/yr
$C_{fixed} = C_{ovhd} + C_{adm} + C_{prop} + C_{ins} + C_{cr}$	C_{ovhd} = overhead cost, \$/yr C_{adm} = administrative cost, \$/yr C_{prop} = property tax, \$/yr C_{ins} = insurance, \$/yr C_{cr} = capital recovery, \$/yr
$C_{ovhd} = 0.6\ (C_{lab} + C_{main})$ $C_{adm} = 0.02\ (TCI)$ $C_{prop} = 0.01\ (TCI)$ $C_{ins} = 0.01\ (TCI)$ $C_{cr} = CRF_{vscrub}\ (TCI)$	C_{lab} = labor cost, \$/yr C_{main} = maintenance cost, \$/yr TCI = total capital investment, \$ CRF_{vscrub} = capital rec factor venturi, \$/yr
$CRF_{vscrub} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs
$C_{variable} = C_{ww} + C_w + C_e + C_{lab} + C_{main}$	C_{ww} = cost of ww disposal, \$/yr C_w = cost of solvent (water), \$/yr C_e = cost of electricity, \$/yr C_{lab} = cost of labor and supervisor, \$/yr C_{main} = cost of maintenance mat&lab, \$/yr

$$C_w = \left[\frac{0.06(è)(CF_w)}{460+T}\right]\left[\frac{0.009084(I_l)(ç)(G_i)(1-h_m)}{SLSC} + 4.77(SH)(G_i)(1-h_m) - 2.96(h_m)\right]$$ $$C_{ww} = \frac{0.00000103(I_l)(ç)(è)(CF_{ww})(G_i)(1-h_m)\left(\frac{530}{460+T}\right)}{SLSC}$$ C_e = See electricity costing sheet C_{lab} = 0.14375 (è)(CF_{lab})(O_f) C_{main} = 0.25 (è)(CF_{main})(M_f)	G_i = inlet gas flow rate, acfm è = operating hours/year CF_{ww} = cost factor for ww disposal, $/gal CF_w = cost factor for water, $/gal CF_{lab} = cost factor for labor, $/hr CF_{main} = cost factor for maintenance, $/hr O_f = operating factor for venturi M_f = maintenance factor for venturi h_m = inlet moisture content, mole fraction SH = saturation absolute humidity, lb/lb bda T = temperature of gas stream, °F I_l = pollutant inlet loading, gr/dscf SLSC = scrubber liquid to solids content, lb/lb H_20 ç = efficiency of scrubber

Electricity Cost

<u>Cost of electricity</u> $C_e = CF_{elec} (E_{pump}+E_{fan})$	C_e = electricty cost, \$/yr CF_{elec} = cost factor for electricy, \$/kw-hr E_{pump}= electricy for pump use, kw E_{fan}= electricity for fan use, kw
<u>Pumps</u> $E_{pump} = \frac{0.000556\ (è)(Pp)(G_i)(h_m)}{(T + 460)å_p}$	Pp = pressure of pump, ft of H_2O $å_p$ = efficiency of pump è = operating hours/year G_i = Gas flow rate, acfm h_m = inlet moisture content, mole fraction T = temperature of gas stream, °F
<u>Fans</u> $E_{fan} = \frac{(0.000117)(G_i)(è)(P_g)}{(å_f)}$ $P_g = P_v + P_d$ $P_v = 4.6814\ (P_{CD})^{2.0273}$ $P_d = 0.136(1/D_d)^{1.18}\ (u_t/1000)^{1.8}\ (L/100) + (L)(N_e/L_D)(k)(u_t/4016)^2$	P_g = pressured drop of gas, in.H_2O P_d = pressure drop through duct, in.H_2O P_v = pressure drop through venturi, in H_2O G_i = Gas flow rate, acfm P_{CD} = particle cut diameter, microns u_t = gas transport velocity, ft/min L = length of ductwork N_e/L_D = # of elbows per length of duct k = friction loss factor for elbow $å_f$ = efficiency of fan D_d = diameter of duct, ft

Appendix C-3. Inputs for Venturi Scrubber Algorithms

Var	Description	Value	Source
COMMON DEFAULTS - VENTURI SCRUBBER			
I	interest rate	0.07	Current EPA default value
N_e/L_D	# of elbows per length of duct	0.02	OCCM Chapter 10 default
L	length of ductwork	500	Engineering judgement
u_t	gas transport velocity, ft/min	3000	OCCM chapter 10 default values
DEFAULTS- TOTAL ANNUAL COST -- VENTURI SCRUBBER			
n	life of equipment, yrs	10	Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html
è	operating hours/year	8400	Engineering judgement
SLSC	scrubber liquid to solids content, lb/ lb H2O	0.25	Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html
O_f	operating factor for venturi	2	
M_f	maintenance factor for venturi	1.5	
CF_{ww}	cost factor for ww disposal, $/gal	0.0038	OCCM chapter 8 costs scaled to 1998
CF_w	cost factor for water, $/gal	0.00077	
CF_{lab}	cost factor for labor, $/hr	18.44	Chemical Engineering magazine 1998
CF_{main}	cost factor for maintenance, $/hr	20.28	
DEFAULTS - ELECTRICITY - VENTURI SCRUBBER			
CF_{elec}	cost factor for electricy, $/kw-hr	0.06	Chemical Engineering magazine 1998
Pp	pressure of pump, ft of H20	60	Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html and OCCM chapter 8
å$_p$	efficiency of pump	0.7	Engineering judgement
k	friction loss factor for elbow	0.35	OCCM chapter 10 default
P_{CD}	particle cut diameter, microns	0.44	Venturi scrubber algorithm from EPA TTN website: http://www.epa.gov/ttncatc1/cica/cicaeng.html and boiler emissions database
å$_f$	efficiency of fan	0.7	Engineering judgement
DEFAULTS - DUCTWORK - VENTURI SCRUBBER			
a	fan coefficient	22.1	OCCM Chapters 8 and 10
b	fan exponent	1.55	
D_d	fan diameter, inches	36.5	
n_duct	life of equipment, yrs	20	

Appendix D

Cost Algorithms and Inputs for Packed Scrubbers

Appendix D-1. Cost Algorithms for Packed Scrubber Total Capital Investment (OAQPS Control Cost Manueal chapter 8)

$TCI_{scrub} = TCI_{tower}+TCI_{pack}+TCI_{pump}$	TCI_{scrub} = Total capital inv scrubber, \$ TCI_{tower} = Total capital inv tower, \$ TCI_{pack} = Total capital inv packing, \$ TCI_{pump} = Total capital inv pump, \$ Site+Bldg = Site and building mod, \$
$TCI_{tower} = 417.956(m)(\text{ð})(D_s)(H_{pack})+453.7808(m)(\text{ð})(D_s^2)+838.8974(m)(\text{ð})(D_s)$	m = factor to convert from FRP to other mat. D_s = diameter of scrubber, ft H_{pack} = height of packing, ft
$D_s=\sqrt{\frac{240(\text{ñ}_g)(G_i)(10^{\text{ä}})}{(MWR)(\text{ñ}_l)(a)(\text{ð})\sqrt{\frac{\text{ñ}_g}{\text{ñ}_l}}}}$	ñ_l = density of liquid, lb/ft^3 G_i = Gas flow rate, acfm ä = scrubber diameter exponent MWR = minimum wetting rate, ft^2/hr ñ_g = density of gas, lb/ft^3 a = packing constant, ft^2/ft^3
$\text{ä}=\frac{-0.915\pm\sqrt{-1.144359-1.188\log\left[\frac{(\text{ø})(F_p)(\frac{\mu_l}{2.42})^{0.2}(MWR)^2(a)^2}{12960000(f)^2(g_c)}\right]}}{-0.594}$	ø = ratio of solvent density to water density F_p = packing factor μ_l = viscosity of liquid, lb/ft-hr f = flooding factor g_c = gravitational constant, 32.2
$H_{pack}=\left[\ln\left(\frac{y_i}{y_o}\right)\right]\left[\left[\frac{\text{á}\left[\frac{240(\text{ñ}_g)(G_i)}{(\text{ð})(D_s^2)}\right]^{\text{â}}}{[(MWR)(\text{ñ}_l)(a)]^{\text{ã}}}\right]\left[\frac{\mu_l^{\text{ã}}}{\mu_g^{\text{â}}}\right]\sqrt{\frac{\mu_g}{\text{ñ}_g D_g}}+\frac{1}{AF}\left[\text{ö}\left[\frac{(MWR)(\text{ñ}_l)(a)}{\mu_l}\right]^b\sqrt{\frac{\mu_l}{\text{ñ}_l D_l}}\right]\right]$	y_i = pollutant mole fracting entering scrubber y_o = pollutant mole fraction exiting scrubber μ_g = viscosity of gas, lb/ft-hr D_g = diffusivity of pollutant in gas, ft^2/hr D_l = diffusivity of pollutant in liquid, ft^2/hr AF = absorption factor á = packing constant ö = packing constant ã = packing constant â = packing constant b = packing constant

$y_o = \frac{y_i(100 - ç)}{100 - y_i ç}$	ç = efficiency of scrubber
$TCI_{pack} = 0.649(C_p)(H_{pack})(ð)(D_s^2)$	C_p = packing cost factor, $/ft^3$
$TCI_{pump} = 0.0312(MWR)(a)(ð)(D_s^2)(CF_{pump})(m)$	CF_{pump} = cost factor for pump, $/gpm

Appendix D-2. Cost Algorithms for Packed Scrubber Total Annual Cost (OAQPS Control Cost Manueal chapter 8)

$TAC_{scrub} = C_{fixed} + C_{variable}$	C_{fixed} = fixed annual cost, \$/yr $C_{variable}$ = variable annual cost, \$/yr
$C_{fixed} = C_{ovhd} + C_{adm} + C_{prop} + C_{ins} + C_{cr}$	C_{ovhd} = overhead cost, \$/yr C_{adm} = administrative cost, \$/yr C_{prop} = property tax, \$/yr C_{ins} = insurance, \$/yr C_{cr} = capital recovery, \$/yr
$C_{ovhd} = 0.6\ (C_{lab} + C_{main})$ $C_{adm} = 0.02\ (TCI)$ $C_{prop} = 0.01\ (TCI)$ $C_{ins} = 0.01\ (TCI)$ $C_{cr} = CRF_{scrub}\ (TCI)$	C_{lab} = labor cost, \$/yr C_{main} = maintenance cost, \$/yr TCI = total capital investment, \$ CRF_{scrub} = capital rec factor scrubber, \$/yr
$CRF_{scrub} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs
$C_{variable} = C_{caus} + C_{ww} + C_w + C_e + C_{lab} + C_{main}$	C_{caus} = cost of caustic, \$/yr C_{ww} = cost of ww disposal, \$/yr C_w = cost of solvent (water), \$/yr C_e = cost of electricity, \$/yr C_{lab} = cost of labor and supervisor, \$/yr C_{main} = cost of maintenance mat&lab, \$/yr
C_{caus} = 0.03 (G_i)(ñ$_g$)(y_i-y_o)(SR_1)($MW_{caustic}$)(è)(CF_{caus})/MW_g C_{ww} = 7.194 (G_i)(ñ$_g$)(y_i-y_o)(SR_2)(MW_{salt})(1/BF)(è)(CF_{ww})/MW_g $C_w = C_{ww}\ (CF_w/CF_{ww})$ C_e = See electricity costing sheet C_{lab} = 0.07188 (è)(CF_{lab}) C_{main} = 0.125 (è)(CF_{main})	G_i = inlet gas flow rate, acfm ñ$_g$ = density of gas, lb/ft3 y_i = pollutant inlet mole fraction y_o = pollutant outlet mole fraction SR_1 = moles caustic/moles pollutant $MW_{caustic}$ = caustic molec wt, lb/lb-mole è = operating hours/year CF_{caus} = cost factor for caustic, \$/ton MW_g = gas molecular weight, lb/lb-mole SR_2 = moles salt/moles HCl $MW_{s\ alt}$ = salt molec weight, lb/lb-mole BF = fraction of waste stream treated CF_{ww} = cost factor for ww disposal, \$/gal CF_w = cost factor for water, \$/gal CF_{lab} = cost factor for labor, \$/hr CF_{main} = cost factor for maintenance, \$/hr

Electricity Cost

<u>Cost of electricity</u> $C_e = CF_{elec} (E_{pump}+E_{fan})$	C_e = electricty cost, \$/yr CF_{elec} = cost factor for electricy, \$/kw-hr E_{pump}= electricy for pump use, kw E_{fan}= electricity for fan use, kw
<u>Pumps</u> $E_{pump} = \frac{0.00000585\ (è)(ð)(D_s^2)(MWR)(a)(Pp)}{å_p}$	D_s = diameter of scrubber, ft MWR = minimum wetting rate, ft^2/hr a = packing constant, ft^2/ft^3 Pp = pressure of pump, ft of H_2O $å_p$ = efficiency of pump è = operating hours/year
<u>Fans</u> $E_{fan} = \frac{(0.000117)(G_i)(è)(P_g)}{(å_f)}$ $P_g = P_c + P_d$ $P_s = \frac{(H_{pack})(G_i)^2(c)(ñ_g)[10^{[(j)(MWR)(ñ_l)(a)/3600]}]}{225(ð^2)(D_s^4)}$ $P_d = 0.136(1/D_d)^{1.18} (u_t/1000)^{1.8} (L/100) + (L)(N_e/L_D)(k)(u_t/4016)^2$	P_g = pressured drop of gas, in.H_2O P_c = pressure drop through control, in.H_2O P_d = pressure drop through duct, in.H_2O P_s = pressure drop through scrubber, in H_2O H_{pack} = height of packing G_i = Gas flow rate, acfm c = packing constant $ñ_g$ = density of gas, lb/ft3 j = packing constant $ñ_l$ = density of liquid, lb/ft3 u_t = gas transport velocity, ft/min L = length of ductwork N_e/L_D = # of elbows per length of duct k = friction loss factor for elbow $å_f$ = efficiency of fan D_d = diameter of duct, ft

Appendix D-3. Inputs for Costing Algorithms

Var	Description	Value	Source
COMMON DEFAULTS - PACKED SCRUBBER			
I	interest rate	0.07	Current EPA default
ñ$_{g}$ =	density of gas, lb/ft3	0.0709	OCCM chapter 8
N$_{e}$/L$_{D}$	# of elbows per length of duct	0.02	OCCM chapter 10
L	length of ductwork	500	Engineering judgement
MWR	minimum wetting rate, ft2/hr	1.3	OCCM chapter 8
u_t	gas transport velocity, ft/min	3000	OCCM chapter 10
ñ$_{l}$	density of liquid, lb/ft3	62.4	OCCM chapter 8
a	packing constant, ft2/ft3	28	OCCM chapter 8
DEFAULTS- TOTAL ANNUAL COST -- PACKED SCRUBBER			
n	life of equipment, yrs	15	OCCM chapter 8
SR_1	moles caustic/moles pollutant	0.5	Stoichiometric calculation for Hcl and base
$MW_{caustic}$	caustic molec wt, lb/lb-mole	62	OCCM chapter 8
è	operating hours/year	8400	Engineering judgement
CFc	cost factor for caustic, $/ton	300	OCCM chapter 8
MW_g	gas molecular weight, lb/lb-mole	29	OCCM chapter 8
SR_2	moles salt/moles HCl	1	Stoirchiometric calculation
$MW_{s\ alt}$	salt molecular weight, lb/lb-mole	58.5	OCCM chapter 8
BF	fraction of waste stream treated	0.1	Engineering judgement
CF_{ww}	cost factor for ww disposal, $/gal	0.0038	OCCM chapter 8
CF_w	cost factor for water, $/gal	0.00077	OCCM chapter 8
SR_3	adjustment for 76% Na2O solution	0.76	OCCM chapter 8
CF_{lab}	cost factor for labor, $/hr	18.44	Chemical engineering magazine 1998
CF_{main}	cost factor for maintenance, $/hr	20.28	Chemical engineering magazine 1998
DEFAULTS - ELECTRICITY - PACKED SCRUBBER			
Cfelec	cost factor for electricy, $/kw-hr	0.06	Chemical engineering magazine 1998
Pp	pressure of pump, ft of H20	60	OCCM chapter 8
å$_{p}$	efficiency of pump	0.7	Engineering judgement
è	operating hours/year	8000	Engineering judgement
c	packing constant	0.24	OCCM chapter 8
j	packing constant	0.17	OCCM chapter 8
k	friction loss factor for elbow	0.35	OCCM chapter 10
å$_{f}$	efficiency of fan	0.7	Engineering judgement
DEFAULTS - DUCTWORK - PACKED SCRUBBER			
a	fan coefficient	22.1	OCCM chapters 8 and 10
b	fan exponent	1.55	
D_d	fan diameter, inches	36.5	
n_duct	life of equipment, yrs	20	
DEFAULTS -TCI - PACKED SCRUBBER			
m	factor to convert from FRP to other material	1	OCCM chapter 8
ø	ratio of solvent density to water density	1	
Fp	packing factor	65	
μ_l	viscosity of liquid, lb/ft-hr	2.16	
f	flooding factor	0.7	
μ_g	viscosity of gas, lb/ft-hr	0.044	
D_g	diffusivity of pollutant in gas, ft2/hr	0.725	
D_l	diffusivity of pollutant in liquid, ft2/hr	0.000102	
AF	absorption factor	17	
á	packing constant	3.82	
ö	packing constant	0.0125	
ã	packing constant	0.45	
â	packing constant	0.41	
b	packing constant	0.22	
C_p	packing cost factor, $/ft3	20	
CF_{pump}	cost factor for pump, $/gpm	16	
å	efficiency of scrubber		Calculated based on reduction requirements

Appendix E

Cost Algorithms and Inputs for Spray Dryers

Appendix E-1. Cost Algorithms for Spray Dryer Total Capital Investment
(U.S. Environmental Protection Agency, Municipal Waste Combustors - Background Information for Proposed Standards: Cost Procedures,)

$TCI_{sds} = TCI_{sd} + TCI_{pump} + Site + Bldg$	TCI_{sds} = Total capit inv spray dryer systm, \$ TCI_{sd} = Total capital inv spray dryer, \$ TCI_{pump} = Total capital inv pump, \$ Site+Bldg = Site and building mod, \$
$TCI_{sd} = 12894.8\ (1.25G_i)^{0.460}(RF)$	G_i = Gas flow rate, acfm RF = retrofit factor
$TCI_{pump} = 0.002(L_{m,i})(CF_{pump})(è\ )$	CF_{pump} = cost factor for pump, \$/gpm è = operating hours/year $L_{m,i}$ = mass of water entering, lb/hr (see TAC)

Appendix E-2. Cost Algorithms for Spray Dryer Total Annual Cost - Spray Dryer (U.S. Environmental Protection Agency, Municipal Waste Combustors - Background Information for Proposed Standards: Cost Procedures,)

$TAC_{sd} = C_{fixed} + C_{variable}$	C_{fixed} = fixed annual cost, \$/yr $C_{variable}$ = variable annual cost, \$/yr
$C_{fixed} = C_{ovhd} + C_{adm} + C_{prop} + C_{ins} + C_{cr}$	C_{ovhd} = overhead cost, \$/yr C_{adm} = administrative cost, \$/yr C_{prop} = property tax, \$/yr C_{ins} = insurance, \$/yr C_{cr} = capital recovery, \$/yr
$C_{ovhd} = 0.6\ (C_{lab} + C_{main})$ $C_{adm} = 0.02\ (TCI)$ $C_{prop} = 0.01\ (TCI)$ $C_{ins} = 0.01\ (TCI)$ $C_{cr} = CRF_{sd}\ (TCI)$	C_{lab} = labor cost, \$/yr C_{main} = maintenance cost, \$/yr TCI = total capital investment, \$ CRF_{sd} = capital rec factor s-dryer, \$/yr
$CRF_{sdryer} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs
$C_{variable} = C_{lime} + C_w + C_e + C_{lab} + C_{main}$	C_{lime} = cost of lime, \$/yr C_w = cost of water, \$/yr C_e = cost of electricity, \$/yr C_{lab} = cost of labor and supervisor, \$/yr C_{main} = cost of maintenance mat&lab, \$/yr
$C_{lime} = 0.42(CF_{lime})(è)[0.015625M_{SO2} + 0.02778M_{HCl}]$ $C_w = 0.002\ (L_{w,i})(CF_w)$ $L_{m,i} = \left[\frac{(2382.91)(G_i)}{460 + T}\right]\left[\frac{(Cp_a)(T - T_f)}{H_v + (Cp_{mv})(T_f - T_v) + (Cp_{wl})(T_v - T_w)}\right]$ C_e = See electricity costing sheet $C_{lab} = 0.2875\ (è)(CF_{lab})$ $C_{main} = 0.275\ (è)(CF_{main})$	G_i = inlet gas flow rate, acfm $L_{m,i}$ = mass of water entering, lb/hr è = operating hours/year CF_w = cost factor for water, \$/gal CF_{lab} = cost factor for labor, \$/hr CF_{main} = cost factor for maintenance, \$/hr CF_{lime} = cost factor for lime, \$/ton M_{SO2} = Mass of SO2 entering, lb/hr M_{HCl} = Mass of Hcl entering, lb/hr Hv = Heat of vaporization, Btu/lb Cp_{mv} = Heat cap of water vapor, Btu/lb-F Cp_a = Heat capacity of air, Btu/lb-F Cp_{wl} = Heat capacity of water, Btu/lb-F T = temperature of gas stream, F T_f = Final temperature of exit stream, F T_v = temperature of vaporization, F T_w = temperature of water entering, F

Electricity Cost-Spray Dryer

Cost of electricity $C_e = CF_{elec} (E_{pump}+E_{fan}+E_{atomizer})$	C_e = electricty cost, $/yr CF_{elec} = cost factor for electricy, $/kw-hr E_{pump}= electricity for pump use, kw E_{fan}= electricity for fan use, kw $E_{atomizer}$= electricity for atomizer use, kw
Atomizer $E_{atomizer} = [0.006 (SF +L_{mi}) + 15]\text{è}$ $SF = 1.3125M_{SO2} + 2.3335\ M_{HCl}$	è = operating hours/year $L_{m,i}$ = mass of water entering, lb/hr (see TAC) SF = lime feed rate, lb/hr M_{SO2} = Mass of SO2 entering, lb/hr M_{HCl} = Mass of Hcl entering, lb/hr
Pumps $E_{pump} = \frac{0.000000375(Pp)(L_{m,i})}{\text{å}_p}$	Pp = pressure of pump, ft of H_2O å_p = efficiency of pump
Fans $E_{fan} = \frac{(0.000117)(G_i)(\text{è})(P_g)}{(\text{å}_f)}$ $P_g = P_d$ $P_d = 0.136(1/D_d)^{1.18} (u_t/1000)^{1.8} (L/100) + (L)(N_e/L_D)(k)(u_t/4016)^2$	P_g = pressured drop of gas, in.H_2O P_c = pressure drop through control, in.H_2O P_d = pressure drop through duct, in.H_2O G_i = Gas flow rate, acfm c = packing constant L = length of ductwork N_e/L_D = # of elbows per length of duct k = friction loss factor for elbow å_f = efficiency of fan D_d = diameter of duct, ft

Appendix E-3. Inputs for Spray Dryer Algorithms

Var	Description	Value	Source
COMMON DEFAULTS - SPRAY DRYER			
I	interest rate	0.07	Current EPA default value
N_e/L_D	# of elbows per length of duct	0.02	OCCM Chapter 10 default
L	length of ductwork	500	Engineering judgement
ut	gas transport velocity, ft/min	3000	OCCM chapter 10 default values
DEFAULTS- TOTAL ANNUAL COST -- SPRAY DRYER			
n	life of equipment, yrs	15	MWC BID and Engineering judgement
è	operating hours/year	8400	Engineering judgement
Hv	Heat of vaporization, Btu/lb	970	Air pollution control, chapter 8
Cp_{mv}	Heat capacity of water vapor, Btu/lb-F	0.44	
Cp_a	Heat capacity of air, Btu/lb-F	0.25	
Cp_{wl}	Heat capacity of water, Btu/lb-F	0.0022	
T_f	Final temperature of exit stream, F	200	
T_v	temperature of vaporization, F	212	
T_w	temperature of water entering, F	77	Engineering judgement
CF_{lime}	cost factor for lime, $/ton	53	OCCM chapter 8
CF_w	cost factor for water, $/gal	0.0002	
CF_{lab}	cost factor for labor, $/hr	18.44	Chemical engineering magazine 1998
CF_{main}	cost factor for maintenance, $/hr	20.28	
DEFAULTS - ELECTRICITY - SPRAY DRYER			
CF_{elec}	cost factor for electricy, $/kw-hr	0.06	Chemical engineering magazine 1998
Pp	pressure of pump, ft of H20	60	OCCM chapter 8
å_p	efficiency of pump	0.7	Engineering judgement
k	friction loss factor for elbow	0.35	OCCM chapter 10
å_f	efficiency of fan	0.7	Engineering judgement
DEFAULTS - DUCTWORK - SPRAY DRYER			
a	fan coefficient	22.1	OCCM chapters 8 and 10
b	fan exponent	1.55	
D_d	fan diameter, inches	36.5	
n_duct	life of equipment, yrs	15	
DEFAULTS -TCI - SPRAY DRYER			
RF	retrofit factor	1	Engineering judgement
CF_{pump}	cost factor for pump, $/gpm	16	OCCM chapter 8

Appendix F

Cost Algorithms and Inputs for Ductwork

Appendix F-1. Cost Algorithms for Ductwork TCI and TAC (OAQPS Control Cost Manual Chapter 10)

Diameter of Duct: $D_d = 1.128 (G_i/u_t)^{1/2}$	D_d = diameter, ft G_i = gas flow, acfm u_t = transport velocity, ft/min
TCI Ductwork $TCI_{ductwork} = 1.458 (C_{duct}+C_{elbow}+C_{dampers}+C_{fan})$	TCI= total capital inv., $ C_{duct}= duct EC cost, $ C_{elbow}=elbow EC cost, $ $C_{dampers}$=damper ECcost, $ C_{fan} = fan EC cost, $
Duct, Elbow, Dampers **FRP Material** $C_{duct} = 11.8(L)e^{0.6504D}$ $C_{elbow} = 34.9(L)(N_e/L_D)e^{1.0092D}$ $C_{dampers} = 35.9(D_d^2 \eth/4)^{0.708}$ **304SS Material** $C_{duct} = 0.39 D_d^2 \eth L$ $C_{elbow} = 74.2(L)(N_e/L_D)e^{0.8016D}$ $C_{dampers} = 23e^{0.6804D_d}$ **Galvanized CS Material** $C_{duct} = 1.55(L)(D_d^2 \eth/4)^{0.936}$ $C_{elbow} = 53.4(L)(N_e/L_D)e^{0.7596D}$ $C_{dampers} = 23e^{0.6804D_d}$	L = ductlenght, ft N_e/L_D = # elbows/length, #/ft
Fan $C_{fan} = aD_f^b$	a = fan coefficient b = fan exponenet D_f = fan diameter, inches
TAC Ductwork $TAC_{ductwork} = TCI (0.04 + CRF_{ductwork}) + C_e$ C_e = see electricity costing sheet	TAC = total annual cost, $/yr CRF = capital rec. Factor Ce = fan electricity cost, $/yr
$CRF = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs

Appendix G

Cost Factors for GCP, Testing, and Monitoring

Appendix G-1. Costs for GCP, Testing, and Monitoring[1]

Practice	Capital Cost	Annual Costs								
		Lifetime	Operation & Maintenance	Annual RATA[2]	Quarterly CGA's [3]	R&R	Annual Review and update	Taxes, ins, admin	Capital Recovery (7%)	Total Annual Costs
Testing										
Initial stack test for PM	8,000	---	---	---	---	---	---	---	---	8,000
Initial stack test for HCl	5,000	---	---	---	---	---	---	---	---	5,000
Initial stack test for metals	8,000	---	---	---	---	---	---	---	---	8,000
Initial and annual fuel analysis for metals and mercury	1,081	---	---	---	---	---	---	---	---	1,081
Initial and annual fuel analysis of chlorine	720	---	---	---	---	---	---	---	---	720
Monitoring										
Initial cost of opacity monitor	29,200	20	4,000	-	-	1,000	1,000	1,168	2,756	9,924
Wet scrubber parametric monitoring (redundant)	40,183	20	7,300	6,000	6,000	2,000	1,000	1,607	3,793	27,700
Good Combustion Practices										
Initial cost of CO & O2 CEM (w/ App. F)	95,800	20	8,000	6,000	3,900	1,500	1,000	3,832	9,043	33,275
Initial cost of CO & O2 (w/o App. F)	93,300	20	6,000	-	-	1,000	1,000	3,732	8,807	20,539
Initial cost of CO & O2 process mon. (w/ ext corr. testing)	37,800	20	7,000	6,000	3,000	1,000	1,000	1,512	3,568	23,080
Initial cost of CO & O2 process mon. (w/o ext corr. testing)	37,800	20	2,000	-	-	1,000	-	1,272	3,568	7,840

[1] Memorandum from Thomas Holloway, Midwest Research Institute, to Rick Copland, U.S. Environmental Protection Agency, *Revised Testing and Monitoring Options and Costs for Medical Waste Incinerators (MWI's) - Methodology and Assumptions*. March 17, 1997.
[2] RATA = Relative Accuracy Test Audit
[3] CGA = Cylinder Gas Audit