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AP-42 Section 9.5.2
Reference 2
Report Sect. 2
Reference 4

OSCAR MAYER FOODS CORPORATION

Oscar Mayer

Note: This is a reference cited in *AP 42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.

April 1, 1992

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AIR MANAGEMENT

Sue Lindem
Wisconsin Department of Natural Resources
Bureau of Air Management
One West Wilson Street
Madison, WI 53707

NR 445 SMOKEHOUSE FORMALDEHYDE COMPLIANCE PLAN

Dear Ms. Lindem:

Please find attached, a compliance plan prepared for the smokehouse formaldehyde emissions required under Wis. Adm. Code NR 445.05(7). As detailed in the report, we are proposing the use of a water scrubber technology as BACT. Evaluations of scrubbers continues, as does further testing to verify our actual formaldehyde emissions.

Recent testing indicates that our facility emissions are lower than previously estimated. Initial estimates were based on the Alkar stack tests in 1991 which used a NIOSH method. The CARB method, which was recently used, eliminates interferences found in the NIOSH method, which is believed to be the basis for the lower emission rates.

Once you have reviewed this compliance plan, we would like to meet with you to discuss the plan and answer any questions you may have. Please feel free to contact me at 241-3311 ext. 4609 at your convenience.

Sincerely,

Jeffrey M. Jaeckels

Jeffrey M. Jaeckels, P.E.
Environmental Project Engineer

JMJ80

cc: R. F. Roemer - P4
Dave Sellers - Southern District Office
R. J. Sherman - 5
J. R. Stieve - P4

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Wisconsin Administrative Code Chapter NR 445
Control of Hazardous Air Pollutants
Formaldehyde Emission Compliance Plan

Oscar Mayer Foods Corporation
Madison, Wisconsin
April 1, 1992

Table of Contents

1.0 INTRODUCTION

1.1 Purpose

This report demonstrates how the Oscar Mayer Foods Corporation (OMFC) facility located in Madison, WI will comply with formaldehyde emission limitations detailed in Wisconsin Administrative Code Chapter NR 445 - Control of Hazardous Air Pollutants. The sources covered in this plan include all smokehouses operated at the facility.

1.2 Formaldehyde Formation in Smoke

Formaldehyde is a product of incomplete combustion -- a condition inherent to meat smoking processes -- and is therefore present at various levels in smokehouse exhaust. The formation of formaldehyde and other carbonyls is believed to be due to the pyrolysis of cellulose[1]. Under pyrolysis conditions, cellulose appears to be hydrolyzed to glucose which is dehydrated to a glucosan. Pyrolysis of the glucosan forms carbonyl compounds including formaldehyde.

The formation and fate of formaldehyde in smoke is dependent on many variables. Smoke generation temperature, ambient air temperature, sawdust type and size, sawdust moisture content, and rate of combustion all influence smoke generation[2,3]. Since formaldehyde is formed with other smoke constituents several reactions can occur on surfaces exposed to smoke as well as in the smoke itself. Identified reactions include the following[4]:

- oxidation with heat to form formic acid,
- combination with water to form formic acid or methylene glycol,
- reduction to methanol, and
- decomposition to carbon monoxide, methanol and hydrogen.

Numerous other reactions with other organic compounds can occur within the smoke atmosphere.

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[1] J. Gilbert and M. E. Knowles, The Chemistry of Smoked Foods: a Review, Journal of Food Technology, 1975, 10, 245-261.

[2] J. A. Maga, Smoke in Food Processing, 1988, CRC Press Inc., 29-38.

[3] K. Potthast and G. Eigner, Formaldehyde in Smokehouse Smoke and Smoke Meat Products, Fleischwirtsch, 65 (10) 1178-1186.

[4] Du Pont Company, Chemicals and Pigments, Formaldehyde Solutions: Properties, Usage, Storage and Handling, Publication H-23417, 1990.

As a result, levels of formaldehyde are believed to vary considerably between process conditions and operations. This has been confirmed through recent stack testing at the OMFC facility.

1.3 Determination of Formaldehyde in Smoke

Formaldehyde emissions for all processes in this document are based on two series of stack tests performed on the OMFC operations. Stack testing performed on the Alkar continuous smokehouse operation in March, 1991 utilized NIOSH Method 3500. An emission factor based on this result was applied to all operations for initial emission estimates. Recent testing was performed on all operations utilizing CARB Method 430 which does not have the interferences found in the NIOSH method[5,6,7]. Results from this operation specific testing indicate that formaldehyde emissions may be 10 times less than indicated by the NIOSH method. Additional testing will be conducted concurrent with control technology development to determine actual and supportable facility emissions.

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[5] NIOSH Method 3500, Formaldehyde, Issued 2/15/84, Revision No. 1 5/15/89.

[6] California Air Resource Board, Method 430, Determination of Formaldehyde and Acetaldehyde in Emissions from Stationary Sources, Adopted September 12, 1989.

[7] E. R. Kennedy, A. W. Teass, and Y. T. Gagnon, Formaldehyde: Analytical Chemistry and Toxicology, American Chemical Society, 1985.

2.0 EMISSION INVENTORY

2.1 Smokehouse Inventory

The Oscar Mayer facility, located in Madison, Wisconsin, is the Corporate Headquarters and largest production facility operated by OMFC. This facility operates 32 meat smokehouses.

Table 1 lists all smokehouses currently operating at the OMFC facility. The last two smokehouse operations are not subject to this compliance plan and therefore not further evaluated within this report. The Alkar continuous smokehouse complies with NR 445 through permit number 90-IRS-082 released for permanent operation September 9, 1991. The research and development smokehouses are exempt from NR 445 under NR 445.05(1)(c)3, NR 445.05(2)(c)1 and NR 445(3)(c)3.

Table 1
Oscar Mayer Foods Corporation
Smokehouse Source Inventory

Process Description	WDNR Stack Number
6th Floor South Stack	S14
6th Floor North Stack	S15
Five Bacon Smokehouses	S16
Continuous Wiener Process (CWP) No. 1	S17
Ham Smokehouse	S18
Dry Sausage Smokehouse No. 11	S19
Dry Sausage Smokehouse No. 10	S50
Dry Sausage Smokehouse No. 12	S51
Dry Sausage Smokehouse No. 9	S61
Continuous Wiener Process (CWP) No. 2	S52
Turkey Bacon Smokehouses (2)	S54
Continuous Large Sausage Process (CLSP)	S56
Knud Simonsen Industries Oven (KSI)	S57
Alkar Continuous Smokehouse	S62
Research Smokehouse	S60

2.2 Formaldehyde Emission Inventory

Table 2 summarizes the actual 1991 formaldehyde emission estimates from each affected smokehouse operation. Emissions are based on stack tests performed on the Alkar continuous smokehouse in March, 1991 which utilized NIOSH Method 3500. An emission factor was developed from this stack test and applied to each operation. Wood sawdust consumption is based on actual purchases for each operation in 1991.

2.3 Test Method Discrepancy

OMFC recently completed further testing of the smokehouse stack emissions using a California Air Resource Board (CARB) formaldehyde method based on 2,4,-dinitrophenylhydrazine (DNPH)[6]. Results from this test are presented in Table 3. As shown the emissions are drastically different than NIOSH results which is believed to be attributed to the positive interferences of oxidizable organic compounds found in the NIOSH method[5].

This discrepancy will be investigated further through more testing at the OMFC facility to establish well founded actual formaldehyde emissions.

NOTE: The emission estimates used for this plan are those in Table 2 which are based on the NIOSH Method. When the CARB method results are verified, the contents of this plan will change since we will use the CARB analytical results to develop our compliance plan.

Table 2 Oscar Mayer Foods Corporation Madison Plant Smokehouses 1991 Formaldehyde Emission Estimates				
Operation	WDNR No.	1991 Wood Use (lb/yr)	Form. Emission Factor lb/lb	Form. Emiss. (lb/yr)
6th Floor South Stack	S14P30	52,800	0.003	158.4
6th Floor North Stack	S15P31	incl.	0.003	0.0
Five Bacon Smokehouses	S16P32	21,700	0.003	65.1
Continuous Wiener Process (CWP) No. 1	S17P33	283,450	0.003	850.4
Ham Smokehouse (No. 1)	S18P34	33,400	0.003	100.2
Dry Sausage Smokehouse No. 11	S19P35	23,650	0.003	71.0
Dry Sausage Smokehouse No. 10	S50P36	23,650	0.003	71.0
Dry Sausage Smokehouse No. 12	S51P37	23,650	0.003	71.0
Dry Sausage Smokehouse No. 9	S61P77	23,650	0.003	71.0
Continuous Wiener Process (CWP) No. 2	S52P38	283,450	0.003	850.4
Turkey Bacon Smokehouses (2)	S54P70	20,600	0.003	61.8
Continuous Large Sausage Process (CLSP)	S56P72	42,900	0.003	128.7
Knud Simonsen Industries Oven (KSI)	S57P73	190,000	0.003	570.0
			Total	3068.7

NOTE: Emission Factor is based on testing conducted March, 1991 using NIOSH3500

Table 3 Oscar Mayer Foods Corporation Madison Plant Smokehouses 1991 Formaldehyde Emission Estimates				
Operation	WDNR No.	1991 Wood Use (lb/yr)	Form. Emission Factor lb/lb	Form. Emiss. (lb/yr)
6th Floor South Stack	S14P30	52,800	0.0037	197.4
6th Floor North Stack	S15P31	incl.	0.0037	0.0
Five Bacon Smokehouses	S16P32	21,700	$3.8X10^{-5}$	0.8
Continuous Wiener Process (CWP) No. 1	S17P33	283,450	$2.6x10^{-6}$	0.75
Ham Smokehouse (No. 1)	S18P34	33,400	0.0019	63.7
Dry Sausage Smokehouse No. 11	S19P35	23,650	$3.9X10^{-5}$	0.925
Dry Sausage Smokehouse No. 10	S50P36	23,650	$3.9X10^{-5}$	0.925
Dry Sausage Smokehouse No. 12	S51P37	23,650	$3.9X10^{-5}$	0.925
Dry Sausage Smokehouse No. 9	S61P77	23,650	$3.9X10^{-5}$	0.925
Continuous Wiener Process (CWP) No. 2	S52P38	283,450	$2.6X10^{-6}$	0.75
Turkey Bacon Smokehouses (2)	S54P70	20,600	$2 X 10^{-4}$	4.1
Continuous Large Sausage Process (CLSP)	S56P72	42,900	0.00011	4.7
Knud Simonsen Industries Oven (KSI)	S57P73	190,000	0.00015	28.7
			Total	304.7

NOTE: Emission Factors are based on specific operation tests conducted March, 1992 using CARB 430.

3.0 BACT Analysis

This section describes the regulatory framework which drives the best available control technology selection, the technologies identified (both control technologies and process changes), and evaluates the feasible alternatives to arrive at OMFC's BACT proposal.

3.1 Regulatory Background

Formaldehyde is a Table 3, Group B compound in NR 445. As stated in NR 445.05(3)(b), Best Available Control Technology (BACT) shall be installed on the largest source of formaldehyde. If control of the largest source does not bring the facility within the threshold limit of 250 lb/yr than decreasingly smaller sources must be controlled by BACT until either the facility emissions are below 250 lb/yr or all sources emitting 10% of the threshold (25 lb/yr) are controlled by BACT.

OMFC pilot testing and research to date has shown that control efficiencies of 80-95% can be expected depending upon exhaust stream conditions. Based on this information and the emission estimates in Table 2 all smokehouse operations would need to be controlled by BACT . Each source is estimated to be above 25 lb/yr and even with all sources controlled with BACT, the facility total smokehouse formaldehyde emissions may be above 250 lb/yr.

3.2 Control Technologies Identified

The following technologies were identified as possible alternatives for the control of formaldehyde emissions. Each option is briefly discussed with an opinion of overall feasibility.

- <u>Afterburner</u> - Natural gas is used to expose the smokehouse exhaust to an elevated temperature of at least 1200 degrees Fahrenheit. Organic compounds in the smoke are further oxidized by this process to minimize organic emissions. OMFC currently operates an afterburner on the Alkar continuous smokehouse operation. Based on its performance it is not believed to be a feasible method of formaldehyde control. Operational costs, the consumption of natural gas, and additional air pollution created by fuel consumption do not justify this control technology .

  As detailed in Appendix A, the annual operational costs of afterburners for the entire facility would exceed $3.5 million. When considering total annualized costs the control effectiveness would be $2.8 million/ton of formaldehyde controlled. This figure is approximately 10 times higher than scrubber control technology estimates.

Smokehouse processes exhaust air at an estimated 97,200 ACFM (432,000 lb/hr). This requires approximately 6.3E8 cubic feet per year of natural gas. The AP-42[8] emission factor for natural gas combustion indicates that over 31 tons per year of nitrogen oxides would be emitted. Formaldehyde is also known to be emitted from the combustion of fuels such as natural gas[9]

For the above mentioned reasons OMFC does not consider afterburners to be a feasible formaldehyde control technology.

- <u>Scrubbers</u> - Formaldehyde is a very soluble gas and is therefore easily controlled by scrubbing the exhaust stream with water. This is method used for formaldehyde control within the chemical process industry[10,11].

All hydraulic scrubbers operate on the principle of absorption. Soluble gases or vapors are contacted with water droplets and/or wetted surfaces to allow the mass transfer into solution. Formaldehyde scrubbing typically utilized a dilute sodium hydroxide solution which converts formaldehyde in solution to methanol and sodium formate. Both of these products are water soluble and biodegrade rather easily through a typical wastewater treatment process.

Different types of scrubbers exist which operate on different contacting principles. These include mist scrubbers, packed bed scrubbers, and vortex scrubbers. Mist scrubbing utilizes high pressure atomization nozzles which introduces a fog into a reaction chamber. Exhaust gases are fed into the chamber where liquid/gas contacting occurs. Packed bed scrubbers consist of an inert packing. Water is distributed at the top of the column which creates a large wetted area within the bed. Exhaust gases flowing up through the bed creates the necessary liquid/gas contacting. Vortex scrubbers use a vortical flow pattern in which water is sheared into droplets. This mechanical action creates a fluidized bed region in which liquid/gas contacting occurs.

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[8] USEPA, Publication AP-42, Compilation of Air Pollutant Emission Factors, Fourth Edition, Table 1.4-1, October, 1986.

[9] WDNR, Publication AM-048-090, Formaldehyde Special Study, Final Report, November, 1990.

[10] Telephone conversation between Phil Reynolds of Croll-Reynolds Company and Jeffrey M. Jaeckels of Oscar Mayer Foods Corporation, August, 1991.

[11] Telephone conversation between Gary Kaiser of E. I. DuPont Corporation and Tom Storck of Oscar Mayer Foods Corporation, January 1992.

After considering all three scrubber technologies OMFC ruled out the vortex scrubber based on performance of such a unit at a similar facility. The contacting time within this scrubbing system is apparently not sufficient for efficient absorption. The remaining two scrubbers are believed to be feasible and cost effective control technologies for formaldehyde control.

3.3 Process Changes Identified

Oscar Mayer has identified and evaluated several process changes which could technically be implemented to minimize formaldehyde emissions. These process changes include:

- Liquid Smoke - The use of liquid smoke would eliminate the use of natural smoke. Liquid smoke is manufactured by scrubbing natural smoke and concentrating this solution to industry specifications. As such, liquid smoke does contain formaldehyde[12]. Depending upon the method of application formaldehyde can be emitted through the use of liquid smoke. In addition to this, OMFC has evaluated liquid smoke formulations for several years and has not found a formulation which will match current product qualities using conventional smoking method. For these reasons OMFC does not consider the use of liquid smoke a viable method of formaldehyde control.

- Vapor Smoke - Vapor smoke is generated by steam distillation of wood chips. This vapor is introduced into a smokehouse as is natural smoke. The vapor is condensed onto the product and essentially is another method of liquid smoke application. OMFC has researched this method of smoking throughout the last 12 years. As with liquid smoke, OMFC has serious concerns about formaldehyde emissions and product quality associated with the use of this process. OMFC does not consider the use of vapor smoke a viable method of formaldehyde control.

3.4 BACT Proposal

Based on the investigations that OMFC has conducted to date as summarized above, one of at least two scrubbing technologies is proposed as BACT. The two scrubber technologies that OMFC is currently evaluating are the mist scrubber and packed bed scrubber.

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[12] Correspondence between Gary Underwood of Red Arrow Products Company Inc. and Jeffrey M. Jaeckels of Oscar Mayer Foods Corporation, October, 1991.

The BACT selection was primarily limited to afterburners and scrubbers. Formaldehyde control efficiencies of afterburners has not been well defined but can be assumed to be within the same range as scrubbers. This is due to the fact that low levels of formaldehyde are in the exhaust stream to begin with and combustion of natural gas will form formaldehyde. Levels of formaldehyde from natural gas combustion will vary with combustion conditions.

Preliminary test results indicate that both the mist scrubber and packed bed scrubbers can achieve efficiencies of 80-95% depending primarily on the levels of formaldehyde in the exhaust stream and air flow rate.

An economic analysis was conducted to estimate the capital and operating costs expected to be required for afterburners and scrubber technologies. Based on this analysis it was concluded that scrubbers can control formaldehyde at an annualized cost approximately 10 times less than the cost of afterburners. In addition to the economic advantage no additional air pollution is generated by the use of scrubbers. The summarized results of the economic study are presented in Table 3. Detailed spreadsheets including assumptions are found in Appendix A.

Table 4
Economic Analysis Summary
Formaldehyde Control Technologies
Oscar Mayer Foods Corporation

Control Technology Description	Est. Control Efficiency	Total Annualized Cost	Control Effectiveness ($/Ton)
Packed Bed Scrubber	90%	$362,000	$262,000
Mist Scrubber	90%	$427,000	$309,000
Afterburner	90%	$3,855,000	$2,791,000

3.5 Compliance Plan Schedule

The following approximate schedule is planned to bring the smokehouse emissions into compliance with the provisions of NR 445. The overall goal of compliance by April 1, 1994 will be met.

Compliance Schedule Smokehouse Formaldehyde Emission Control Oscar Mayer Foods Corporation	
Target Date	**Description of Activity**
Nov 1991	Start Process Control Studies
Nov 1991	Start Emission Control Studies
Feb 1992	Start Pilot Testing of Scrubbers
Jun 1992	Start Process Control Pilot Studies
Oct 1992	Complete All Pilot Testing
Nov 1992	Determine Scrubber Selection as BACT
Nov 1992	Start Control Systems Design
Mar 1993	Start Fabrication of Control Systems
Sep 1993	Start Installation of Control Systems
Jan 1994	Startup of Control Systems
Mar 1994	Confirm Compliance With NR 445

As more information is developed the contents of this plan and/or the compliance schedule itself may be modified to reflect the most current information. However, smokehouse emissions will be in compliance with the formaldehyde emission limitations by the times specified in NR 445.

Appendix A

Economic Analysis Data

Afterburners
Mist Scrubbers
Packed Bed Scrubbers

Control Technology Cost Estimate Summary

Control Technology: Afterburners (1200 degrees, 0.6 second retention time)
Estimated Control Efficiency 90 Percent

Total Base Formaldehyde Emissions 3,069 lb/yr

Control Unit No.	Unit Size (ACFM)	Annual Hours Operated	Purchase Cost	Install. Cost	Process Control Cost	Total Direct Cost	* Total An. Dir. Cost	Annual Operating Cost	** Total Annual Cost
1	12,000	8,760	$123,000	$26,888	$5,000	$154,888	$25,200	$516,931	$542,131
2	17,000	8,760	$134,000	$33,916	$5,000	$172,916	$28,134	$732,319	$760,453
3	15,000	1,460	$130,000	$31,201	$5,000	$166,201	$27,041	$107,694	$134,735
4	15,000	1,460	$130,000	$31,201	$5,000	$166,201	$27,041	$107,694	$134,735
5	15,000	1,460	$130,000	$31,201	$5,000	$166,201	$27,041	$107,694	$134,735
6	15,000	1,460	$130,000	$31,201	$5,000	$166,201	$27,041	$107,694	$134,735
7	15,000	1,460	$130,000	$31,201	$5,000	$166,201	$27,041	$107,694	$134,735
8	8,600	8,760	$114,000	$21,533	$5,000	$140,533	$22,865	$370,467	$393,332
9	20,000	8,760	$139,000	$37,798	$5,000	$181,798	$29,578	$861,551	$891,129
10	4,000	8,760	$95,000	$12,927	$5,000	$112,927	$18,373	$172,310	$190,683
11	1,500	2,190	$76,000	$6,722	$5,000	$87,722	$14,272	$16,154	$30,426
12	2,000	2,190	$81,000	$8,143	$5,000	$94,143	$15,317	$21,539	$36,856
13	2,000	8,760	$81,000	$8,143	$5,000	$94,143	$15,317	$86,155	$101,472
14	5,000	8,760	$100,000	$15,000	$5,000	$120,000	$19,524	$215,388	$234,912
Total	147,100		$1,593,000	$327,077	$70,000	$1,990,077	$323,786	$3,531,284	$3,855,070

Total Annualized Cost $3,855,070
Control Effectiveness $2,791,405 $/ton Formaldehyde Removed

* Annualized direct costs assume an alternative investment of 10% and a lifetime of 10 years.
** To be used for comparison only. This is not a budget figure

Notes:

Purchase based on recent installation in Kirksville and EPA cost curves.

Installation costs for a 5,000 ACFM is assumed to be $15,000. Costs for other size units is estimated to be $15,000*(ACFM/5,000)^(2/3)

Process control costs are assumed to be $5,000 per unit.

Annual operatin costs are based on natural gas consumption.

COSTAB.WK1

Control Technology Cost Estimate Summary

Control Technology: Mist Scrubber
Estimated Control Efficiency 90 Percent

Total Base Formaldehyde Emissions 3,069 lb/yr

Control Unit No.	Unit Size (ACFM)	Annual Hours Operated	Purchase Cost	Install. Cost	Process Control Cost	Total Direct Cost	* Total An. Dir. Cost	Annual Operating Cost	** Total Annual Cost
1	12,000	8,760	$125,000	$26,888	$5,000	$156,888	$25,526	$9,492	$35,018
2	17,000	8,760	$218,000	$33,916	$5,000	$256,916	$41,800	$16,864	$58,664
3	15,000	1,460	$127,000	$31,201	$5,000	$163,201	$26,553	$2,128	$28,681
4	15,000	1,460	$127,000	$31,201	$5,000	$163,201	$26,553	$2,128	$28,681
5	15,000	1,460	$127,000	$31,201	$5,000	$163,201	$26,553	$2,128	$28,681
6	15,000	1,460	$127,000	$31,201	$5,000	$163,201	$26,553	$2,128	$28,681
7	15,000	1,460	$127,000	$31,201	$5,000	$163,201	$26,553	$2,128	$28,681
8	8,600	8,760	$101,000	$21,533	$5,000	$127,533	$20,750	$9,376	$30,126
9	20,000	8,760	$155,000	$37,798	$5,000	$197,798	$32,182	$13,407	$45,589
10	4,000	8,760	$88,000	$12,927	$5,000	$105,927	$17,234	$8,850	$26,084
11	1,500	2,190	$80,000	$6,722	$5,000	$91,722	$14,923	$2,453	$17,376
12	2,000	2,190	$88,000	$8,143	$5,000	$101,143	$16,456	$2,213	$18,669
13	2,000	8,760	$88,000	$8,143	$5,000	$101,143	$16,456	$8,850	$25,306
14	5,000	8,760	$88,000	$15,000	$5,000	$108,000	$17,572	$9,112	$26,684
Total	147,100		$1,666,000	$327,077	$70,000	$2,063,077	$335,663	$91,257	$426,920

Total Annualized Cost $426,920
Control Effectiveness $309,127 $/ton Formaldehyde Removed

* Annualized direct costs assume an alternative investment of 10% and a lifetime of 10 years.
** To be used for comparison only. This is not a budget figure

Notes:

Purchase costs provided by QUAD Envoronmental Systems.

Installation costs for a 5,000 ACFM is assumed to be $15,000. Costs for other size units is estimated to be $15,000*(ACFM/5,000)^(2/3)

Process control costs are assumed to be $5,000 per unit.

Annual operatin costs include: water supply, chemicals, treatment, pumping and air handling.

COSTQUAD.WK1

Control Technology Cost Estimate Summary

Control Technology: Venturi Scrubber followed by Packed Bed
Estimated Control Efficiency 90 Percent

Total Base Formaldehyde Emissions 3,069 lb/yr

Control Unit No.	Unit Size (ACFM)	Annual Hours Operated	Purchase Cost	Acc. & Install. Cost	Process Control Cost	Total Direct Cost	* Total An. Dir. Cost	Annual Operating Cost	** Total Annual Cost
1	12,000	8,760	$67,000	$53,777	$5,000	$125,777	$20,464	$15,682	$36,146
2	17,000	8,760	$89,500	$67,833	$5,000	$162,333	$26,412	$20,665	$47,077
3	15,000	1,460	$86,000	$62,403	$5,000	$153,403	$24,959	$2,968	$27,927
4	15,000	1,460	$86,000	$62,403	$5,000	$153,403	$24,959	$2,968	$27,927
5	15,000	1,460	$86,000	$62,403	$5,000	$153,403	$24,959	$2,968	$27,927
6	15,000	1,460	$86,000	$62,403	$5,000	$153,403	$24,959	$2,968	$27,927
7	15,000	1,460	$86,000	$62,403	$5,000	$153,403	$24,959	$2,968	$27,927
8	8,600	8,760	$59,000	$43,067	$5,000	$107,067	$17,420	$10,907	$28,327
9	20,000	8,760	$100,000	$75,595	$5,000	$180,595	$29,383	$23,687	$53,070
10	4,000	8,760	$32,000	$25,853	$5,000	$62,853	$10,226	$4,701	$14,927
11	1,500	2,190	$22,500	$13,444	$5,000	$40,944	$6,662	$482	$7,144
12	2,000	2,190	$23,500	$16,287	$5,000	$44,787	$7,287	$664	$7,951
13	2,000	8,760	$23,500	$16,287	$5,000	$44,787	$7,287	$2,658	$9,945
14	5,000	8,760	$38,000	$30,000	$5,000	$73,000	$11,877	$5,479	$17,356
Total	147,100		$885,000	$654,155	$70,000	$1,609,155	$261,909	$99,765	$361,574

Total Annualized Cost $361.574
Control Effectiveness $261,811 $/ton Formaldehyde Removed

* Annualized direct costs assume an alternative investment of 10% and a lifetime of 10 years.
** To be used for comparison only. This is not a budget figure

Notes:

Purchase costs provided by Croll-Reynolds Company

Accesory and installation costs for a 5,000 ACFM unit include $10,000 for pumps, $5,000 for a fan and $15,000 for installation. Accessory and installation costs for other size units are estimated by $30,000*(ACFM/5,000)^(2/3)

Process control costs are assumed to be $5,000 per unit.

Annual operatin costs include: water supply, chemicals, treatment, pumping and air handling.

CONTVP.WK1