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ASSESSMENT OF FORMALDEHYDE AS A POTENTIAL AIR POLLUTION PROBLEM

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Volume VIII

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ABSTRACT

This report is one of a series which assesses the potential air pollution impacts of 14 industrial chemicals outside the work environment. Topics covered in each assessment include physical and chemical properties, health and welfare effects, ambient concentrations and measurement methods, emission sources, and emission controls. The chemicals investigated in this report series are:

Volume I	Acetylene
Volume II	Methyl Alcohol
Volume III	Ethylene Dichloride
Volume IV	Benzene
Volume V	Acetone
Volume VI	Acrylonitrile
Volume VII	Cyclohexanone
Volume VIII	Formaldehyde
Volume IX	Methyl Methacrylate
Volume X	Ortho-Xylene
Volume XI	Maleic Anhydride
Volume XII	Dimethyl Terephthalate
Volume XIII	Adipic Acid
Volume XIV	Phthalic Anhydride.

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SECTION I

SUMMARY AND CONCLUSIONS

Formaldehyde is a colorless gas with a pungent, irritating odor. It is produced from methyl alcohol by catalytic vapor-phase oxidation or by an oxidation-dehydration process, and its main use is as an intermediate in the preparation of explosives, dyes, synthetic lacquers, and resins. Formaldehyde polymerizes in the presence of air and moisture to form the solid paraformaldehyde. This solid is easily decomposed to yield aqueous formaldehyde solutions, which are available commercially in a solution containing 37 percent 50 percent formaldehyde by weight.

Inhalation of formaldehyde at about 10 ppm causes rapid and severe irritation of the eyes, nose, and upper respiratory tract. The odor detection threshold is 0.05 ppm, while eye irritation has been reported at 0.01 ppm. The U.S. occupational standard is 3 ppm for an 8-hour time weighted average, while the American Conference of Governmental Industrial Hygienists has recommended a threshold limit value (TLV) of 3 mg/m^3 (2 ppm). Aerosols have a synergistic effect on human response to formaldehyde. Formaldehyde is known to be a component of photochemical smog formation.

Simple diffusion modeling estimates place the likely maximum 1-hour average ambient concentration at about 2 ppm. The maximum 24-hour average ambient concentration might be expected to be about 1 ppm. These estimates assume a location about 300 meters from the largest production facility, and are more than 2.5 times the estimated concentration near the next largest facility. Average ambient concentrations of 0.05 ppm have been measured in Los Angeles, with peak values being about 0.15 ppm.

Almost 6 billion pounds of formaldehyde solution (37 percent formaldehyde by weight) were produced in 1974, with about 30 percent of this being used for the production of urea-formaldehyde resins. Production is expected to increase at 7.5 percent per year through 1978. Phenolformaldehyde resin manufacture consumed about 24 percent of production. The primary emission sources in descending order are production, end product manufacture, and bulk storage. Total emissions of formaldehyde are estimated to have been about 10 million pounds in 1974.

Emissions from manufacture by the silver catalyst process occur mainly from the absorber vent gas and the fractionator off-gas vent. These are uncontrolled at most U.S. plants. Control methods which are currently used for absorber vent emissions are thermal incineration and redirection of vent gases to plant boilers for use as a fuel supplement. The only device reported for the fractionator vent is a water absorber. Systems that are feasible but not currently employed are plume burners (no supplemental fuel required) and catalytic incinerators.

Emissions from manufacture by the mixed catalyst process occur primarily from the absorber vent gas, and one firm is currently controlling these using a water scrubber. Other feasible control methods are thermal and catalytic incineration, and a flare system.

Based on the results of health effects research presented in this report, and the ambient concentration estimates, it appears that formaldehyde in air may produce eye and respiratory tract irritation in sensitive members of the general population. This applies especially to those living near the largest production facility; however, eye irritation from photochemical smog must be due, in part, to formaldehyde. A small-scale sampling program might be undertaken at two or three locations (near the plant and near the population centroid) in conjunction with a public response survey to determine ambient concentrations and to determine if irritating effects are occurring.

SECTION II

AIR POLLUTION ASSESSMENT REPORT

PHYSICAL AND CHEMICAL PROPERTIES

Formaldehyde is a colorless gas with a pungent, irritating odor. Its aqueous solution is referred to as formalin. Industrially it is made from methanol by catalytic vapor-phase oxidation or by an oxidation-dehydration process. Its largest use is as an intermediate in the preparation of explosives, dyes, synthetic lacquers, and resins. Because of its antiseptic properties it is used in the medical, brewing, and agricultural industries.[1]

In the presence of air and moisture at room temperature, formaldehyde polymerizes to paraformaldehyde, a solid with the molecular formula $(CH_2O)_n H_2O$. The polymer can be easily decomposed to yield aqueous formaldehyde solutions. Commercially, formaldehyde is available in a 37 percent - 50 percent by weight aqueous solution, with up to 15 percent methanol added to prevent polymerization. The toxicity of paraformaldehyde is similar to that of formaldehyde.[2] Significant physical properties are listed in Table 1.

HEALTH AND WELFARE EFFECTS

Effects on Man

Acute Poisoning Human sensory response to formaldehyde inhalation is summarized in Table 2. The inhalation of formaldehyde even at low

Table 1. SIGNIFICANT PROPERTIES OF FORMALDEHYDE

Synonyms	Methanal, oxomethane, oxymethane
Chemical formula	HCHO
Molecular weight	30.03
Boiling point	-19.5°C
Vapor density	1.067 (air = 1)
Solubility	Very soluble in water, alcohol, ether, and most organic solvents
Explosive limits	7% to 72% by volume in air
Ignition temperature	136°C
Flash point of a 37% formaldehyde solution with 15% methanol	50°C (closed cup)
At 25°C and 760 mm·Hg	1 ppm vapor = 1.227 mg/m^3 1 mg/m^3 vapor = 0.815 ppm

Table 2. ACUTE SENSORY RESPONSE OF MAN TO FORMALDEHYDE VAPORS

Dose, ppm	Time	Response	Ref.
0.01	5 min.	Eye irritation threshold	3
0.05		Odor threshold	4
0.5		Throat irritation	4
1.0		Detectable by nearly all people	5
2.0-3.0	8 hours	Tolerable; mild irritation of eyes, nose, and posterior pharynx	5
4.0-5.0	10-30 min.	Intolerable to most people; mild lachrymation; throat irritation	5,6
10.0	few min.	Profuse lachrymation	5
10.0-20.0		Burning of nose, throat, trachea; coughing	5
20.0	15-30 sec.	Lachrymation	7
20.0	30 sec.	Nose and throat irritation	7
20.0	1-2 min.	Sneezing	7
50-100	5-10 min.	May cause serious injury; serious bronchial inflammation	5

concentrations causes rapid and severe irritation of the eyes, nose, and other portions of the upper respiratory tract. Symptoms of exposure may include lachrymation, sneezing, coughing, a feeling of suffocation, rapid pulse, headache, and fluctuations in body temperature. A concentration of 0.01 ppm is the lowest reported eye irritation value,[3] and 0.05 ppm is the lowest reported value for the detection of the odor.[4] People acclimated to exposure may not complain of irritation until concentrations above 1 ppm are reached as is the case in most industrial exposure. Men exposed to 13.8 ppm for 30 minutes tolerated the exposure, despite considerable nasal and eye irritation and lachrymation. The eye irritation was not severe and wore off after 10 minutes in the test chamber.[8] Sensory response to formaldehyde will vary among individuals, with the values in Table 2 given as typical lower limits.

At exposure to between 10 and 20 ppm, normal breathing becomes difficult. Lachrymation subsides promptly after removal from exposure, but nasal and respiratory irritation may persist for an hour.[5] Inhalation of higher concentrations can cause laryngitis, bronchitis, and bronchopneumonia.[6]

The vapor may cause skin irritation, but skin sensitization to formaldehyde in the vapor state is rare. Individuals who have already developed a sensitivity to formalin will show skin irritation upon exposure to gaseous formaldehyde.[5]

No significant toxic effects from oral exposure were seen in humans despite the daily ingestion of 22 to 200 mg over a period of 13 weeks. Higher doses caused moderate irritation of the upper digestive tract.[5] Very high doses may result in respiratory depression and death.

<u>Chronic Poisoning</u> - The U.S. occupational standard for exposure to formaldehyde is 3 ppm for an 8-hour time weighted average, with exposure between 5 ppm and 10 ppm permissible for 30 minutes.[9] The

American Conference of Governmental Industrial Hygienists just reduced their recommended threshold limit value from 5 ppm to 2 ppm for an 8-hour workday.[10] These standards are based on acute sensory response data and are low enough to prevent respiratory damage, but they may not be low enough to prevent all chronic irritation.

Recent studies indicate chronic exposure to formaldehyde below 2 or 3 ppm may cause health problems. A Russian study mentions hypotonicity, chronic anxiety neurosis, and neurocirculatory asthenia among workers chronically exposed to concentrations of 0.48 ppm.[11] There have been complaints in fabric shops where the concentration has been measured at 0.13 to 0.45 ppm.[12] A study of embalmers exposed to average concentrations varying from 0.25 to 1.30 ppm daily shows a high incidence of respiratory irritation such as eye and nose burns, sneezing, coughing, and headaches.[10] Sleepiness, weakness, and tightness in the chest were not encountered; these are characteristics of higher, more toxic concentrations.

Dermatitis is only seen in chronic vapor exposure when people have had previous exposure to formalin or paraformaldehyde powder for sensitization.[5]

<u>Effects on Animals</u>

<u>Acute Poisoning</u> - Animal studies reveal that in addition to causing severe eye and respiratory tract irritation, the inhalation of high concentrations of formaldehyde vapor may result in lung injury and damage to other organs. In one study the LC_{50} for rats for a 30-minute inhalation exposure was determined to be 800 ppm.[13] Rats exposed to such concentrations became listless and showed lachrymation with increased secretion from the nose. Autopsies typically revealed hemorrhages and pulmonary edema, and signs of kidney and liver damage. Death was due to lung injury, not to an induced narcotic effect on the

central nervous system. Those rats that survived appeared to recover normally in 2 to 3 days. Groups of 50 mice, 20 guinea pigs, and 5 rabbits were exposed to 16 ppm for 10 hours.[14] Deaths took place after exposure, with autopsies showing expanded edematous and hemorrhagic lungs, fluid in the pleural and peritoneal cavities, distended alveoli, ruptured alveolar walls, and enlarged livers. A concentration of 250 ppm inhaled over 4 hours caused death in rats.

Low levels of formaldehyde can cause cessation of ciliary activity. Exposure to 3 ppm for 50 seconds or 0.5 ppm for 150 seconds caused cessation of the ciliary beat in the respiratory tract in anesthetized, tracheotomized rats.[15]

Chronic Poisoning Fifteen rats, thirteen rabbits, three monkeys and two dogs were exposed continuously for 90 days to 3.8 ppm formaldehyde vapor.[16] Only one rat died, with the other animals showing normal hematological values and no signs of illness. The lungs of all exposed species showed varying degrees of interstitial inflammation.

Pregnant rats were continuously exposed to 0.1 ppm and 0.83 ppm formaldehyde vapor.[17] The mean duration of pregnancy was prolonged 14 to 15 percent as compared to pregnant control rats, with a decrease in the number of fetuses per female at 0.83 ppm. The lungs and liver, the organs directly affected by inhalation, weighed less than those of the control offspring. More work must be done in determining the toxic effects of chronic exposure to formaldehyde and relating the results to set chronic exposure standards for humans.

Effects on Vegetation

Not many studies have been done illustrating the phytotoxicity of formaldehyde. Alfalfa was not damaged after exposure to 2 ppm for 2 hours, but there was some leaf damage after exposure to 0.7 ppm for

5 hours.[18] Irradiation of formaldehyde at 5.6 and 6.1 ppm for 4 hours with nitrogen oxides present did not damage pinto beans, tobacco wrapper, and petunias.[19]

A Russian study indicates that some plants may be sensitive to formaldehyde concentrations in the magnitude of 0.017 ppm (0.02 mg/m^3).[20] This value represents the formaldehyde concentration that did not produce a decrease in photosynthesis in several tree species during a 5-minute exposure.

Other Effects

Formaldehyde and Aerosols The effects of formaldehyde inhalation may be increased in the presence of an aerosol. Mice were exposed to 12.5 ppm formaldehyde in the presence of nine different aerosols.[21] The formaldehyde/aerosol mixtures had a synergistic effect, resulting in an increase in deaths and the severity of pulmonary edema. Specific results of the study are shown in Table 3.

Guinea pigs were exposed to formaldehyde concentrations between 0.07 and 47 ppm with and without the presence of 10,000 μg/m^3 0.04-micron diameter sodium chloride aerosol.[22] Statistically significant increases in "respiratory work" were found as a result of aerosol exposure with a formaldehyde concentration above 0.3 ppm. The formaldehyde/aerosol mixture delayed recovery after discontinuation of exposure. The increased toxicity may be due to the concentrating effect of the aerosol on formaldehyde, resulting in locally high formaldehyde levels on each aerosol.

Formaldehyde and Photochemical Smog Formaldehyde is a product of the atmospheric photochemical reactions of many hydrocarbons, and it serves as an indication of the intensity of smog as measured by eye irritation. It can be photooxidized with a nitrogen oxide mixture in air to yield ozone, toxic to man and implicated in plant damage.[23]

Table 3. DEATHS OF MICE FROM EXPOSURE TO FORMALDEHYDE/AEROSOL MIXTURES[21]

Aerosol	Size, microns	Aerosol concentration, μg/liter	ST_{50},[a] min	Significance of increased death rate[b]
Triethylene glycol	1.8	2,210	71	++
Ethylene glycol	2.0	2,920	168	0
Mineral oil	2.1	1,420	72	++
Glycerin	2.0	1,280	114	+
Sodium chloride	2.6	2,320	114	+
Dicalite	3.3	420	118	+
Diatomaceous earth	2.9	360	102	++
Absorptive clay	3.3	960	157	0
Silica gel	2.7	310	145	0

[a] ST_{50} is the time for 50 percent survival of mice. For 12.5 ppm formaldehyde in the absence of aerosols, the ST_{50} was 147 minutes.

[b] Significance code: 0 = no significance
+ = significant
++ = highly significant.

AMBIENT CONCENTRATIONS AND MEASUREMENTS

Formaldehyde concentrations in Los Angeles on 26 days from September through October 1966 averaged 0.05 to 0.12 ppm.[24] Earlier measurements[25] in the fall of 1961 averaged 0.04 ppm with the average daily maximum 0.06 ppm. About 13 percent of the daily maximum values were over 0.10 ppm, and the highest concentration measured during the period was 0.16 ppm.

Ambient Concentration Estimates

The largest installation for formaldehyde production is located in a town of about 3,700 population, and it has a capacity of about 1,300 million lb/yr. Assuming a 0.1 percent loss, this converts to an emission rate of:

$$\frac{(0.001 \text{ emission factor})\ (1300 \times 10^6 \text{ lb/yr})\ (453.6 \text{ g/lb})}{3.1536 \times 10^7 \text{ sec/yr}}$$

$$= 18.7 \text{ g/sec of formaldehyde.}$$

Some assumptions must be made regarding this formaldehyde release to the atmosphere. First of all, the emissions do not all come from one source location, but rather from a number of locations within the plant where formaldehyde leaks to the atmosphere. Thus, the emissions can be characterized as coming from an area source which will be taken to be 100 meters on a side. Secondly, the emissions occur at different heights, and an average emission height of 10 meters is assumed.

Ground level concentrations can then be estimated at locations downwind of the facility.[26] To do this a virtual point source of emission is assumed upwind of the facility at a distance where the initial horizontal dispersion coefficient equals the length of a side of the area divided by 4.3. In this case:

$$\sigma_{yo} = 100\text{m}/4.3 = 23.3\text{m}$$

Assuming neutral stability conditions (Pasquill-Gifford Stability Class D) with overcast skies and light winds, the upwind distance of the virtual point source is approximately 310 meters. With consideration of the plant boundary, it is reasonable to assume that the nearest receptor location is thus about 500 meters from the virtual point source. Finally, taking 2 m/sec as an average wind speed, the ground level concentration may be calculated from:

$$X = \frac{Q}{u\pi\sigma_y\sigma_z}\ e^{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2}$$

or

$$X = \frac{18.7}{(2)\ \pi\ (36)\ (18.5)}\ e^{-\frac{1}{2}\left(\frac{10}{18.5}\right)^2}$$

$$= 3.86 \times 10^{-3}\ g/m^3$$

for a 10-minute average concentration. Over a period of an hour this becomes $3.86 \times 10^{-3}\ g/m^3\ (0.72) = 2.78 \times 10^{-3}\ g/m^3$ or 2.3 ppm 1-hour average concentration. Over a 24-hour period, the average concentration might roughly be expected to be about 1.3 ppm.

Measurement Techniques

Several methods are available for measuring formaldehyde concentrations in ambient air and from emission sources. The source methods are the potassium hydroxide method, the sodium bisulfite method, the acidified distilled water method and the methylamine hydrochloride method. The ambient air sampling procedures are the phenylhydrazine hydrochloride method, and the water method. Specific details of the ambient air sampling procedures are given below.

Formaldehyde in concentrations from 2 to 20 ppm can be determined by collection in a solution of phenylhydrazine hydrochloride.[27] After the sample is collected it is treated with potassium ferricyanide and hydrochloric acid. The resulting magenta-stained solution is read on a spectrophotometer at 515 $m\mu$ and is compared to a calibration curve. Iron in any form will interfere, and other aldehydes will cause some degree of interference.

Another method for determining formaldehyde concentrations involves collecting the air sample in a midget impinger containing water.[28] A solution of sodium sulfite in sodium tetrachloromercurate is added to the sample, followed by addition of an acidic solution of pararosaniline hydrochloride, which produces a blue-violet color.

The color is then read on a spectrophotometer at 560 mμ. This method is accurate to 0.01 ppm. The only interferences are from acetaldehyde and propionaldehyde.

SOURCES OF FORMALDEHYDE EMISSIONS

Formaldehyde Production and Consumption

The production of formaldehyde in solution in 1974 was 5,846 million pounds (37 percent formaldehyde by weight)[29] and is expected to increase at 7.5 percent per year through 1978.[30] The largest end use of formaldehyde is for the production of urea-formaldehyde resins, accounting for 30 percent of total production. Urea-formaldehyde is primarily used in adhesives, textile, and paper treating and coating; and in surface coatings as a cross linking agent. Phenol-formaldehyde resin, the second largest end use for formaldehyde, consumed an estimated 24 percent of the total production. It is primarily used as an adhesive for the plywood industry. The consumption of formaldehyde for all other end products is shown in Table 4. This table also shows the expected growth rates for each sector of the market.

Table 4. ESTIMATED FORMALDEHYDE CONSUMPTION - 1974[31]

	Millions of pounds solution	% annual growth
Urea-formaldehyde resins	1,728	12
Phenol-formaldehyde resins	1,420	7
Melamine-formaldehyde resins	223	5
Pentaerythritol	367	3.5
Hexamethylenetetramine	339	6
Acetal resins	511	8
Urea-formaldehyde concentrates	142	3
Acrylic esters	81	0
Trimethylolpropane	95	8
Textile treating applications	104	3
Tetrahydrofuran	189	7
Chelating agent	189	7
Acetylenic chemicals	189	5
4,4-metaylenedianiline	142	5
Other	127	5
Total	5,846	7.5

Formaldehyde Sources and Emission Estimates

Primary sources of emissions of formaldehyde occur from formaldehyde production, end product manufacturing, and bulk storage. Total emissions of formaldehyde are estimated to be 10.14 million pounds (100 percent formaldehyde), representing 0.47 percent of total production. Table 5 shows the breakdown by source type.

Table 5. SOURCES AND EMISSION ESTIMATES OF FORMALDEHYDE - 1974

	Million pounds-100% basis	
Formaldehyde production		5.04
Silver catalyst process	4.50	
Mixed oxide catalyst process	0.54	
End product manufacture		5.04
Bulk storage		0.06
Total		10.14

The major source of emissions of formaldehyde results from formaldehyde production. Formaldehyde is produced solely from methanol in the United States. Two processes are dominant, the mixed oxide catalyst process and the silver catalyst process, the latter accounting for an estimated 77 percent of the total production. Currently, 35 plants are using the silver catalyst process and 19 plants are using the mixed oxide catalyst process. Names and locations of the production facilities are listed in Appendix A.

A study concerning emissions from the formaldehyde industry has recently estimated losses from both processes.[30,32] It is reported that approximately 0.001 pounds of formaldehyde are lost from the absorber vent gas and the fractionator off-gas vent per pound of formaldehyde solution produced using the silver catalyst process.[32] Using this factor and the production figure for this process (4.5 billion pounds) results in 4.5 million pounds of formaldehyde emitted.

The emission factor reported for the mixed oxide catalyst process is 0.0004 pounds lost per pound of formaldehyde solution produced.[30] Using this factor and the estimated production (1.345 billion pounds) by this process results in 0.54 million pounds of formaldehyde lost to the atmosphere.

Since there are no data readily available in the literature concerning emissions of formaldehyde from end product manufacturing, it is estimated that emissions from this category will be similar to emissions from formaldehyde products; or 5.04 million pounds.

The last major emission source is from bulk storage. It has been reported that most tanks storing formaldehyde do not use any type of control equipment, and have an emission rate of 0.00001 pound emitted per pound stored.[30] Using this factor, total evaporative emissions are 0.06 million pounds.

FORMALDEHYDE CONTROL METHODS

It appears from information reported in two recent studies that the majority of U.S. plants do not employ emission control devices.[30,32] However, in a few isolated cases some control devices are used and are described below.

Emissions from the silver catalyst process are primarily from the absorber vent and the product fractionator vent. Control devices that are currently used on the absorber vent are thermal incinerators and the redirection of the vent gases (both 99+ percent efficient) to the plant boiler as a fuel supplement. The only control device currently reported for the fractionator vent is a water absorber (94 percent efficient).

Systems that are feasible but not currently employed are plume burners and catalytic incinerators. Cost data for all five methods of control are presented in Table 6.[32]

Emissions from the mixed catalyst process result primarily from the absorber vent gas. It has been reported that only one firm is currently using control equipment on this stream: a water scrubber.[30] The efficiency of this equipment is indicated to be approximately 67 percent.

Other systems that are currently feasible but not employed are thermal incinerators, catalytic incinerators, and a flare system. Cost data and their expected efficiencies are presented in Table 7.[30]

Table 6. EMISSION CONTROL DEVICES - SILVER CATALYST PROCESS[a,32]

	Type of emission control device				
	Water scrubber	Thermal incinerator	Catalytic incinerator	Plume burner	Boiler house vent gas burner
Number of units	1	1	1	1	?
Capacity of each unit, %	100	100	100	100	?
Feed					
Total flow, lb/hr	8,146	8,146	8,146	8,146	8,146
scfm	2,170	2,170	2,170	2,170	2,170
Combined effluent					
Total flow, lb/hr	8,109	15,132	22,979		15,000
scfm	2,163	3,515	5,244	>2,200	3,500
Total capital investment, $	28,700	58,500	54,700	35,600	55,900
Total operating cost, $/yr	10,420	12,840	17,920	8,640	-3,940
Efficiency, %	94.6	99+	99+	89+	99+

[a]Costs updated to first quarter of 1975.

Note: Values based on 100 MM lb/yr formaldehyde production.

Table 7. EMISSION CONTROL DEVICES - MIXED OXIDE CATALYST PROCESS[a,30]

	Type of emission control device				
	Thermal incinerator		Catalytic incinerator	Flare system	Water scrubber
	No heat recovery	40% heat recovery			
Number of units	1	1	1	1	1
Capacity of each unit, %	100	100	100	100	100
Feed					
Total flow, lb/hr	14,968	14,968	14,968	14,968	14,968
scfm	3,390	3,390	3,390	3,390	3,390
Combined effluent					
Total flow, lb/hr	21,145	21,145	18,885	18,885	14,943
scfm	4,790	4,790	4,270	4,270	3,385
Total capital investment, $	68,600	86,400	38,100	36,900	102,900
Total operating cost, $/yr	46,500	37,600	33,900	40,300	25,300
Efficiency, %	99+	99+	99+	90	65

[a]Costs updated to first quarter of 1975.

Note: Values based on 100 MM lb/yr formaldehyde production.

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APPENDIX A

FORMALDEHYDE MANUFACTURERS[30]

		Capacity, million pounds/year	
		Silver process	Metal oxide process
Allied	Ironton, Ohio	308	
Borden	Demopolis, Ala.	80	
	Diboll, Texas	70	
	Fayetteville, N.C.	200	
	Fremont, Calif.	80	
	Kent, Wash.	70	
	La Grande, Oregon	40	
	Louisville, Ky.	70	
	Missoula, Mont.	80	
	Sheboygan, Wisc.	120	
	Springfield, Oregon	260	
Celanese	Bishop, Texas	1,300	
	Newark, N.J.		117
	Rock Hill, S.C.		117
Commercial Solvents	Sterlington, La.	30	
	Seiple, Pa.	80	
Du Pont	Belle, W.Va.	485	
	Grasselli, N.J.	150	
	Healing Spring, N.C.	200	
	La Porte, Texas	200	
	Toledo, Ohio	320	
	Linden, N.J.	150	
GAF	Calvert City, Ky.		100
Georgia Pacific	Columbus, Ohio		100
	Coos Bay, Oregon		80
	Crosett, Ark.	100	60
	Albany, Oregon		100
	Taylorsville, Miss.		100
	Vienna, Ga.	100	

FORMALDEHYDE MANUFACTURERS[30] (continued)

		Capacity, million pounds/year	
		Silver process	Metal oxide process
Gulf	Vicksburg, Miss.		40
Hercules	Louisiana, Mo.	170	
	Wilmington, N.C.	95	
Hooker	N. Tonawanda, N.Y.	135	
Monsanto	Alvin, Texas	150	
	Addyston, Ohio	110	
	Eugene, Oregon	100	
	Springfield, Mass.	280	
Reichhold	Hampton, S.C.	36	
	Houston, Texas		100
	Moncure, N.C.		100
	Tacoma, Wash.		40
	Tuscaloosa, Ala.	70	
	Kansas City, Kansas	40	
	White City, Oregon		50
	Malvern, Ark.		100
Rohm & Haas	Philadelphia, Pa.	25	
Skelly	Springfield, Oregon		70
	Winfield, La.		70
Tenneco	Fords, N.J.	105	160
	Garfield, N.J.	105	
Union Carbide	Bound Brook, N.J.		150
Wright	Acme, N.C.		75
Total		5,914	1,729