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Project Summary

Catalytic Incineration of Low Concentration Organic Vapors

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Catalytic abatement of low concentration hydrocarbon vapors has been demonstrated. This report presents the results of the demonstration conducted on both a pilot and full-scale system. The tests were conducted on industrial exhausts which contained carbon monoxide as well as volatile hydrocarbons. Utilizing this data an economic comparison was made between thermal and catalytic abatement systems.

The pilot data was obtained in a plastic printing plant in which the major solvents were ethanol, n-propyl acetate, and heptane. Test data was obtained for a 5-month period.

The full-scale data was obtained from the exhaust of a Formox* formaldehyde plant. The exhaust contained carbon monoxide, dimethyl ether, methanol, and formaldehyde. Test data was gathered over a 9-month period.

The pilot and full-scale units were able to convert 97%-99% of the pollutants to carbon dioxide and water.

This report was submitted in fulfillment of Contract No. 68-02-3133 by the Systems Department of the Engelhard Industries Division of Engelhard Minerals & Chemicals Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1, 1978 to March 31, 1980, and was completed November 15, 1980.

*Trademark of Reichhold Chemical Company

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A study of catalytic incineration of low concentration organic vapors has been conducted. The scope of the study included both pilot-scale and full-scale demonstration testing of catalytic abatement systems. In addition to the assessment of the catalytic system's abilities to reduce organic emissions, an economic comparison was made between catalytic and thermal air pollution abatement systems.

Catalysis is the process of changing the velocity of a chemical reaction by the presence of a substance (catalyst) that remains apparently chemically unaffected throughout the reaction.

The catalyst used in this study is a precious metal formula evenly distributed over a high-surface-area aluminum oxide support material. The support material comes in two forms, pellet and honeycomb. High catalyst surface area is a major contributing factor in catalyst activity in that it assists in exposing a maximum number of active catalytic sites to the flowing gas. Many catalyst formulas using platinum, paladium, or other precious metals are used in combination with surface preparation to give the properties necessary for each application. Selection of a catalyst formulation and operating temperature depends on many interrelating factors. These include the organic materials to be removed, the outlet concentration to be achieved, the operating temperature, and the catalyst life which in itself is dependent on temperature, solid particles concentration in the gas, and elements (such as sulfur) which reduce catalyst life.

Pelletized catalyst makes for easy loading and unloading and is less expensive than honeycomb catalyst. It is used in pressurized chemical processes. Honeycomb catalyst, with its fixed direct flow-through passages, has a much lower pressure drop resulting in a smaller reactor vessel and lower power consumption by the gas moving device. Honeycomb catalyst is used in the catalytic abatement systems.

Organic vapors as well as carbon monoxide can be removed effectively from many kinds of off-gas streams by oxidation in catalytic reactors. When the off-gases containing these pollutants are heated to suitable temperatures at a given space velocity, the combustible components react with oxygen from the air to form harmless carbon dioxide and water vapor. The term "space velocity" is defined as the volume of gas flowing through the catalyst per hour, divided by the volume occupied by the catalyst. Space velocity replaces the term "contact time" used in thermal incinerators. As a frame of reference, contact times in thermal units are usually 0.3 to 0.5 seconds. A space velocity of 50,000 hr^{-1} is equivalent to a contact time of 0.072 seconds.

In a thermal incinerator, pollutants are oxidized directly in the residence chamber at high temperature—typically above 704°C. Because of the high fuel consumption required to maintain these temperatures in a thermal incinerator, the alternative of catalytic reaction is often preferable.

In a catalytic reactor, the catalyst induces oxidation at lower temperatures, typically at 316-427°C.

Lower operating temperatures mean lower fuel consumption. Lower equipment costs from smaller reactors and heat exchangers help balance the additional cost of catalyst, making the overall equipment cost comparable to thermal systems.

In some cases, the heat generated by the chemical reaction within the catalytic reactor permits self-sustained operation: depending on concentration and other factors, a well-designed catalytic abatement system equipped with a heat recuperator may be self-sufficient after initial lightoff. Lower operating temperatures also have the advantage of preventing NO_x formation.

The study was divided into four phases. Phase I was the process selection. Phase II was the preparation and installation of a pilot demonstration unit on a plastic printing plant. Phase III was a full-scale demonstration of a catalytic air pollution abatement system installed on a Formox type formaldehyde plant. Phase IV is this final report in which the data are presented and analyzed.

Conclusions

Pilot Test Unit

The catalytic abatement of low level hydrocarbons from the slip stream of a plastic printing press exhaust has resulted in low level emissions in that stream.

1. The catalytic abater at a space velocity of 50,000/hr^{-1} and an exhaust temperature of 315°C would reduce total hydrocarbons from the plastic printing plant 95% or more for a period of 3 years.
2. Increased conversion efficiency may be obtained by increasing temperature or reducing space velocity.
3. Increased catalyst life may be obtained by increasing temperature.
4. Conversion efficiency varies for the different components of the exhaust.

Full-Scale Unit

The catalytic abatement system has been operating on the exhaust of a Formox formaldehyde plant for a year.

1. The removal efficiency of the catalytic abatement system has remained in the range of 97.9% to 98.5%. There is no trend in the data points which would predict a maximum catalyst life. A minimum of 3 to 5 years is indicated.
2. The catalytic abatement system was not receiving any appreciable (1 ppm) NO_x nor was any NO_x produced by the system.

Pilot Test

Process Description

The test was conducted on the exhaust stream of a plastic film printing press manufactured by the Paper Converting Machine Company. It is a six-station, 60-in. (152-cm) wide central impression cylinder flexographic printing press. The press contains dryers which evaporate volatile organic solvents from the plastic film after printing.

The inks employed are solvent based polyamid printing inks which are approximately 78% by weight volatile at the proper printing viscosity. The major volatile components of the inks are ethanol, n-propyl and 2-propyl alcohol, heptane, and n-propyl and 2-propyl acetate. Ethanol is the major solvent component but the percentage of all components varies widely with different colors as does the amount of additional solvent added to the original inks to bring them to the proper printing viscosity.

Pilot Test Unit Description

The pilot test unit consists of a blower, electric heater, catalytic reactor, and temperature, flow and pressure instrumentation. A flow schematic of the unit is shown in Figure 1. The reactor contains Engelhard's proprietary catalyst. The catalyst is a precious metal formula on a unitary ceramic substrate. The Pilot Test Unit contains two catalyst elements, each 1.5 in. (3.8 cm) in diameter by 3 in. (7.6 cm) deep. The total volume of the bed is 0.006 ft^3 (170 cm^3).

Pilot Test Program

The test program was conducted over a period of 6 months (July-December 1979). Five tests were conducted during the 6-month period. The tests were all performed at three temperatures and three space velocities. A target for conversion efficiency of 95% for a 3-year period was chosen. These numbers were chosen arbitrarily from past experience but proper selection of the data would make it possible to alter these numbers to meet a specific application.

During the initial testing periods, the inlet and outlet were sampled to determine the content of n-propyl acetate, ethanol, and n-propyl alcohol. After testing, the actual temperature rise was compared to the calculated temperature rise. It was found that the calculated rise from the measured hydrocarbon contact was less than actual temperature rise. This indicated that additional unmeasured hydrocarbon was probably present and that additional testing was necessary. As a result, it was decided to also monitor total

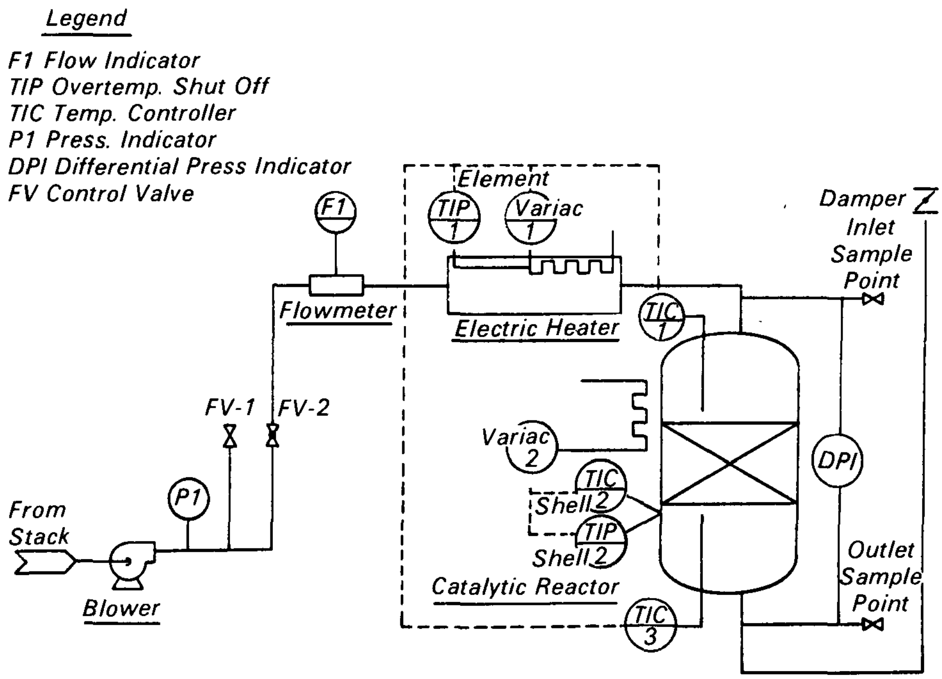


Figure 1. *Flow schematic pilot test unit.*

organic carbon and heptane in the exhaust. Heptane monitoring began on September 25. Total hydrocarbon monitoring began on October 30.

Results

A summary of the results of the pilot test program is provided in Tables 1, 2, and 3.

Full Scale Catalytic Unit

Installation

The full-scale unit is an Engelhard Deoxo Catalytic Pollution Abatement System, Model PAS-4, installed on a formaldehyde plant using the Formox process under license from Reichhold Chemicals, Inc. The process makes formaldehyde by passing preheated air and recycled process gas mixed with methanol through a Formox catalyst. The reaction without balancing the equation is:

$$CH_3OH + O_2 + \text{inerts} \longrightarrow$$

methanol oxygen

$$HCHO + CH_3OCH_3 + CO + \text{inerts}$$

formaldehyde dimethyl ether carbon monoxide

Recycling takes place with sufficient air addition to keep the inlet oxygen level at about 10%. It is, therefore, necessary to withdraw approximately 25% of the exhaust gas to remove the inerts; i.e., nitrogen, dimethyl ether, and carbon monoxide.

The catalyst is contained in a multiple tube converter where a controlled reaction takes place. Formaldehyde is absorbed in multiplate columns which produce an essentially methanol-free product.

Process Description

The catalytic incinerator (Figure 2) is used to reduce hydrocarbon emissions being exhausted in the off-gas from a Formox formaldehyde plant. The gas stream, under saturated conditions, exits the plant at a rate of 4500-6000 m^3/h entering the catalytic incinerator at 32-43°C. The entering gas passes through a gas-to-gas recuperative heat exchanger to raise the temperature to 232°C minimum. The gas then proceeds through a gas-fired preheater which is used to start the system or add heat if the incoming exhaust is low in heat content. It then passes through a mixing section to ensure even distribution of the heat before entering the catalyst bed. After combustion, the temperature rises to 427-621°C, depending on hydrocarbon loading, and the hot exhaust gas passes through the heat exchanger to the exhaust stack. A bypass of the inlet gas around the heat exchanger permits regulation of the incoming gas stream temperature.

The exhaust stream inlet has the following composition on a dry basis (actual gas is saturated at 25-38°C):

Carbon Monoxide 3000-8000 ppm
Methanol 100-900 ppm

Table 1. *Pilot Test Data Summary, Preliminary*

Test	*Preliminary Testing*													
Date	*7/17*	*7/17*	*7/17*	*7/17*	*7/17*	*7/17*	*7/17*	*7/17*	*7/18*	*7/18*	*7/18*	*7/19*	*7/19*	*7/19*
Time	*0929*	*1001*	*1030*	*1305*	*1400*	*1430*	*1500*	*1643*	*1320*	*1352*	*1515*	*1021*	*1200*	*1115*
Measurement No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Flow Rate (m^3/h)	*8.3*	*11.9*	*15.3*	*14.6*	*11.9*	*8.5*	*5.1*	*5.1*	*11.9*	*8.5*	*5.1*	*5.1*	*8.5*	*12.2*
Space Velocity x 1000	*49*	*70*	*90*	*86*	*70*	*50*	*30*	*30*	*70*	*50*	*30*	*30*	*50*	*72*
Catalyst Inlet Temp. (°C)	*371*	*371*	*371*	*316*	*316*	*316*	*313*	*260*	*266*	*291*	*277*	*338*	*346*	*340*
Catalyst Outlet Temp. (°C)	*402*	*406*	*407*	*360*	*362*	*362*	*360*	*316*	*316*	*313*	*311*	*354*	*371*	*368*
Catalyst Press. Drop (Pa)	*622*	*846*	*1120*	*996*	*871*	*572*	*373*	*249*	*747*	*498*	*249*	*249*	*498*	*747*
Removal %														
Ethanol	*99.7*	*99.6*	*99.6*	*99.6*	*99.6*	*99.6*	*99.8*	*99.6*	*98.6*	*99.0*	*99.8*	*99.8*	*99.4*	*98.9*
N-Propanol	*99.8*	*99.8*	*99.4*	*99.1*	*99.2*	*99.6*	*99.9*	*99.8*	*98.7*	*99.3*	*99.9*	*99.8*	*99.6*	*99.1*
N-Propyl Acetate	*97.8*	*97.8*	*93.1*	*94.6*	*97.1*	*97.2*	*99.4*	*97.5*	*99.4*	*92.2*	*97.7*	*94.4*	*97.7*	*90.8*
Total	*99.7*	*99.6*	*99.4*	*99.3*	*99.4*	*99.5*	*99.8*	*99.6*	*98.6*	*99.0*	*99.8*	*99.7*	*99.4*	*98.9*

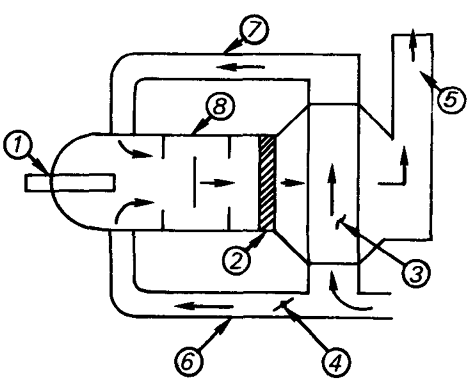
Table 2. *Pilot Test Data Summary, Months 1 and 2*

Test	Month 1									Month 2								
Date	8/15	8/15	8/15	8/15	8/15	8/15	8/16	8/16	8/16	9/17	9/17	9/17	9/18	9/18	9/18	9/18	9/18	9/18
Time	1221	1301	1346	1542	1614	1642	1112	1138	1303	1420	1445	1545	0925	0957	1005	1208	1253	1357
Measurement No	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Flow Rate (m^3/h)	11 9	8 5	5 1	11 9	8 5	5 1	11 9	8 5	5 1	12 1	8 5	5 1	11 7	8 5	4 9	11 7	8 5	5 1
Space Velocity x 1000	70	50	30	70	50	30	70	50	30	71	50	30	69	50	29	69	50	30
Catalyst Inlet Temp (°C)	327	327	333	230	232	227	285	288	282	337	335	326	285	288	285	232	229	241
Catalyst Outlet Temp (°C)	365	368	368	260	260	260	316	316	316	371	371	371	316	316	313	260	263	257
Catalyst Press Drop (Pa)	747	622	373	622	373	249	747	498	249	747	809	373	747	498	249	622	373	249
Removal %																		
Ethanol	98 8	99 2	99 7	99 4	99 4	99 8	98 4	98 8	99 8	99 4	99 5	99 9	98 2	98 9	99 3	96 9	98 1	99 7
N-Propanol	99 0	99 4	99 8	98 0	99 1	99 7	96 5	97 8	99 6	99 7	99 9	99 9	97 9	98 8	99 4	97 0	97 2	99 8
N-Propyl Acetate	95 1	97 8	99 8	58 6	68 3	82.0	91 7	94 5	99 2	96 5	99 0	99 6	93 5	95 8	99 1	54 8	59 8	93 3
Heptane	—	—	—	—	—	—	—	—	—	96 9	97 3	97 4	88 1	84 0	98 0	34 7	58 0	92 7
Total	98 7	99 2	99 7	97 0	98 2	99 1	97 4	98 3	99 7	99 5	99 6	99 9	97 8	98 9	99 3	95 1	95 9	99 4

Table 3. *Pilot Test Data Summary, Months 3 and 5*

Test	Month 3									Month 5								
Date	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	12/11	12/11	12/12	12/12	12/12	12/12	12/12	12/12	12/12
Time	*	*	*	*	*	*	*	*	*	1458	1615	1019	1117	1230	1318	1453	1515	1540
Measurement	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Flow Rate (m^3/h)	11 9	8 5	5 1	11 9	8 5	5 1	11 9	8 5	5 1	11 9	8 5	5 1	11 9	8 5	5 1	11 9	8 5	5 1
Space Velocity x 1000	70	50	30	70	50	30	70	50	30	70	50	30	70	50	30	70	50	30
Catalyst Inlet Temp (°C)	337	337	327	279	285	271	238	230	232	330	330	319	260	260	252	221	224	221
Catalyst Outlet Temp (°C)	371	371	362	316	316	316	266	260	260	371	371	365	321	319	319	260	265	260
Catalyst Press Drop (Pa)	647	498	299	647	498	249	622	373	249	560	436	249	498	373	249	436	324	199
Removal %																		
Ethanol	98 3	99 1	99 8	97 2	98 0	99 7	95 7	97 6	99 7	98 7	99 5	99 8	97 8	98 9	99 7	96 0	97 5	99 6
N-Propanol	99 9	99 9	99 9	96 3	97 3	99 8	95 0	97 2	99 7	98 6	99 5	99 8	97 3	98 8	99 8	95 5	97 5	99 8
N-Propyl Acetate	96 2	99 6	99 7	86 5	93 0	98 5	52 9	51 0	61 5	96 2	99 8	99 8	85 0	93 1	99 0	44 2	59 6	78 0
Heptane	—	—	—	83 3	63 8	97 7	57 7	62 0	78 0	—	—	99 0	85 3	91 9	98 3	24 1	50 4	77 0
Total	98 9	99 5	99 9	96 2	97 3	99 6	93 0	95 9	98 9	98 5	99 5	99 8	96.9	98 5	99 7	90 7	94 0	97 9
Total Organics**	97 7	98 0	98 0	94 3	95 0	95 2	82 6	85 8	87 5									

*Average of three or more tests
**As analyzed.



1. *Burner*
2. *Catalyst Bed*
3. *Heat Exchanger*
4. *Bypass Valve*
5. *Stack*
6. *Bypass Duct*
7. *Warm Gas Duct*
8. *Mixing Section*

Figure 2. *Full scale catalytic system.*

Dimethyl Ether	2500-4500 ppm
Formaldehyde	50-500 ppm
Nitrogen	90-92%
Oxygen	6-7%

Test Program

The test program began in July 1979, and is now part of a continuous monitoring system of the process. The program was conducted so that samples were obtained once or twice a week. Each test reading is an average of two samples. Grab samples were used on both the inlet and exhaust from the abatement system. Difficulty in separating the hydrocarbon components in the packed columns of the gas chromatograph prevented acceptable data from being obtained until October; the program was extended until February 1980 to achieve a 6-month program.

Testing on the full-scale system, compared to the pilot systems, was restricted. Very little variation of temperature or flow was obtained: the system was abating a plant under steady state conditions. Minor variations in feed conditions and plant operating conditions varied the inlet pollutant concentrations as shown in the data. Within these ranges, little or no effect was found in the outlet or abated concentrations.

Results

Results of the full-scale demonstration are provided in Table 4.

Economic Comparison

The economic comparison of a thermal and catalytic system presented here is limited to a comparison of units with similar efficiencies of operation, reduction of pollutants, and material costs. The capital and annual costs of operating an air pollution abatement system are shown in Table 5.

Table 4. *Full-Scale Test Data Summary*

Test Date	Flow Rate (m^3/h)	Outlet Temp. (°C)	Removal Efficiency (%) CO	CH_3OH	CH_3OCH_3	HCHO	Overall
11/30/79	4945	540	98.9	97.2	96.8	95.0	97.9
12/18/79	5149	432	99.1	98.6	97.2	98.6	98.5
1/11/80	2957	540	99.3	99.2	96.6	97.0	98.3
3/13/80	—	—	99.0	93.2	96.6	98.6	97.9
3/18/80	4124	505	99.0	98.9	96.7	99.1	98.3
3/25/80	4590	510	99.0	97.1	96.5	98.7	98.0

Table 5. *Capital and Annual Costs ($)*

	Plastic Printing				Formaldehyde			
	Catalytic		Thermal		Catalytic		Thermal	
Capacity (m^3/h)	16,992	33,984	16,992	33,984	8,496	16,992	8,496	16,992
Purchase	186,000	271,000	177,000	247,000	150,000	207,000	135,000	174,000
Installed	186,000	271,000	177,000	274,000	150,000	207,000	135,000	174,000
Capital Cost	372,000	542,000	354,000	494,000	300,000	414,000	270,000	348,000
Capital Recovery* (16.3%)	60,600	88,300	57,700	80,500	48,900	67,500	44,000	56,700
Catalyst Repl.	19,300	38,600	—	—	10,500	20,900	—	—
Maintenance (2%)	7,500	10,800	7,100	9,900	6,000	8,300	5,400	7,000
Fuel	36,500	73,000	107,500	214,000	—	—	198,000	370,000
Annual Cost	123,900	210,700	172,300	304,400	65,400	96,700	247,400	433,700

*Capital Recovery Factor of 16.3% is based on 10% interest over a 10-year period.

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The complete report, entitled "Catalytic Incineration of Low Concentration Organic Vapors," (Order No. PB 81 158 446; Cost: $9.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
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