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**WPI** WORCESTER  
POLYTECHNIC  
INSTITUTE

Worcester  
Massachusetts 01609  
(617) 793-5000



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February 29, 1988.

Dr. Frank Ciavattieri,  
Environmental Protection Agency  
90 Canal St.  
Boston, MA 02110

Dear Dr. Ciavattieri:

After speaking with you, I decided that it might be useful to prepare a concept paper for our discussions. I have enclosed two copies for you.

Very truly yours,

Alvin H. Weiss  
Professor of Chemical Engineering

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**MAR 10 88**

WASTE MANAGEMENT DIVISION

## CONCEPT PAPER

### CATALYTIC HYDROGENATION OF NEW BEDFORD DREDGING SPOILS

by

Professor Alvin H. Weiss  
Department of Chemical Engineering  
Worcester Polytechnic Institute  
Worcester, MA 01609

#### INTRODUCTION

There are eight candidate processes described in the September 1987 report by Research Triangle Institute (1) that are promulgated as approaches to eliminating PCB's from New Bedford, MA, dredging spoils. The candidate processes are ranked, and each, of course, has its merits and disadvantages. However, not included in this listing is one process that may be both technically effective and economically the lowest investment and operating cost of any listed. This process is catalytic hydrogenation.

It should be understood when considering oxidation as a method of removal of PCB's that these chlorinated aromatic hydrocarbons are quite refractory. Other organics can be oxidized far more readily than chlorinated aromatics. The consequence is that other organics present in a sludge matrix will oxidize before PCB's oxidize to a reasonable extent. This results in the considerable materials cost of a rather high oxygen consumption per ton of sludge.

On the other hand, functional groups, such as the Cl atoms on PCB's, the sulfide and disulfide linkages in malodorous compounds such as mercaptans and skatole, as well as olefinic, diolefinic, and acetylenic bonds formed from anaerobic decomposition processes, are the most reactive species for hydrogenation in a sludge. They are far more reactive than hydrocarbons or carbohydrates, for example. This means that the hydrogen in a treating process would be selectively and efficiently used to remove undesirable moieties from the organic - inorganic matrix. Hydrogen consumption for treating New Bedford dredging spoils is projected to be only for desired catalytic reactions, and hence, economically low.

#### PROCESS CONCEPT

Catalytic hydrogenation will proceed on the extended surface of the inorganic solids in the aqueous phase of a wet pumpable sludge. The upper limit of the process in temperature is the critical temperature of water, 374°C (705.5°F), in that the cost of vaporizing water is so high as to preclude anything but a liquid phase process. To maintain economic equipment costs, catalytic petrochemical processes are usually no higher in pressure than 137 atm (2000 psig). Continuous processing would most probably be in a trickle bed reactor, since, because of the low concentration of adsorbed PCB's, reactions would be rate,

rather than diffusion, controlled. (Note this difference from solvent extraction, which is a diffusion controlled process.)

Capacity is identified in (1) as 152,000 m<sup>3</sup> per year. This is not large by petrochemical standards. Operation 24 hrs/day, 5 days/week, 50 weeks/year would require a processing capacity of 25 m<sup>3</sup>/hour. Such a unit, including hydrogen generator, could most probably be either truck or barge mounted, so that it could eventually service fouled areas other than New Bedford.

The catalysts for the hydrogenation process are contained in the sludge, by its very nature. As an example, Table 1 [Table 4 ex (1)] shows trace metals analyses of Hudson River Sediments. The literature is replete with studies of the hydrogenative activities of most of the metals listed. Most would be reduced to the metallic form in situ during sludge hydrogenation. The metals are located on the extended surface of the pore structure of the porous clays in sediment and are in proximity to adsorbed heavy species such as PCB's and sulfur compounds.

This is exactly the situation in petrochemical catalysis. For example, ethylene is purified from acetylene commercially by selectively hydrogenating 10,000 ppm acetylene to <1 ppm in a single pass at 80 C. Weiss has published extensively on the process and has used catalysts which contain as little as 0.016 % Pd (160 ppm) on porous aluminum oxide (2,3,4). This is the same order of magnitude as Nickel and Copper are found in sludges.

The inorganic clays and silts of sediments are very similar to catalyst supports and cracking catalysts used to process petroleum and petrochemicals. These include amorphous and crystalline aluminosilicates, kaolin, aluminum oxide, silica, montmorillonite, etc. Catalysts supports generally have extended surface areas, due to pore structures. Metals, as well as Bronsted and Lewis acid sites, are located within the pore structures. Reactants diffuse into the pores, react at the active sites, and products diffuse out. It is characteristic of usual catalytic process design that reaction rates are slower than diffusion rates.

It is possible to obtain conversions above 99.99 % in catalytic purification processes at conventional single-pass conditions. Weiss describes (5,6) hydrogenation of 10,000 ppm thiophene in benzene to 0.02 ppm thiophene in a commercial process using porous chromium oxide catalyst with a surface area of about 55 m<sup>2</sup>/gram. The reaction is gas phase, but similar liquid phase reactions are also done commercially. These include reactions where the hydrogenation proceeds in an aqueous phase, such as the Raney nickel catalyzed hydrogenation of glucose to sorbitol and mannitol (7). In this latter reaction, hydrogen dissolves in the water reaction medium, diffuses to the metal surface, dissociates there to its atoms, and diffuses back out into solution to reduce the sugar.

#### PROCESS FLOW SHEET

Figure 1 shows a flow sheet for a conceptual process to remove PCB's from New Bedford dredging spoils. These would be

TABLE 1

TABLE 4.(c) HUDSON RIVER SEDIMENTS, METAL CONCENTRATIONS AND PCB CONTENT

Sample Number	K, %	Ca, %	Tl, %	Mn, $\mu\text{g/g}$	Fe, %	Cu, $\mu\text{g/g}$	Zn, $\mu\text{g/g}$	Rb, $\mu\text{g/g}$	Sr, $\mu\text{g/g}$	PCB ppm	Cr, $\mu\text{g/g}$	Pb, $\mu\text{g/g}$	Ni, $\mu\text{g/g}$
25	8.0	4.4	1.7	1930	6.5	120	750	130	385	240	7000	1600	60
26	8.6	5.7	2.2	1125	5.5	80	280	140	410	80-34	1540	525	60
27	8.1	4.8	1.5	950	4.5	45	200	140	390	36-66	760	400	45
29	3.9	1.8	0.6	580	2.1	10	<10	110	310	142-37	170	120	20

Analysis by X-ray fluorescence

Reference: Tofflemire and Quinn, 1979.

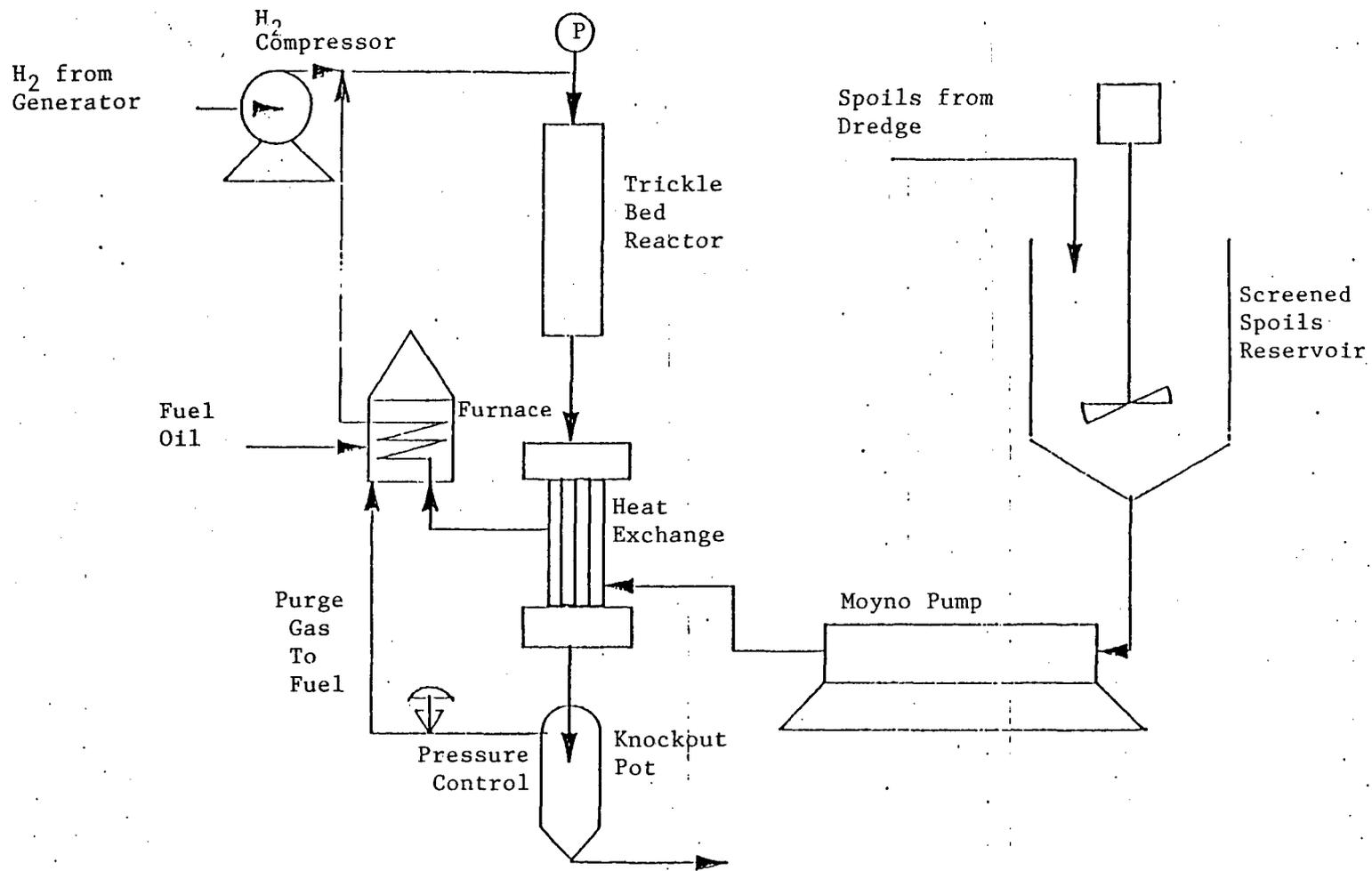


FIGURE 1

Process For Catalytic Hydrogenation of PCB's in New Bedford Spoils

screened to remove tramp material, such as stones and debris. The goal of the process will be to hydrodechlorinate the chlorine content of PCB's so that the spoils can be returned to the harbor. A first goal will be to reduce PCB's from about 1,000 to 2 ppm to meet New Bedford's needs. (Other areas may have significantly higher PCB contents). Bioassays of partially dechlorinated products can establish bioaccumulation, mutagenicity, and toxicity and indicate the degree of chlorination that is actually necessary.

The spoils charged to the process must be pumpable, and commercial helix pumps (such as Moyno) are available to pump to process pressures. The water content of the spoils must be at least adequate to allow flow. The porosity, surface area, and particle size distribution of the sedimental inorganics, as well as trace metals content, will be reflected in the operating conditions of the reactor.

To conserve energy costs, the cold feed stream is heat exchanged with hot treated spoils from the reactor. The feed is then heated to reaction temperature in a flow furnace fired with heating oil and waste gas from the process. Hydrogen is generated from a commercial unit, compressed to reaction pressure, and admixed with the hot feed. The feed trickles down over a bed of e.g. 1" spheres or saddles, which may or may not be coated with nickel. Hydrogen in the reactor voids saturates the extended liquid surface, and reaction proceeds as the slurry trickles down. Because of the small ppm quantities of reactants, it is not expected that mass transport of hydrogen to the adsorbed reactants will be a problem. If it is, then a continuous stirred tank reactor will be used.

Reactor effluent is cooled by cross-exchange with influent and then passes to a knock-out pot to separate gases from liquids. Pressure is controlled at this point and sufficient gas is purged to prevent accumulation of species other than Hydrogen in the gas phase, e.g. methane, nitrogen, hydrogen sulfide. The heating value of the vent gas is recovered in the furnace. Treated sludge can be returned directly to the sea.

There is reason to believe that, ancillary to the benefits of removing noxious compounds, the process could produce enough reduced metals to be economically recoverable, e.g., by magnetic separation. This is a secondary consideration; and no efforts are planned in the present study to pursue metals recovery.

As mentioned, it is probable that this plant could be barge-mounted at full scale. A pilot scale plant - e.g. 100 lbs/hr could also be barge mounted and should incorporate on site PCB monitoring GC capability.

## SLUDGE HYDROGENATION

The Resource Recovery Laboratory of Worcester Polytechnic Institute was organized by Professor Weiss to study the hydrogenation of Municipal Solid Waste Organic Sludges and Sewage Sludges. References (8) thru (17) describe the work that was done, which was for the purpose of converting the cellulose to oil. This is a far more severe reaction than the PCB hydrodechlorination being considered in this proposal - temperatures of about 450 C were used. It was found optimal to mix the sludge with oil produced by the process. Nickel salts were added to feeds such as powdered newspaper, which simulated municipal solid waste by its clay pigment and cellulose content. These salts reduced to metal in a reaction system quite similar to that of Figure 1. Sewage sludge did not require the addition of reducible metal content for catalysis.

The continuous stirred tank reaction system used was quite small - one liter - and flows were in the range of 1 liter/hr. The work showed the feasibility of hydrogenating sludges and defined the process to convert them to oil. Because of the current price of oil, the process is not economic.

The most difficult operational problem encountered was pumping sludge to high pressure at very low rates. Frequent blockages of valves of the Milton-Roy pump used were experienced. Consequently, it was decided that if further studies were initiated on sludge, they would be confined to batch autoclave reactions at the laboratory scale. These are adequate to screen catalysts and feedstocks as a function of reaction conditions. Scale-up data are obtained by process variable screening in a continuous pilot plant system. Such operation should be ideally on the order of 25 to 100 gallons per hour, both to avoid pumping problems and to compensate for the variable composition of actual sludges, such as dredging spoils. Such a plant would be large enough to be considered a "Demonstration Plant" in Superfund terminology.

## CATALYTIC HYDROGENATION OF PCB'S AND OTHER TOXICS

Prof. Weiss presented his first work on catalytic hydrodechlorination of olefinic chlorinated species in 1966 (18). At that time, and prior, hydrodechlorination was a neglected area of catalysis, with no practical application envisioned. However, as problems with hazardous and toxic wastes developed, it soon became apparent that hydrogenative rupture of the Carbon - Chlorine bond was of practical interest, as well as of interest for more arcane reasons.

One approach to the hazardous and toxic waste problem was to convert large quantities of these to chemicals having an economic value. As an example, it is well known that almost any organic can be burnt in chlorine to carbon tetrachloride. However, this compound is undesirable, also. However, chloroform is a different story. There is a shortage in the marketplace. So the hydrodechlorination of  $\text{CCl}_4$  to  $\text{CHCl}_3$  was studied by Weiss (19,20). It was found that two types of catalytic reactions with hydrogen occur simultaneously: removal

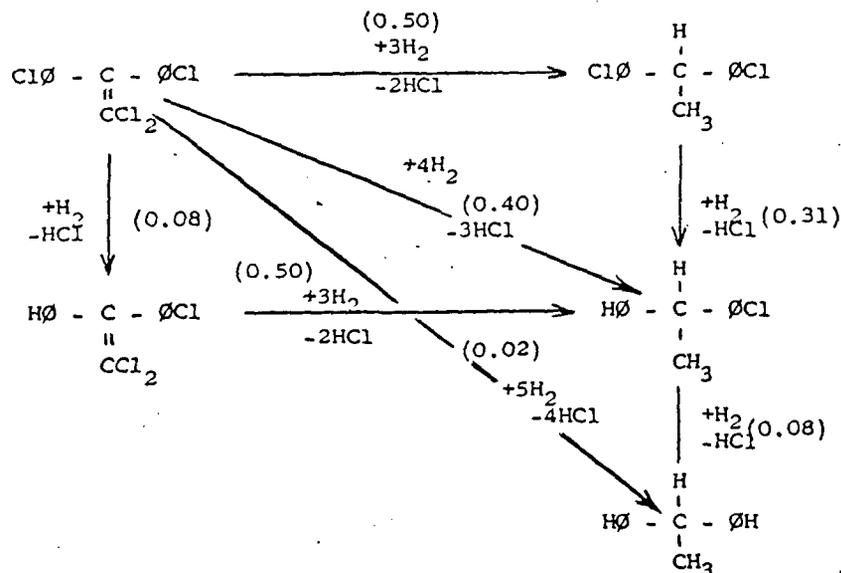
of one chlorine in one reaction event; and removal of three chlorines in one reaction event.

This "concerted" reaction behavior was found in subsequent studies in both liquid and gas phases of DDE, DDD, DDT, dieldrin, aldrin, toxaphene, and PCB's. The reaction networks were established for these species in a series of papers (21-27) as well as a formal EPA Report (28).

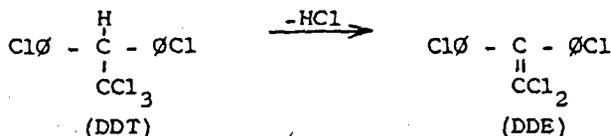
Figure 2 shows the reaction network for DDE. Note the complexity of the network, with parallel and consecutive paths, and single step as well as concerted chlorine removal to produce the completely chlorine-free hydrocarbon precursor. The numbers indicated are the relative rate constants for each reaction step.

Figure 3 shows that PCB's hydrodechlorinate as a series of consecutive reactions, with the indicated relative rate constants. The chlorines are removed readily by hydrogenation over nickel catalyst in the liquid phase. Appendix 1 reproduces pages 19 through 28 of (28), which summarize the experimental findings of the PCB hydrodechlorination work by Weiss' group.

The above work was for the purpose of producing macro quantities of non-toxic compounds from toxic chlorinated species. There should be no expectation for sludge hydrogenation that the amounts of hydrocarbons produced would be either economic or even recoverable. They would be disposed of in the treated sludge, which would contain no quantities of chlorinated species capable of bioaccumulation.



**DDI-DDE.** In the presence of sodium hydroxide in ethanol solvent, DDT is quickly converted non-catalytically to DDE.



The subsequent reactions of DDE are more complex. They not only involve consecutive aromatic hydrodechlorination but also parallel reactions in which olefinic chlorines are removed and the associated olefin is saturated without intermediate desorption from the catalyst. Note in the following reaction network that as many as five hydrogen molecules react in one step. The numbers shown are first order rate constants relative to the total rate of reaction of DDE by all four paths, for liquid phase reaction with hydrogen at 50 bar, Ni catalyst, over the temperature range 20-100°C. These constants have been used to calculate the product distribution shown in Figure 2, superimposed on the experimental data.

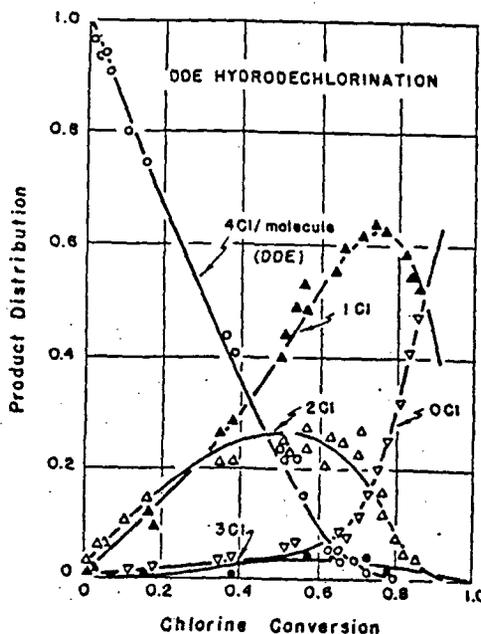
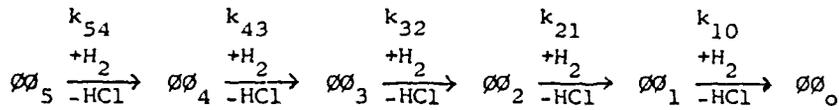


Figure 2. Product distribution vs. chlorine conversion for hydrodechlorination of DDE (DDT)

PCB. The catalyzed hydrodechlorination reactions to remove chlorine from PCBs proceed one step at a time in a consecutive manner.  $\text{PCB}_n$  represents a biphenyl nucleus substituted with  $n$  chlorine atoms



Kinetics are well represented by a series of successive reactions. If simple first order rate constants ( $k_{mn}$ ) are calculated relative to the first step, a single set of constants represents the data over the range of 60-130°C at 50 bar hydrogen pressure for liquid-phase reactions

in ethanol solvent with nickel catalyst (Girdler G49) and NaOH as acid acceptor. Product distributions based on  $k_{54}=1$ ,  $k_{43}=0.40$ ,  $k_{32}=0.23$ ,  $k_{21}=0.36$ , and  $k_{10}=0.40$  are shown in Figure 3 superimposed on the experimental data.

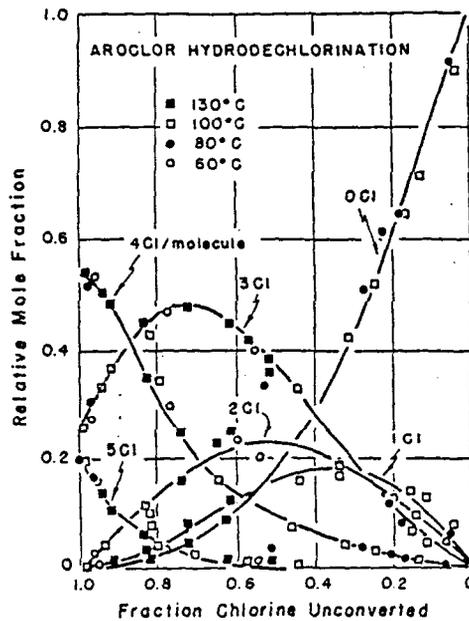


Figure 3. Product distribution vs. chlorine conversion for hydrodechlorination of PCB (Aroclor 1248)

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APPENDIX I

Experimental Results  
for  
PCB Hydrodechlorination  
ex

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## SECTION 5

### RESULTS

#### AROCLOR 1248

Aroclor 1248, a clear viscous oil containing 48 wt% chlorine, was the polychlorinated biphenyl (PCB) used as the model reaction mixture. Three sets of experiments were conducted using Aroclor 1248. Firstly, the pulsed microreactor was used to verify reactivity of the volatilized PCB in the presence of the Pd catalyst. Secondly, preliminary experiments in the teflon lined autoclave established the reactivity in the liquid phase using the Ni catalyst. Thirdly, continuous sampling experiments in the teflon lined autoclave provided data for rate and selectivity analysis. Chlorine conversion,  $X$ , is used as the indicator of extent of reaction and is defined as:

$$X = 1 - \frac{\sum_{i=0}^n i\phi_i^t}{\sum_{i=0}^n i\phi_i^0}$$

where  $\phi_i^t$  is the percentage of biphenyl containing  $i$  chlorine atoms per molecule, and  $\phi_i^0$  is the initial percent of a given molecule containing  $i$  chlorine atoms.

#### 1. Gas Phase Pulsed Microreactor Screening

Four experiments were conducted at the same temperature (220°C), pressure (2.3 atm.H<sub>2</sub>), space time (10<sup>-2</sup> seconds), and feed composition (0.7 wt% Aroclor in n-heptane). The concentrations of Pd catalyst on 5mg of Al<sub>2</sub>O<sub>3</sub> support were varied. These experiments demonstrated the feasibility of catalytic hydrodechlorination of Aroclor 1248. The results are presented in Table 3. A semi-log plot of (1-x) versus g Pd indicates that the chlorine conversion approximates first order behavior in Pd.

TABLE 3. PULSE MICROREACTOR AROCLOR 1248 HYDRODECHLORINATION

220°C 2.3 ATM H <sub>2</sub>	$\tau = .01 \text{ sec.}$			
Catalyst wt (mg)	5.0	4.6	5.0	5.0
wt % Pd	.00	.05	.10	.35
$\phi\phi_0$	—	.134	.296	.758
$\phi\phi_1$	.003	.058	.068	.043
$\phi\phi_2$	.013	.129	.140	.094
$\phi\phi_3$	.305	.337	.279	.078
$\phi\phi_4$	.493	.236	.166	.026
$\phi\phi_5$	.189	.091	.046	—
X	.013	.304	.469	.855

## 2. Preliminary Liquid Phase Experiments

In these experiments the teflon-lined autoclave was initially charged with Aroclor in ethanol using 61% Ni on kieselguhr as catalyst, and with the acid acceptor, NaOH. The reactor was then heated, pressurized with H<sub>2</sub>, maintained near these conditions for the reaction time, and finally cooled. The contents were analyzed at this final condition. Temperature, H<sub>2</sub> pressure, reaction time, and ratio of weight of reactant to weight of catalyst were varied. The conditions and results are summarized in Table 4. The following conclusions were drawn from this set of experiments:

- 1) Complete hydrodechlorination of PCB can be obtained using Ni catalyst at elevated H<sub>2</sub> pressure (50 atm) and temperature (115°C) in a six hour reaction period.
- 2) The reaction has positive dependence on H<sub>2</sub> pressure above 25 atmospheres.
- 3) Catalyst poisoning occurs at 175°C placing an upper limit on reaction temperature.

## 3. Continuous Sampling Liquid Phase Experiments

Experiments were conducted at four temperatures (68°, 80°, 100°, 130°C) in the teflon-lined autoclave. In each experiment, the H<sub>2</sub> pressure (50 atm), catalyst (Ni), acid acceptor (NaOH), and initial reactant composition (2 wt% Aroclor in ethanol) were reproduced. Samples were withdrawn and analyzed at

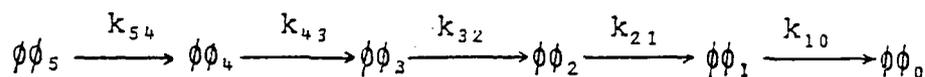
TABLE 4 PRELIMINARY LIQUID PHASE AROCLOR EXPERIMENTAL CONDITIONS

Run	1	3	5	15	16	17	18	19	20	21
Aroclor 1248 (gm)	5.27	4.57	11.0	13.3	12.19	11.29	12.01	12.96	10.67	11.45
Aroclor 1248 (gm mole)	.0180	.0157	.0377	.0455	.0417	.0387	.0411	.0444	.0365	.0392
Ethanol (gm.)	98.6	86.8	110.5	131.8	110	102	108	117	96	103
Wt. % Aroclor 1248	5.07	5.00	9.05	7.38	9.98	9.97	10.01	9.97	10.00	10.00
NaOH gms	4.0	2.6	6.4	7.3	6.66	6.12	6.50	7.04	5.80	6.23
NaOH (gm-mole)	0.100	.065	.160	.183	.167	.153	.164	.176	.145	.156
$\frac{\text{NaOH}}{\text{Aroclor 1248}}$	5.5	4.1	4.2	4.0	4.0	3.95	3.99	3.96	3.97	3.97
Ni on Kieselguhr	2.5	0.55	1.1	1.39	1.25	1.12	1.23	1.30	1.08	1.11
$\frac{\text{wt. Aroclor}}{\text{wt. catalyst}}$	2.1	8.3	10.0	9.6	9.75	10.08	9.76	9.97	9.88	10.32
Reaction time (hrs)	2	2	4	2	6	2	2	4	1.2	2
Pressure (Bar)	50	50	50	50	50 (50-42)	25 (25-21)	50 (50-48)	50 (54-47)	0(atm)	50 (50-60)
Temperature °C	100	100	100	100	100-115	100-110	25	100	25-100	175
Chlorine Conversion	.628	.293	.574	.559	1.000	.390	.099	.888	0.00	.107

intervals during the reaction. Selectivity data are plotted versus chlorine conversion in Figures 9, 10 and 11. Selectivity data obtained at these four temperatures were sufficiently similar that they were treated as one set of data. Two models were developed to interpret the reaction results.

(a) Consecutive Reaction Scheme

The observed selectivity data were fitted to a consecutive reaction



scheme described by a set of first order reaction path expressions.

$$\frac{d\phi\phi_4}{d\phi\phi_5} = \frac{k_{43}}{k_{54}} \frac{\phi\phi_4}{\phi\phi_5} - 1$$

$$\frac{d\phi\phi_3}{d\phi\phi_5} = \frac{k_{43}\phi\phi_4 - k_{32}\phi\phi_3}{k_{54}\phi\phi_5}$$

$$\frac{d\phi\phi_2}{d\phi\phi_5} = \frac{k_{32}\phi\phi_3 - k_{21}\phi\phi_2}{k_{54}\phi\phi_5}$$

$$\frac{d\phi\phi_1}{d\phi\phi_5} = \frac{k_{21}\phi\phi_2 - k_{10}\phi\phi_1}{k_{54}\phi\phi_5}$$

$$\frac{d\phi\phi}{d\phi\phi} = \frac{k_{10}\phi\phi_1}{k_{54}\phi\phi_5}$$

The best fit was obtained with the following set of relative rate constants.

$\frac{k_{43}}{k_{54}}$	$\frac{k_{32}}{k_{54}}$	$\frac{k_{21}}{k_{54}}$	$\frac{k_{10}}{k_{54}}$
0.40	0.23	0.36	0.40

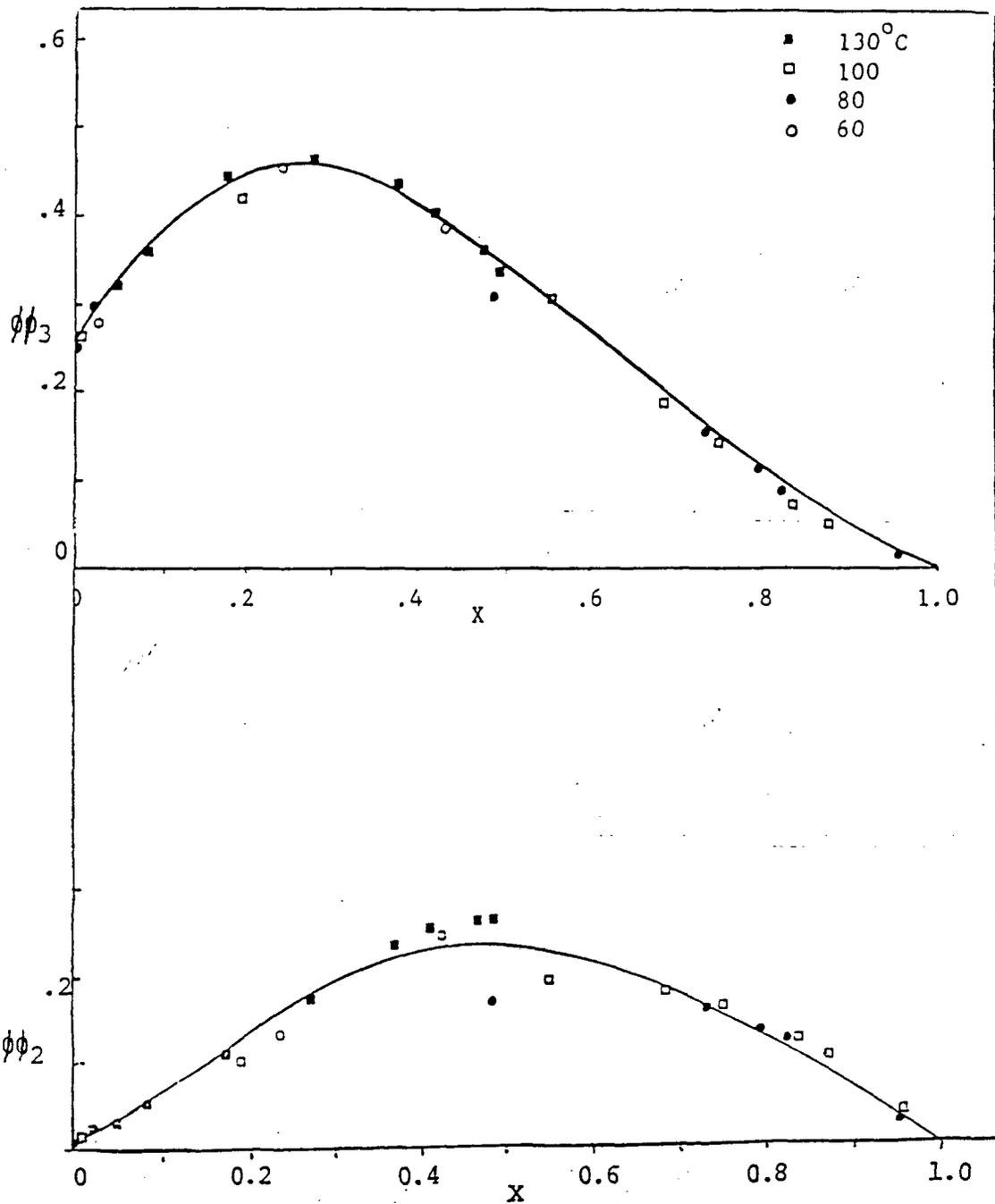


Figure 10. Aroclor 1248 relative product distribution data (50 atm.H<sub>2</sub>, Ni on kieselguhr).

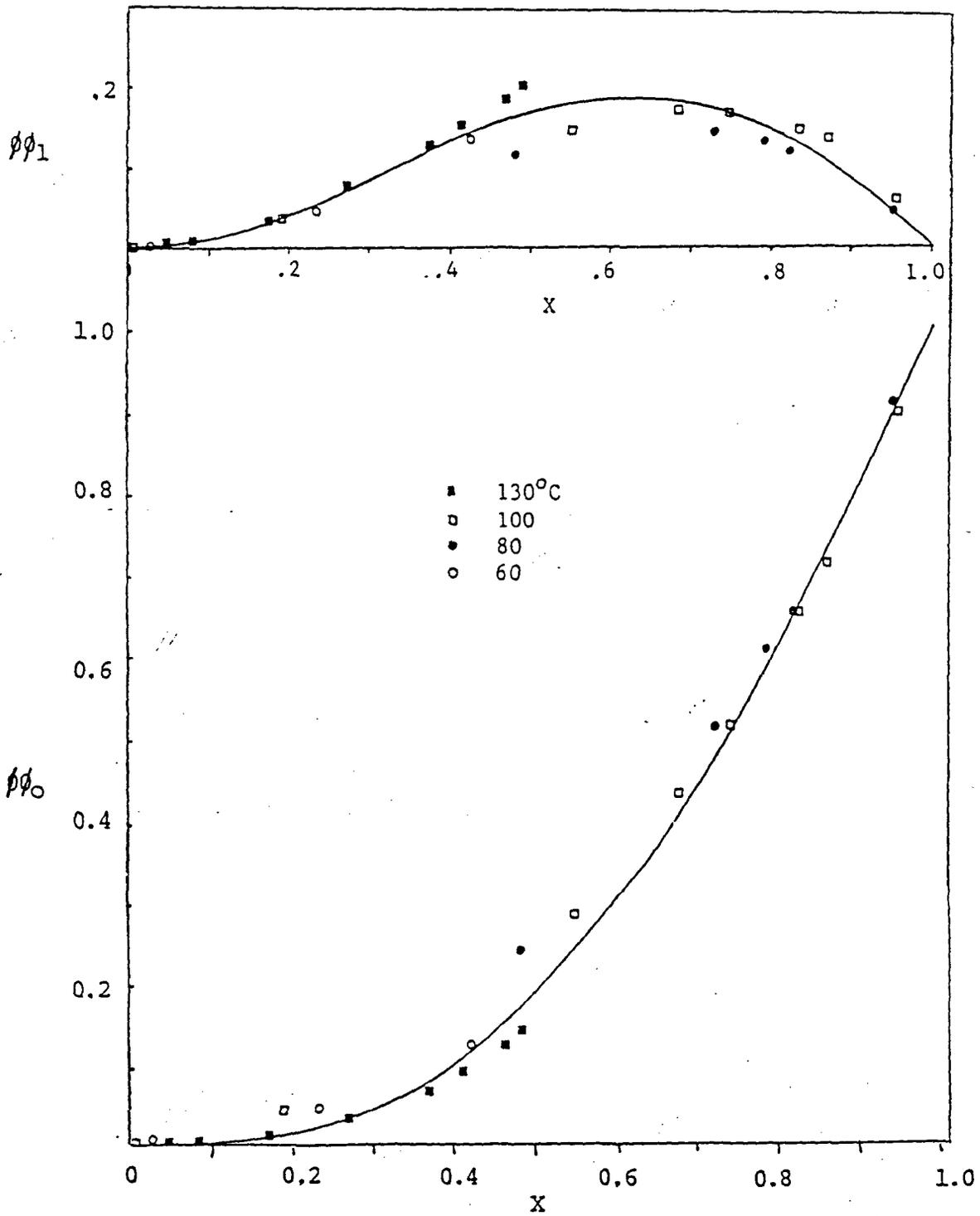


Figure 9. Aroclor 1248 relative product distribution data (50 atm. H<sub>2</sub>, Ni on kieselguhr).

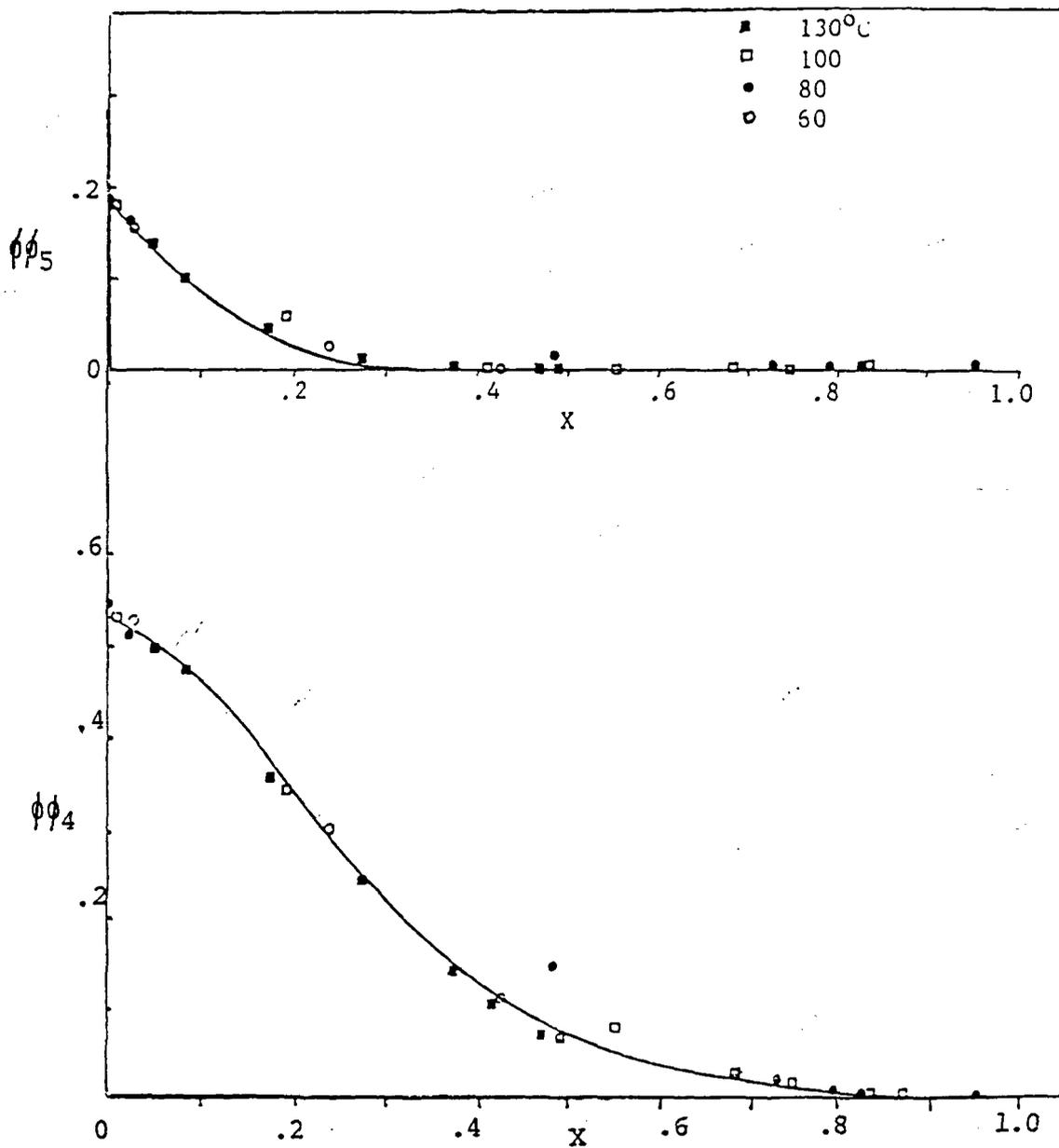


Figure 11. Aroclor 1248 relative product distribution data (50 atm.  $H_2$ , Ni on kieselguhr).

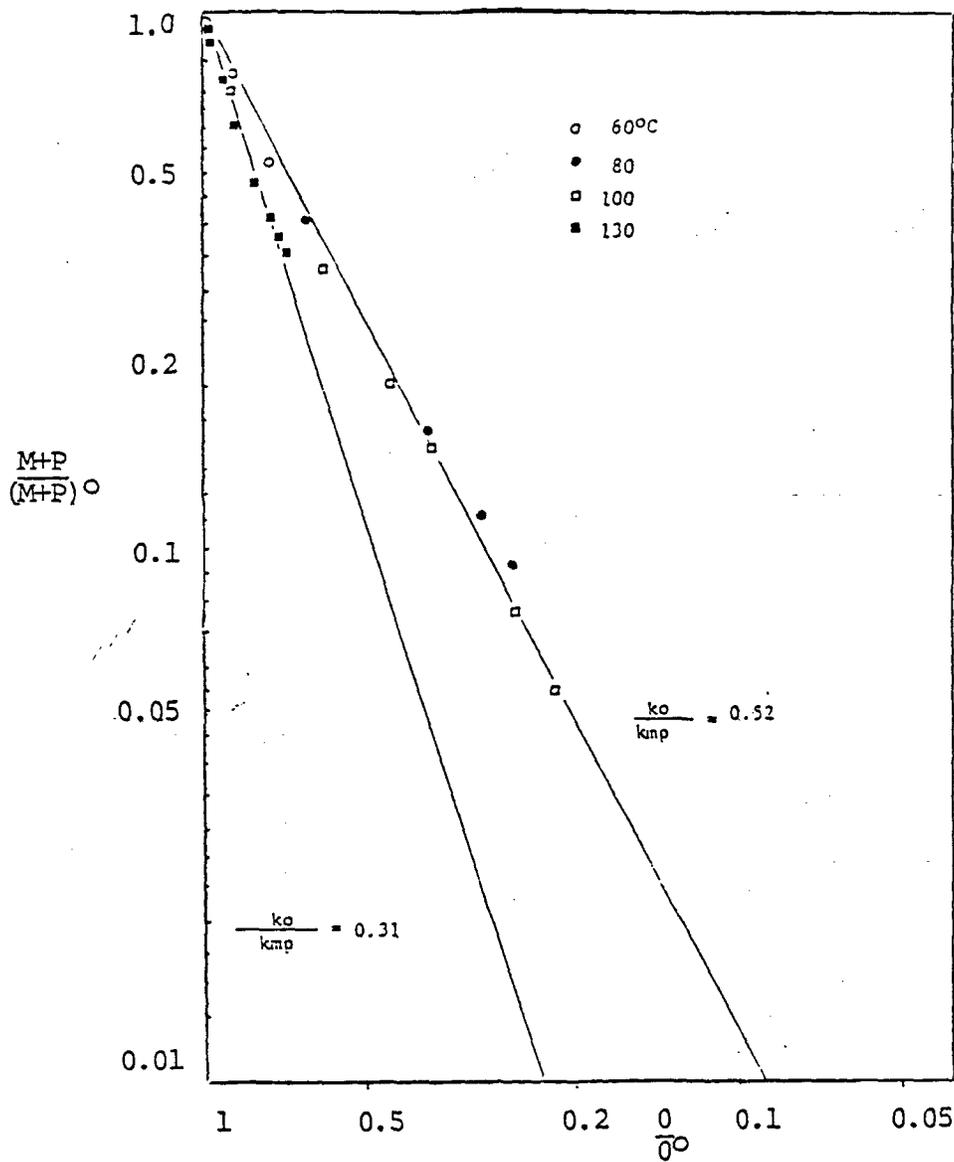


Figure 13. Aroclor 1248 hydrodechlorination as characterized by  $\frac{0}{0_0}$  vs.  $\frac{m+p}{m+p_0}$  substitution.

The curves obtained using this set of constants are superimposed on the data in Figures 9, 10 and 11. A semi-log plot of (1-X) versus time for data is given in Figure 12. An analogous plot obtained from the model would be convex and consequently in disagreement with the data. A Langmuir Hinshelwood kinetic model which takes into account adsorption effects provided insight into this problem.

(b) Relative Rates of Isomeric Reactions

In the course of these studies it was observed that, within each group of PCB isomers containing the same number of chlorine atoms per molecule, certain isomers were selectively produced and reacted. In all cases, during a reaction the amount of ortho substituted isomers increased relative to the amount of meta and para isomers present. First order rate expressions were proposed.

$$\frac{dO}{d\theta} = k_o O$$

$$\frac{dMP}{d\theta} = k_{mp} MP$$

Dividing these expressions and integrating gives:

$$\frac{\log \frac{O}{O_0}}{\log \frac{MP}{MP_0}} = \frac{k_o}{k_{mp}}$$

A log-log plot (Figure 13) fits a straight line as predicted by the model. A differing slope for the 130°C experiment is indicative of catalyst deactivation.

DDT, DDE, DDD

Three reactors were used in this portion of the study. The pulsed microreactor was used to screen for the thermal and catalytic reactivity of DDT and DDD. The continuous gas phase reactor was used to hydrodechlorinate DDD and DDE. The teflon-lined autoclave was used in a series of dechlorinated reactions involving DDT and DDE.

1. Gas Phase Pulsed Microreactor Experiments

The three sets of experiments conducted in this reactor established the practicality of catalytic hydrodechlorination of DDT, DDD, and DDE.

a) Using no catalyst and no hydrogen and with helium as the carrier gas, it was found that 0.5 µl samples of 9.5 wt% DDT in p-xylene underwent thermal decomposition over a range of temperatures (200-360°C). DDE was the major reaction product.

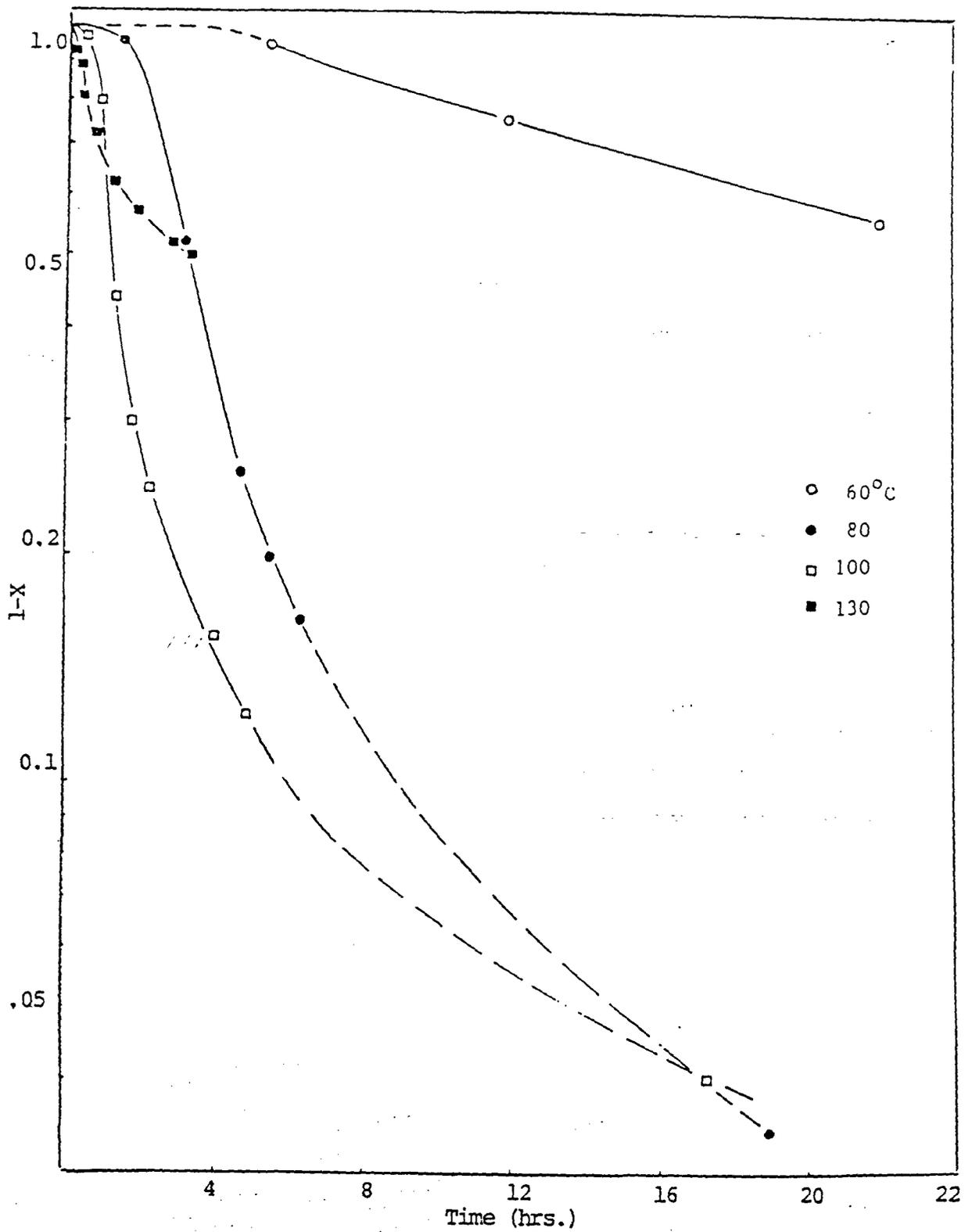


Figure 12. Experimentally observed Aroclor 1248 kinetics.

Tel: Off. 508\*-793-5380  
Res. 508\*-853-3788

**PROFESSOR ALVIN H. WEISS**  
Department of Chemical Engineering  
Worcester Polytechnic Institute  
Worcester, MA 01609

B.S.	1949	University of Pennsylvania, Chemical Engineering
M.S.	1955	Newark College of Engineering, Chemical Engineering
Ph.D.	1965	University of Pennsylvania, Physical Chemistry
P.E.	1962	Registered Prof. Eng. in Delaware and Massachusetts

**PROFESSIONAL EMPLOYMENT:**

Academic Research and Teaching:

Professor of Chemical Engineering  
Worcester Polytechnic Institute, 1966-present  
Lecturer in Chemical Engineering and Research Associate,  
University of Pennsylvania, Philadelphia, PA 1963-66

Industrial Process Development:

Houdry Process and Chemicals Co., Linwood, PA, 1956-63  
Colgate Palmolive Co., Jersey City, NJ, 1952-55  
Fiber Chemical Co., Cliffwood, NJ 1949-51

Toxic Gas Protection:

Institute for Cooperative Research, U of PA, Phila., PA, 1963-66  
Edgewood Proving Ground, Army Chemical Center, MD, 1951-52  
Chemical Systems Laboratory, Army Chemical Center, MD, 1981

**RESEARCH AWARDS:**

Worcester Engineering Society Award for Scientific Achievement, Feb. 1984.  
WPI Outstanding Researcher and Creative Scholar Award, May 1984.  
Fellow of the American Institute of Chemical Engineers, 1977.

**PROFESSIONAL SOCIETY MEMBERSHIPS:**

American Institute of Chemical Engineers (1949-present).  
American Chemical Society (1947-present).  
American Association for the Advancement of Science (1963-82).  
Catalysis Club of Philadelphia (1960-68).  
Catalysis Society of New England (1967-present).  
Catalysis Society (1960-present).  
Deutsche Gesellschaft fur Chemisches Apparatewesen (1970-87).  
New York Academy of Sciences (1981-84).  
International Society for Study of the Origins of Life (1983-present).  
American Council for the United Nations University (1983-87).  
Lake Quinsigamond Watershed Association (1983-present).  
American Professors for Peace in the Middle East (1970-present).  
Committee of Concerned Scientists (1970-present)  
Worcester Engineering Society (1967-88)

\* Before July 1, 1988, use area code 617

## RESEARCH AND TEACHING APPOINTMENTS:

### ASEE:

Faculty Fellow. Stanford University and NASA Ames Research Center, Mountainview, CA, Summers of 1967-68.  
Senior Research Fellow, Chemical Systems Laboratory, Army Chemical Center, MD, February to July, 1981.

### FULBRIGHT-HAYS:

Senior Faculty Fellow, Chem. Eng. Dept., Ben-Gurion University of the Negev, Beersheva, Israel, AY 1973-74; Visiting Prof., Dec. 1974.  
Visiting Lecturer, Chem. Eng. Dept., Middle East Technical University, Ankara, Turkey, June, 1974.  
Visiting Research Scientist, Dept. of Organic Chemistry, Weizmann Institute, Rehovoth, Israel, Dec., 1974.

### US-USSR COOPERATIVE SCIENCE PROGRAM IN CHEMICAL CATALYSIS:

US Coordinator and Principal Investigator, "Catalysis for Life Support Systems", Institute of Chemical Physics, Moscow, and Institute of Chemical Physics, Kiev, USSR, 1973-78.  
Principal Investigator, "Applied Catalyst Systems for Chemicals from Non-Petroleum Sources", Institute of Catalysis, Novosibirsk, 1978-80.

### WPI-HUNGARIAN ACADEMY OF SCIENCE RESEARCH COLLABORATION IN CATALYSIS:

US Principal Investigator, "Isotopic Studies of Acetylene Hydrogenation", Institute of Isotopes, Budapest, Hungary 1976-86.  
Visiting Lecturer, Institute of Isotopes and Central Institute of Chemistry, June, 1976; Institute for Cultural Relations and Institute of Isotopes, Budapest, Hungary, May, 1978, and May, 1980.

### UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION:

Chief Technical Advisor to the Petrochemical Complex of Bahia Blanca, Argentina, January to December, 1980.  
General Reporter on Catalysis, Fifth International Conference on Zeolites, Naples, Italy, June 2-6, 1980.  
Chemical Process Development Expert, Research Institute for Chemical Industry, Beijing, China, August - September, 1982.  
Technical Advisor, Polo Petroquimica do Sul, Porto Alegre, Brazil, May, 1982.  
Catalyst Testing Expert, PETKIM R&D Dept., Yarimca, Turkey, January, 1986 and 1987, August, 1987.

### US COMMITTEE FOR SCIENTIFIC COOPERATION:

Visiting Lecturer, Institute of Chemistry, National Center for Scientific Research, Hanoi; Institute of Industrial Chemistry, Ho Chi Minh City, Vietnam, February, 1986.

### NATIONAL RESEARCH COUNCIL:

Research Fellow, Bulgarian Academy of Sciences, Institute for Kinetics and Catalysis, Sofia, Bulgaria, May, 1986 and 1988.

**PROFESSIONAL SOCIETY ACTIVITIES:**

Catalysis Society (Director and Secretary, 1968-1979, 1983-88).  
Catalysis Society of New England (Chairman 1967, Director 1968-77,  
1981-present).  
American Institute of Chemical Engineers (Research Committee),  
1968-80).  
American Chemical Society (Petroleum Div. Area IV Representative,  
1967-present).  
Worcester Engineering Society Admiral Earle Award Committee (Chairman  
1984-87).  
American Association of University Professors, 1967-present. (Chairman,  
WPI Chapter, 1983-85; Vice Chair, 1988).

**MEETINGS AND SOCIETIES ORGANIZED:**

Catalysis Society of New England (Founding Chairman, 1967-68).  
AIChE Research Committee Subcommittee in Catalysis (Founding Chairman,  
1970-78).  
AIChE Conferences in Catalysis Program (Founding Chairman, 1968-70).  
AIChE Research Committee on Food Synthesis (Founding Chairman, 1976-79).  
AIChE Subcommittee on Research on Non-Conventional Production of Food.  
Founded Subcommittee August 1979.  
Seventh North American Meeting of the Catalysis Society, Co-Chairman with  
Eric Stern, October 1981, Boston, MA.  
The 18th Biennial Conference on Carbon, (Co-Chairman with Albert Sacco,  
Jr.), WPI, Worcester, MA, July 19-24, 1987.

**ACADEMIC HONOR SOCIETIES:**

Tau Beta Pi; Sigma Tau; Phi Lambda Upsilon;  
Sigma Xi (President, WPI Chapter, 1976-79).

**PATENTS AND COPYRIGHTS:**

Houdry LITOL Process:	United States 3,081,259, France 1, 269,843, Belgium 593,755, Italy 635,688, also Brazil, Canada, United Kingdom, Japan, Germany.
Houdry DETOL Process:	United States 3,178,486, France 1,348,649, Argentina 132,974, Japan 427,958, United Kingdom 959,609, also Canada, Germany, Italy.
Purification of Coke Oven Light Oil:	United States 3,207,802, France 1,320,756, United Kingdom 971,779, Italy 660,970, also Canada, Germany, Japan.
Glycolaldehyde and Glycol from Formaldehyde:	United States 4,238,418 and 4,322,568
Breathing Mask for Fires	Patent Application in Process
Kinetics and Selectivity of Consecutive Reactions	Computer Program Copyright TX-2-118-971

**BOOKS:**

Translation from the Russian - O.V. Krylov, "*Catalysis by Non-Metals*".  
No. 17 in Physical Chemistry Series, Academic Press, Inc., NY (1970)  
(with M. Delleo, G. Dembinski and J. Happel).

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1. "Moudry DETOL Process Shows Good Results at Crown Central Refinery", *Oil and Gas J.*, 60, No. 4 64 (Jan. 22, 1962) (with J.B. Maerker and R. Newirth).
2. "First DETOL Plant On-Stream", *Petr. Ref.*, 41, No. 1, 39 (Jan. 1962) (with J.B. Maerker and R. Newirth).
3. "Demethylate Toluene Thermally", *Petr. Ref.*, 41, No. 6, 185 (June 1962).
4. "The Development of the Moudry DETOL Process", *Ind. Eng. Chem., Process Design and Development Quarterly*, 2, 163 (1963). Presented at ACS 142nd Nat. Mtg., Atlantic City, NJ, Sept. 1962.
5. "The Kinetics of Catalytic Methyl and Dimethyl Naphthalenes Hydrodealkylation", *Ind. Eng. Chem., Process Design and Development Quarterly*, 2, 169 (1963). Presented at ACS 142nd Nat. Mtg., Atlantic City, NJ, Sept. 1962 (with L.C. Doelp and A.K. Logwinuk).
6. "Reaction Paths for Consecutive and Simultaneous Reactions", *Chem. Eng.*, 70, 89 (1963).
7. "The Kinetics of Catalytic Xylene Hydrodealkylation", *Ind. Eng. Chem. Process Design and Development Quarterly*, 3, 73 (1964) (with L.C. Doelp and A.K. Logwinuk).
8. "Production of Xylenes by Hydrodealkylation", *Ind. Eng. Chem., Process Design and Development Quarterly*, 4, 92 (1965). Presented at ACS 147th Nat. Mtg., Philadelphia, PA, Apr. 1964 (with L.C. Doelp and W. Brenner). Presented at Worcester Polytechnic Institute Chemical Engineering Dept. Seminar Series, March 1966.
9. "Upgrading Coke Oven Aromatics", *Ind. Eng. Chem.*, 56, No. 4, 20 (April 1964) (with A.K. Logwinuk and L. Friedman).
10. "The Moudry LITOL Process", *Erdol und Kohle*, 7, 532 (1964) (with A.K. Logwinuk and L. Friedman).
11. "Properties of Aluminum-Deficient Large Port Mordenites", Preprints Second Int'l. Conf. on Molecular Sieve Zeolites, Worcester Polytechnic Inst., Worcester, MA, Sept. 8-11, 1970, p. 802. *Advances in Chemistry Series 101 "Molecular Sieve Zeolites"*, p. 502, ACS, Washington, DC (1971) (with W.L. Kranich, Y.H. Ma, L.B. Sand, and I. Zwiebel).
12. "Cumene Cracking over Aluminum-Deficient Large Port Mordenites", presented at Second North American Mtg. of the Catalysis Society, Houston, TX., Feb. 24-26, 1971. *J. of Catal.*, 23, 61-70 (1971) (with H.S. Bierenbaum and S. Chiramongkol). Presented at Cities Service Oil Co. Research & Development Seminar Series, Hightstown, NJ, March 23, 1971; at U.S. Bureau of Mines, Pittsburgh Energy Research Center, Bruceton, PA, April 27, 1971; at Catalysis Society of New England Spring Symposium, Worcester, MA, April 7, 1971.
13. "Interactive Effects of Alumina Tetrahedra in Mordenites", presented at Third Int'l. Conf. on Molecular Sieves, Zurich, Switzerland, Sept. 1973; at Catalysis Club of Philadelphia 1973 Spring Symp., Widener College, Chester, PA, May, 1973. *Advances in Chemistry Series 121 "Molecular Sieves"*, p. 605, ACS, Washington, DC (1973) (with H.S. Bierenbaum and R.D. Partridge).
14. "Which Propylene Process is Best?", *Hydrocarbon Processing*, 47, No. 4, 123-127 (1968).
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16. "The Manufacture of Propylene", presented at ACS 158th Nat. Mtg., New York, NY, Sept. 1969. Chap. 9 in *Advances in Chemistry, Vol. 97, "Refining Petroleum for Chemicals"*, p. 153, Amer. Chem. Soc., Washington, DC (1970).
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18. "Acetylene Deuteration in the Presence of  $^{14}\text{C}$  Ethylene", presented at the Division of Petroleum Chemistry Symposium "New Tools in Catalysis", ACS National Meeting, Miami, FL, Sept. 10-15, 1978. *ACS Div. of Petr. Chem. Preprints*, 23, No. 4, 1265-1275, Sept. 1978, *J. Catal.*, 60, 83 (1979) (with L. Guzzi, R.B. LaPierre, and E. Biron).
19. "The Effect of Catalyst Treatment in Acetylene Hydrogenation", presented at Tiszai Vegyi Kombinat, Leninvaros, Hungary, May 22, 1980; presented at Montedison S.p.a. Petrochemical Division, Bollate Research Center, Milano, Italy, May 13, 1980, *J. Catal.* 86, 417-426 (1984) (with John Moses, K. Matusek, and L. Guzzi).
20. "Reaction Routes for Hydrogenation of Acetylene-Ethylene Mixtures Using a Double Labeling Method", *React. Kinet. Catal. Lett.*, 15, No. 4, 475-479 (1980) with J. Margitfalvi and L. Guzzi).
21. "Reactions of Acetylene During Hydrogenation on Pd Black Catalyst", *J. Catal.*, 72, 185-198 (1981) (with J. Margitfalvi, L. Guzzi).
22. "Acetylene Hydrogenation Mechanism and Selectivity Control", Abstracts of 8th North American Meeting of

- the Catalysis Society, Philadelphia, PA, May 1-4, 1983 (with Zoltan Schay, L. Guzzi, and V. Nair).
23. "Acetylene Hydrogenation Selectivity Control on PdCu/Al<sub>2</sub>O<sub>3</sub> Catalysts", Second European Symposium on Catalysis by Metals, Universite Libre de Bruxelles, Brussels, Belgium, Sept. 19, 1983, *J. Molec. Catal.*, **25**, 131-140 (1984) (co-authors: Stephen LeViness, Vinayan Nair, Zoltan Schay, and Laszlo Guzzi).
  24. "Acetylene Hydrogenation Selectivity Control Using Pd/Cu Catalysts", *Reaction Kinetics and Catalysis Letters*, **27**, No. 1, 147-151 (1985) (with Laszlo Guzzi, Zoltan Schay, Vinayan Nair and Stephen LeViness).
  25. "Selective Hydrogenation of Trace Acetylene in Ethylene over Pd-Cu/Al<sub>2</sub>O<sub>3</sub> Catalysts". Proceedings of the Fifth International Symposium on Heterogeneous Catalysis, Varna, Bulgaria, October 3-6, 1983, pp. 315-320 (with Zoltan Schay, Antal Sarkany, Laszlo Guzzi, and Vinayan Nair).
  26. "The Effect of Pd Dispersion in Acetylene Selective Hydrogenation", Presented at the Eighth International Congress on Catalysis, West Berlin, DFR, July 2-6, 1984, In Proceedings pp. V591-V600, (with S. LeViness, V. Nair, L. Guzzi, A. Sarkany and Z. Schay).
  27. "Acetylene/Ethylene Hydrogenation Structure Sensitivity on Dispersed Pd", Presented at the 9th North American Meeting of the Catalysis Society, Houston, TX, March 18-21, 1985. In Abstracts. At Shell Chemical Co., Houston, TX, March 22, 1985. At Stone and Webster Corp., Boston, MA, January 15, 1985. (with L. Guzzi and Antal Sarkany).
  28. "Deactivation, Oligomer Formation, and Structure Sensitivity During Acetylene Hydrogenation". Presented at the Joint New York-New England Catalysis Societies' Symposium, Yale University, New Haven, CT, March 13, 1985. In Abstracts (with L. Guzzi and Antal Sarkany).
  29. "Palladium Zeolites as Acetylene Hydrogenation Catalysts", *J. of the Washington Academy of Sciences*, **74**, No. 1, 19-26 (March, 1984) (with R.P. Denkwicz and W.L. Kranich).
  30. "On the Aging Phenomenon in Palladium Catalyzed Acetylene Hydrogenation", *J. Applied Catal.*, **10**, 369-380 (1984) (with A. Sarkany and L. Guzzi).
  31. "Green Oil Poisoning of a Pd/Al<sub>2</sub>O<sub>3</sub> Acetylene Hydrogenation Catalyst", *J. Applied Catal.*, **12**, 373-379 (1984) (with A. Sarkany, T. Szilagyi, P. Sandor and L. Guzzi).
  32. "Structure Sensitivity of Acetylene-Ethylene Hydrogenation Over Pd Catalysts", Note in *J. Catal.*, **98**, 550-553 (1987) (with A. Sarkany and L. Guzzi).
  33. "Zeolite Pd Supports for Selective Hydrogenation of Acetylene", Proceedings of Ninth International Congress on Catalysis, Calgary, Canada, June 20, 1988. (With Walter Plante).

#### CATALYTIC CONVERSION OF TOXIC CHEMICALS

1. "Hydrodechlorination Kinetics and Reaction Mechanisms", presented at ACS 152nd Nat. Mtg., New York, NY, Sept. 1966; *J. Catal.*, **6**, No. 2, 167-185, October 1966 (with K.A. Krieger).
2. "The Selectivity of Zero Order Reactions", preprints of papers of Fourth Int'l. Cong. on Catalysis, Moscow, USSR, pp. 2190-2208, Rice University Printing & Reproduction Dept., Houston, TX, July 1969. Presented at Symposium on the Porous Structure of Catalysts and the Role of Transport Processes in Heterogeneous Catalysis, Novosibirsk, July 1968. Proceedings in Russian, Proistaya Strukt. Katal. Protresig Perenosa Geterogenuom Katal., pp. 46-58 (1970). Proceedings in English, Boreskov, G.K., "The Porous Structure of Catalysts and Transport Processes in Heterogeneous Catalysis", pp. 85-104, Akademiai Kiado, Budapest (1972).
3. "Hydrodechlorination of Carbon Tetrachloride", presented at ACS 161st Nat. Mtg., Division of Petroleum Chemistry, Los Angeles, CA, March 28, 1971. *J. Catal.*, **22**, No. 2, 245-254 (1971) (with B. Gambhir and R. Leon).
4. "Depletion of Reactants on a Catalytic Surface During Reaction", Petroleum Division Preprints, ACS 163rd Nat. Mtg., Boston, Ma, April 1972; *J. Catal.*, **26**, No. 1, 82-91 (1972) (with B. Gambhir).
5. "Direct Measurement of Reacting Species on a Catalyst with Dispersed Sites", J.W. Hightower, Editor, "Proceedings of V International Congress on Catalysis, Palm Beach, FL, Aug. 1972", in "Catalysis", American Elsevier Co., Vol. 2, pp. 1319-1327, New York (1973), presented at Univ. of Conn. Chem. Eng'g Seminar Series, Feb. 14, 1972, Northwestern Univ. Chem. Eng'g Colloquium, Jan. 21, 1972, Catalysis Club of Philadelphia Spring Symposium, Wilmington, DE, May 9, 1972, Catalysis Society of New England Spring Symposium, New Haven, Ct, April 4, 1972 (with B. Gambhir).
6. "Effectiveness Factors for Peripherally Deposited Catalysts", presented at 74th National AIChE Meeting, New Orleans, LA, March 1973; at Ben Gurion University of the Negev Chemical Engineering Dept. Seminar Series, Beersheva, March 1974; *J. Catal.*, **31**, 243-256 (1973) (with B.S. Gambhir).
7. "Hydrodechlorination of 1,1-Bis (p-Chlorophenyl)-2,2-dichloroethylene (p,p'-DDE) in the Liquid Phase", *J. Catal.*, **52**, 218-229 (1978) (R.B. LaPierre, L. Guzzi, W.L. Kranich, and A.H. Weiss).

8. "Catalytic Conversion of Hazardous and Toxic Chemicals: Catalytic Hydrodechlorination of Polychlorinated Pesticides and Related Substances", National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA, 22161, Document No. PB 262804, EPA-600/3-77-018, January 1977, (with R.B. LaPierre, E. Biron, D. Wu, L. Guzzi, and W.L. Kranich). See also "Catalytic Hydrodechlorination of Polychlorinated Pesticides and Related Substances; An Executive Summary", EPA-600/8-77-013, available thru NTIS.
9. "GC/MS Analysis of DDT, DDD and DDE Homologs", Environmental International 3, 353-357 (1980) (with R.B. LaPierre).
10. "Hydrodechlorination of Aldrin, Dieldrin, and Toxaphene". In English in Acta Chimica Hung. Acad. Sci., 102, No. 1, 1-10 (1979); in Hungarian in Kemiai Kozlemenyek (Chemical Communications) 51, 191-200 (1979) (R.B. LaPierre, E. Biron, L. Guzzi, and W.L. Kranich).
11. "1-1-Bis (p-chlorophenyl)-2,2-dichloroethylene Vapor Phase Hydrodechlorination", presented at Fifth North American Mtg. of the Catalysis Society, Pittsburgh, PA, April 25-29, 1977; J. Catal., 52, 59-71 (1978) (with D. Wu and W.L. Kranich).
12. "Hydrodechlorination of Polychlorinated Biphenyl", J. Catal., 52, 230-238 (1978) (R.B. LaPierre, L. Guzzi, and W.L. Kranich).
13. "Catalytic Hydrodechlorination of Polychlorinated Compounds", presented at ACS National Meeting, Div. of Pesticide Chemistry, Chicago, IL, Aug. 29, 1977; ACS Symposium Series No. 73, pp. 24-34, "Disposal and Decontamination of Pesticides", M.V. Kennedy, Editor, American Chemical Society, Washington, DC, 1978 (with W.L. Kranich, R.B. LaPierre, and L. Guzzi).
14. "Pulse Microreactor Pesticides Hydrodechlorination", Acta Chimica Hung. Acad. Sci., 103(2), 111-121 (1980) (with R.B. LaPierre).
15. "Hydrodechlorination and Oligomerization of Carbon Tetrachloride Over Nickel Y Zeolites", presented at the 7th North American Meeting of the Catalysis Society, Boston, MA, October 1981; J. Catal., 74, 136-143 (1982) (with S.M. Valinski and G.V. Antoshin).

#### FORMALDEHYDE BASE CATALYSIS

1. "Extraction Procedure for TMS Derivatives", J. Chromat. Sci., 8, 553 (Sept. 1970) (with R.D. Partridge).
2. "Polyols from Formaldehyde", presented at ACHEMA, European Mtg. for Chem. Eng., Frankfurt am Main, June 22, 1970. Neue Verfahren der Chemischen Technik, Verlag G.M.B.H., Wern Leim/Bergstrasse, 1971, p. 239 (with R.D. Partridge, H. Tambawala and J.A. Shapira).
3. "Detection of Sugars by Direct Combustion in a Flame Ionization Detector", J. of Chromat. Sci., 9, 266-270 (May 1971) (with E. Foster).
4. "Manufacture of Sugars", presented at the Amer. Inst. of Chem. Eng. National Mtg., Portland, OR, Aug. 27, 1969. AIChE Symposium Series, No. 18, 67, 137 (1971) (with J.A. Shapira).
5. "Make Sugars from Formaldehyde", Hydr. Proc., 49, No. 2, 119-126, Feb. 1970 (with J.A. Shapira).
6. "Homogeneously Catalyzed Formaldehyde Condensation to Carbohydrates", J. Catal., 16, 332 (1970). Presented at ACS 159th Nat. Mtg., Petroleum Div., Houston, TX, Feb. 22, 1970 (with R. LaPierre and J.A. Shapira).
7. "Homogeneously Catalyzed Formaldehyde Condensation to Carbohydrates. II. Instabilities and Cannizzaro Effects", preprints of the Petroleum Division 163rd ACS Nat. Mtg., Apr. 9-14, 1972, Boston, MA, J. Catal., 26, 388 (1972). Presented at Catalysis Society of New England Spring Symposium, April 1972. (with H. Tambawala).
8. "TMS Derivatization in Aqueous Solutions", J. Chromat. Sci., 10, 120-122 (1972) (with H. Tambawala).
9. "Branched Carbohydrate Structures Resulting from Formaldehyde Condensation", presented at Div. of Carbohydrate Research, 163rd ACS Nat. Mtg., April 9-14, 1972, Boston, MA, J. Carbohydr. Res., 24, 29-44 (1972) (with R.D. Partridge and D. Todd).
10. "Synthesis and Utilization of Formose Sugars", Review Article, Chap. 5, pp. 173-227, Vol. 29 (1974), Adv. in Carbohydrate Chemistry and Biochemistry (with T. Mizuno).
11. "Homogeneously Catalyzed Formaldehyde Condensation to Carbohydrates III, Concentration Instabilities, Nature of the Catalyst and Mechanisms", J. Catal., 32, 216-29 (1974). Presented at the Academy of Sciences of the USSR, Institute of Chemical Physics, June, 1973; at the Ukrainian Academy of Sciences, Institute of Physical Chemistry, June, 1973; at the Third North American Meeting of the Catalysis Society, San Francisco, CA, February 1974; at the Ben-Gurion University of the Negev Chemistry Dept. Seminar Series, Beersheva, Dec. 1973; at the Technion Chemical Engineering Dept. Seminar Series, Haifa, March 1974; at the Middle East Technical University Chemical Engineering Dept. Seminar Series, Ankara, June 1974 (with Tom John).

12. "Simultaneously Catalyzed Reactions of Formaldehyde in Alkaline Systems", presented at Organic Reactions Catalysis Society, 6th Conference on Catalysis in Organic Systems, Boston, MA, May 11, 1976. Proceedings in Smith, G.V., "Catalysis in Organic Synthesis 1977", pp. 153-164, Academic Press Inc., NY (1977) (with V.A. Seleznev and R. Partridge).
13. "Homogeneously Catalyzed Formaldehyde Condensation to Carbohydrates IV. Alkaline Earth Hydroxide Catalysts Used with Glycoaldehyde Cocatalyst", J. Catal., 45, 356-366 (1976) (with T.I. Khomenko, O.A. Golovina, M.M. Sakharov, O.V. Krylov and R.D. Partridge).
14. "Homogeneously Catalyzed Condensation of Formaldehyde to Carbohydrates V. Complexing and pH Behavior with Glucose Cocatalyst", J. Catal., 48, 354-364 (1977) (with V.A. Seleznev, M.M. Sakharov, O.V. Krylov, Y.B. Ghorochovatskii and N.P. Evmenenko).
15. "Synthetic Carbohydrates from Formaldehyde", presented at First International Congress on Engineering and Food, Boston, MA, Aug. 10, 1976, p. 28, Digest of Papers, Amer. Soc. of Agric. Eng., St. Joseph, MO (1976), J. Food Processing and Preservation, 2, No. 1, 63-71 (1978) (with M.M. Sakharov, O.V. Krylov and Y.B. Ghorochovatskii).
16. "Investigation of the Influence of pH and Complexing in the Reaction of Formaldehyde Condensation to Sugars" (in Russian), Izvestia AN, USSR, ser. chim. pp. 1614-1620, July, 1978 (with V.A. Seleznev, M.M. Sakharov, Y.B. Ghorochovatskii, and N.P. Yevmenenko).
17. "Homogeneously Catalyzed Condensation of Formaldehyde to Carbohydrates, VI. Preparation and Spectroscopic Investigation of Complexes Active in Formaldehyde Condensation", J. Catal., 50, 455-463 (1977) (with S.B. Ziemecki, R.B. LaPierre, and M.M. Sakharov).
18. "The Use of Temperature to Simplify Formose Sugar Composition", Reaction Kinetics and Catalysis Letters, 8, No. 2, 155-166 (April 1978) (with V.A. Likholobov and M.M. Sakharov).
19. "On the Step Scheme of the Mechanism of Formose Synthesis in the Presence of Alkaline Earth Hydroxide Catalysts", Proceedings of the 4th Soviet-American Symposium on Catalysis, Snowmass Village, CO, June 22-25, 1977 (with T.I. Khomenko, O.A. Golovina, V.A. Seleznev, M.M. Sakharov, O.V. Krylov, R.D. Partridge, S.S. Ziemecki, and R.G. Socha).
20. "Simultaneous Autocatalytic and Non-Autocatalytic Formaldehyde Reactions", Plenary Lecture at Third Soviet-American Symposium on Catalysis, Kiev, USSR, July 5, 1976; Kinetika i Kataliz, 18, No. 4, 539-542 (1977).
21. "Kinetics and Selectivity of Formose Synthesis in the Presence of Alkaline Earth Metal Hydroxides and Mechanisms of Autocatalysis", presented at 3rd Soviet-American Symposium on Catalysis, Kiev, USSR, July 5, 1976. Kinetika i Kataliz, 18, No. 4, 557-558 (1977) (with R.D. Partridge, T.I. Khomenko, O.A. Golovina, M.M. Sakharov, and O.V. Krylov) (in Russian).
22. "Formaldehyde Base Catalysis by NaX Zeolite", presented at 4th International Conference on Molecular Sieves, Chicago, IL, April 18-22, 1977. Reaction Kinetics and Catalysis Letters, 6, (3) 269 (1977) (with S. Trigerman and E. Biron).
23. "A Process for the Synthesis of Ethylene Glycol from Formaldehyde", presented at Fifth Soviet-American Symposium on Catalysis, Baku, USSR, May 18, 1978. AIChE National Meeting, Miami, FL, Nov. 14, 1978. Manuscript available as Preprint of Meeting. Presented at Department of Energy Seminar Series, Pittsburgh Energy Technology Center, Bruceton, PA, Jan. 9, 1979; at Union Carbide Corp., R&D Laboratories, South Charleston, WV, Jan. 22, 1979.
24. "Ethylene Glycol from Formaldehyde", Ind. Eng. Chem. Proc. Des. Dev., 18, No. 3, 522-527 (1979) (with S. Trigerman, G. Dunnell, V.A. Likholobov, and E. Biron).
25. "The Potential for Producing Edible Sugars from Formaldehyde", presented at AIChE 87th National Meeting, Boston, MA, Aug. 19-22, 1979, J. Applied Catalysis, 1, 237-246 (1981).
26. Zinc Oxide as a Formose Catalyst", React. Kinet. Catal. Lett., 14(3), 259-63 (1980) (with S. Trigerman).
27. "Study of the Catalytic Activity of Cr(III) Complexes in the Reaction of Condensation of Formaldehyde into Carbohydrates", Proceedings of Fifth Soviet-American Symposium on Catalysis, Baku, USSR, May 17, 1978 (with V.A. Likholobov, M.M. Sakharov, and Y.I. Ermakov).
28. "The Mechanism of Autocatalysis in the Synthesis of Carbohydrates from Formaldehyde", Proceedings of Fifth Soviet-American Symposium on Catalysis, Baku, USSR, May 18, 1978; Reaction Kinetics and Catalysis Letters, 3, No. 4, 407-412 (1980) (with T.I. Khomenko, O.A. Golovina, M.M. Sakharov, and O.V. Krylov).
29. "Formose Sugars and Polyols from Formaldehyde", presented at Szeged Branch of the Hungarian Academy of Sciences, Chemistry Dept., Szeged University, Szeged, Hungary, May 28, 1980; presented at Seventh Simposio Iberoamericano de Catalysis, La Plata, Argentina, July 14-18, 1980; in Proceedings, pp. 550-567 (with R.F. Socha, V.A. Likholobov, and M.M. Sakharov).
30. "Homogeneously Catalyzed Condensation of Formaldehyde to Carbohydrates. VII. An Overall Formose

Reaction Model", J. Catal., 67, 207-217 (1981) (R.F. Socha and M.M. Sakharov).

31. "Autocatalysis in the Formose Reaction", Reaction Kinetics and Catalysis Letters, 14, No. 2, 119-128 (1980) (with R.F. Socha and M.M. Sakharov).
32. "Formose and Polyols from Formaldehyde", Chem. Tech., 10, 643-647 (1980) (with V.A. Likholobov and M.M. Sakharov).

#### TOXIC GAS ADSORPTION AND AIR PURIFICATION

1. "A Test for Residual Adsorption Capacity of Charcoal Filters", 14th Biennial Conference on Carbon, Extended Abstracts, The Pennsylvania State University, University Park, PA, June 25-29, 1979, pp. 24-25 (with W.F. Kladnig and L.A. Jonas).
2. "A Method to Determine the Residual Capacity of an Adsorber", Chemical Engineer, London, No. 355, pp. 213-215 (April 1980) (with T. Freund and E. Biron).
3. "Non-Destructive Measurement of Residual Adsorption Capacity of Charcoal Filters", Carbon, 18, 31-35 (1980) (with W.F. Kladnig and L.A. Jonas).
4. "Gas Chromatography Principles Applied to Air Filters", Proceedings of 1981 Chemical Defense Research Conference, Aberdeen Proving Ground, Edgewood Area, MD, November 1981, ARCSL-SP-83026, p.295. (with A. Sacco, Jr.).
5. "Pulse Test Measurement of Residual Adsorption Capacity of Air Filters", Proceedings of 1981 Chemical Defense Research Conference, Aberdeen Proving Ground, Edgewood Area, MD, November 1981, ARCSL-SP-83026, p. 307. (with A. Sacco, Jr.).
6. "Gas Filter Performance and Possible Improvements", Chemical Systems Laboratory Report ARCSL-TR-81097, Aberdeen Proving Ground, Edgewood Area, MD, September 1982. Presented at Naval Research Laboratory Chemistry Seminar, Reston, VA, May 20, 1981. Presented at Chemical Systems Laboratory Research Division Seminar, Aberdeen Proving Ground, Edgewood Area, MD, May 4, 1981.
7. "Capacity Reduction of Regenerated Air Filters", Proceedings of the 1982 Scientific Conference on Chemical Defense Research, Aberdeen Proving Ground, Edgewood Area, MD, Nov. 15-19, 1982. pp. 351-358, Special Publication ARCSL-SP-87030. (with K. Guruz and Don Guo).
8. "Zeolite Catalysts for Gas Mask Canisters", Proceedings of the 1982 Scientific Conference in Chemical Defense Research, Nov. 15-19, 1982 Aberdeen Proving Ground, Edgewood Area, MD pp. 359-368, Special Publication ARCSL-SP-83030. (with R. Szostak).
9. "Capacity Decay of Regenerated Carbon Air Filters", presented at 16th Biennial Conference on Carbon, San Diego, CA, July 18-22, 1983; in Extended Abstracts (with K. Guruz and D. Guo).
10. "Microanalysis of ASC Whetlerite Using X-Ray Emission Spectroscopy", presented at 16th Biennial Conference on Carbon, San Diego, CA, July 18-22, 1983; in Extended Abstracts (with R. Szostak and A. Sacco, Jr.).
11. "Energy Dispersive X-Ray Analyses of Whetlerized Charcoal Microareas"; in Abstracts of 1983 Spring Symposium of New York-New England Catalysis Societies, New Haven, CT, March 16, 1983 (with R. Szostak and A. Sacco).
12. "The Reactions of HCN with Zeolites" pp. 417-427, in Dimmick, R.L., Jr. and Rausa, M., "Proceedings of the 1983 Scientific Conference on Chemical Defense Research"; Aberdeen Proving Ground, Edgewood Area, MD, CRDC-SP-84014, October 1984. (with John A. Scholl, and Rosemarie Szostak).
13. "Deactivation of BPL Carbon During Cyclic Adsorption", pp. 511-523, *ibid.* (with Don Guo and Chandramouli Venkat).
14. "Cyclic Adsorption of Hydrogen Cyanide, Cyanogen Chloride, and Phosgene on BPL Carbon". Extended Abstract, Presented at the Seventeenth Biennial Conference on Carbon, Lexington, KY, June 16-21 (1985). In Proceedings, pp. 102-3 (with Chandra M. Vanket).
15. "Cyclic Adsorption of Styrene and of Plasticizer on BPL Carbon". Adsorption Science and Technology, 4, 15-23 (1987).

#### HYDROGENATION OF LIGNITE AND SOLID WASTE TO OIL

1. "Conversion of Solid Waste to Liquid Fuel", Div. of Cellulose, Wood and Fiber Chemistry", ACS 163rd Nat. Mtg., Boston, MA, April 1972; Textile Research J., 42, 526 (1972).
2. "Cellulose as a Novel Energy Source", Chapter in Advances in Biochemical Engineering, 2, 181-200 (1973) (with M. Mandels and E.T. Reese).
3. "Catalytic Hydrogenation of Solid Waste Carbohydrates to Fuel Oil", presented at Deutsche Gesellschaft fur Chemische Apparatuswesen, ACHEMA 73, June 1973. Presented at Ben Gurion University of the Negev

- Chemical Eng. Dept. Symposium Series, March 1974. Proceedings in Dechema Monographien, 75, "Abgas-Abwasser-World, 2, No. 4, 55 (1974); Synopsis in Chemie Ingenieur Technik, 14, 609 (1974) (with J.A. Kaufman, D.V. Gupta, and T.S. Szatkowski).
- 4. "Cellulose Liquefaction (or Solid Waste to Oil)", presented at Second Solid Waste Management Conference, Worcester Polytechnic Institute, Worcester, MA, Jan. 1973. Proceedings, pp. 269-284; presented at 27th Annual Eastern Colleges Science Conference, Pennsylvania State University, State College, April 1973.
- 5. "Energy from Waste", presented at the Tenth Annual Meeting of the Israel Institute of Chemical Engineers, The Technion, Haifa, April 15, 1974, Israel Journal of Chemical Engineering, pp. 19-23 (June 1974).
- 6. "Catalytic Hydrogenation and Hydrocracking of Oxygenated Compounds to Liquid and Gaseous Fuels", presented at Institute of Catalysis, Siberian Academy of Sciences, Novosibirsk, Nov. 1974; Israel Fiber Institute, Jerusalem; Chemical Engineering Dept., Ben Gurion University of the Negev, Beersheva; Dept. of Organic Chemistry, Weizman Institute, Rehovoth; Chemistry Dept., Bar-Ilan University, Ramat Gan, Israel, Dec. 1974; at the Joint Symposium of the New York and New England Catalysis Societies, New Haven, CT, March 1974; Ind. Eng. Chem. Process Des. Dev., 18, 352 (1977) (with D.V. Gupta and W.L. Kranich).
- 7. "Solid Waste Conversion: Cellulose Liquefaction", Report No. EPA-670/ 2-75-03, National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA, Document No. PB-239-509 (with James A. Kaufman).
- 8. "Oil and Gas from Biomass by Catalytic Hydrogenation", Proceedings of the 29th Canadian Chemical Engineering Conference - Sessions on Synthetic Fuels from Coal and Biomass, Sarnia, Ontario, Oct. 3, 1979, pp. 364-380 (with W.L. Kranich).
- 9. "Hydroliquefaction of Sewage Sludge", Proceedings of National Conference on Municipal and Industrial Sludge Utilization and Disposal, Alexandria, VA, May 28-30, 1980, pp. 137-141. Information Transfer, Inc. (with W.L. Kranich, and K. Guruz).
- 10. "Catalytic Hydrogenation of Turkish Lignites to Oxygen-Free Oil and Gas", Proceedings of Second Miami International Conference on Alternative Energy Sources, Miami Beach, FL, December 10-13, 1979 (with Y. Yorulmaz).
- 11. "Oil and Gas from Cellulose by Catalytic Hydrogenation", Can. J. Chem. Eng., 58, 735-738 (Dec. 1980) (with Wilmer L. Kranich).
- 12. "Catalytic Hydroliquefaction of North Dakota Lignite, Part I. Effects of Process Variables on Product Distribution", Fuel Proc. Techn., 6, 183-201 (1982) (with K. Guruz, W.L. Kranich, A.H. Weiss, C. Dyke, P. Rambelli, and A. Foutsitzis).
- 13. "Catalytic Hydroliquefaction of North Dakota Lignite, Part II. Kinetics of Dissolution", *ibid.*, 6, 200-213 (1982) (with W.L. Kranich, K. Guruz, G. Guruz, and A. Foutsitzis).

#### MISCELLANEOUS

- 1. "The Erratic Nature of the Transcutaneous Diffusion of CO<sub>2</sub>", Proceedings of the 24th Annual Conf. on Eng'g in Medicine and Biology, Las Vegas, NV, Vol. 13, p. 246, Nov. 3, 1971 (with S.M. Yerow, and R.A. Peura).
- 2. "Considerations in the Study of Reaction Sets", presented at New York University Chem, Eng'g Seminar, March 15, 1971; Catal. Revs., 5(2), 283-330 (1971).
- 3. "Industrial Needs in Catalysis", Chem. Eng. Progress, 69, No. 5, 59-64, May 1973 (with D. Luss, D.E. Mears, and R. Heck).
- 4. "Diary of a Scientific Visit to the Soviet Union", Chemical Technology, 3, No. 12, 722-726 (Dec. 1973).
- 5. "A Trip to Africa", Chemical Technology, 4, No. 6, 384-5, June 1974.
- 6. "Physical Aspects of a High Pressure Liquid Chromatographic Separation", Proceedings of the 2nd Annual New England Bioengineering Conference, Worcester, MA, March 29-30, 1974, Vermont University Press (with E.M. Wolshin, A. Feldstein, and R. Peura).
- 7. "A Review of Twelve Catalysis Papers of the Fifth International Conference on Zeolites, Naples, Italy, June 2-6, 1980", in Recent Progress Reports of Conference; presented at 3rd Reunion Internacional de Tecnologia Petroquimica, Universidad Nacional del Sur, Bahia Blanca, Argentina, Aug. 12-13, 1980, in Proceedings.
- 8. "The Technical Center in an Industrial Complex"; presented at the "Seminário de Petroquímica e Polimeros", Hotel Lage de Pedra, Canela, RS, Brazil, May 16-21, 1982; in Proceedings (English); Middle East Technical University Journal of Applied Research, (Turkish).
- 9. "A Scientific Visit to Viet Nam", Chem Tech, 17, 265 (May, 1987).

## TECHNICAL SESSIONS:

- Symposium on "Catalytic Process for Environmental Control", Chairman of Session on "Liquid and Solid Waste Control", American Chemical Society, Ind. Eng. Chem. Div., 165th National Mtg., Dallas, TX, April 8-13, 1973.
- Symposium on "Exhaust Gas, Waste Water, Refuse", Co-Chairman of Session, June 24, 1973,ACHEMA 1973, Frankfurt (Main), Germany.
- Second US-USSR Symposium on Chemical Catalysis, Chairman of Session on "Application of Catalysis to Life Support Systems for Possible Use in Future Space Exploration", Princeton Univ., Princeton, NJ, June 23-25, 1975.
- Third US-USSR Symposium on Catalysis, Co-Chairman of Plenary Session on "Chemical Reaction Engineering", July 6, 1976, Kiev, USSR (with D.B. Sokolsky).
- Fifth Ibero-American Symposium on Catalysis, Chairman of Session A-2, July 28, 1976, Lisbon, Portugal.
- ERDA New England Region Public Meeting, Panelist in Workshop on "Biomass, Energy from Wastes, and Advanced Systems", Boston, MA, Nov. 30, 1976.
- Fifth US-USSR Symposium on Catalysis, Co-Chairman of Session on "Applications of Catalysis", May 8, 1978, Baku, USSR (with V.M. Gryaznov).
- AICHE 87th National Meeting, Chairman of Symposium on "Research on Non-Conventional Production of Food", Boston, MA, Aug. 21, 1979 (I. Zwiebel, Co-Chairman).
- EPA Pesticide Disposal R&D Symposium, Reston, VA, Sept. 6, 1978, Member of Physical/Chemical Technique Panel.
- Advisor for "Chemistry and the Food System, A Study by the Committee on Chemistry and Public Affairs", American Chemical Society, Washington, DC (1980).
- Seventh Simposio Iberoamericano de Catalisis, Moderator for Section 1 Session on Catalysis, La Plata, Argentina, July 15, 1980 (with R. Cid).
- Fifth International Conference on Zeolites, General Reporter on Catalysis, Naples, Italy, June 2-6, 1980.
- Sixteenth Biennial Conference on Carbon, Chairman of Session on Adsorption, Surface Area, and Porosity. July 19, 1983, San Diego, CA.
- AICHE Spring 1984 National Meeting, Chairman of Symposium on "Catalyst/Support Interactions", (A. Sacco, Co-Chairman). Co-Chairman of Symposium on "Catalyst and Adsorbent Deactivation", (A. Sacco Chairman) Anaheim, CA., May 20-24, 1984.
- Seventeenth Biennial Conference on Carbon, Topical Area Chairman in "Surface Science", Lexington, KY, June 16-21, 1985.
- Sixth Danube Symposium on Chromatography, Starter for Round Table Discussion "Applications of Catalysis in Gas Chromatography", Varna, Bulgaria, October 17, 1987.

## LECTURES, SEMINARS, AND SHORT COURSES

- "Production of Xylenes", Seminar at University of Connecticut, Dept. of Chem. Eng., Storrs, Conn., April, 1968.
- "The Kinetics of the Formose Reaction", presented at ACS 155th National Meeting, San Francisco, Calif., April 1968 (with J.A. Shapira).
- "The Formose Reaction", presented at the First Spring Symposium of the Catalysis Club of New England, Boston, Mass., April 1, 1970. Presented at Montecatini Edison, Bollate Research Laboratory, Milano, June 15, 1970. Presented at Third International Congress of Food Science and Technology, Washington, D.C., August 10, 1970.
- "A Study of a Complex Reaction", October 30, 1970, University of Houston, Dept. of Chemical Engineering Seminar Series, Houston, Texas.
- "Reactions of Sulfur and Propane", presented at Cities Service Oil Co., Research & Development Seminar Series, Hightstown, N.J., May 21, 1970.
- "Solid Waste Conversion and Food Synthesis", Interview with Hugh Downs, NBC Today Show, September 16, 1971.
- "Research on Solid Waste Conversion to Oil at WPI", Lecture to Boston Chapter, WPI Alumni Society (April 1972); Pittsburgh Chap. (Oct. 1972).
- Short Course "Catalyst Selection and Evaluation", Lectures in Petroleum Refining, The Center for Professional Advancement, Somerville, N.J., (April 1972). Middle East Technical University, Ankara, Turkey (June 1974).
- Mini Course: "Gas Chromatography and Mass Spectrometry", The Ben Gurion University of the Negev, Beersheva,

Jan-March 1974.

- "Relationships Between Ben-Gurion University and the Industry of the Negev", Beersheva, May 12, 1974.
- "Hydrogenation of Cellulosic Materials to Hydrocarbons", Israel Fiber Institute Seminar Series, Jerusalem, May 22, 1974.
- "Conversion of Organic Solid Waste to Fuel Oils by a Catalytic Hydrogenation Process", Presented at the Joint Symposium of the New England and New York Catalysis Societies, Yale University, New Haven, Conn., March 18, 1974; at the 9th Mid Atlantic Meeting of the ACS, Wilkesbarre, Pa., April 26, 1974.
- Mini-Course: "Fundamentals of Gas Chromatography", Chemical Engineering Dept., Ben Gurion University of the Negev, Beersheva, Israel (Dec. 1974).
- "Homogeneously Catalyzed Cannizzaro and Aldol Reactions of Formaldehyde", Dept. of Organic Chemistry, Weizmann Institute, Rehovoth, Israel (December 1974).
- "pH Behavior during the Induction Period of the Formose Reaction", USSR Academy of Sciences, Institute of Chemical Physics, Moscow; Ukrainian Academy of Sciences, Institute of Physical Chemistry, Kiev, USSR (November 1974).
- "US-USSR Detente Research Collaboration", Interview with Anatoly Deronin, Guests of Moscow Program, USSR Radio Network, Nov. 12, 1974.
- "The US-USSR Research Collaboration at Worcester Polytechnic Institute", to the WPI Board of Trustees, Feb. 7, 1974.
- "Surface Diffusion Effects in Acetylene Deuteration", Israel Catalysis Society, Rehovoth, Israel, Dec. 1974; Fourth North American Meeting of the Catalysis Society, Toronto, Ontario, Feb. 1975.
- "Catalytic Hydrogenation of Cellulose to Oil and Gas", Ch.E. Dept. University of Massachusetts, Amherst, Mass., March 4, 1976.
- "Catalytic Conversion of Solid Waste into Oil and Gas", Sigma Xi Chapter, University of Lowell, Lowell, Mass., Feb. 26, 1976.
- "Selectivity Control in Homogeneous Formaldehyde Condensation to Sugars", Hungarian Catalysis Society and Central Institute of Chemistry, Hungarian Academy of Sciences, Budapest, June 23, 1976.
- "Cellulose Hydrogenation Using Nickel Catalyst", Institute of Isotopes, Hungarian Academy of Sciences, Budapest, June 22, 1976.
- "The Relationship of the Formose Complex to Reaction Behavior", Institute of Physical Chemistry, Kossuth Lajos Univ., Debrecen, Hungary, June 24, 1976.
- "Recent Progress in Formose Research", Seminar at Chemistry Dept., University of Southern Illinois, Carbondale, Il, June 21, 1977.
- "Hydrogenolysis of Formose Sugars to Polyols", presented at ACS National Meeting, Div. of Carbohydrate Chemistry, Chicago, Il, Aug. 30 1977.
- "Formaldehyde Self-Condensation", Celanese Research Co., Summit, N.J., Mar. 10, 1977.
- "Concerted Reactions and Selectivity Phenomena in Catalytic Hydrodechlorination of Polychlorinated Compounds", presented at Joint Spring Symposium of the New York and New England Catalysis Societies, Yale University, New Haven, Conn., March 16, 1977.
- "Biomass Conversion to Oil and Gas", ERDA New England Region Public Meeting, Boston, Mass., Nov. 30, 1976.
- "Selectivity Optimization, Catalyst Modification, and Process Research at MPI", Dow Chemical Co. New England Laboratories, Wayland, Mass., Nov. 17, 1976.
- "Conversion of Formaldehyde to Ethylene Glycol Over Zeolites", Seminar at Department of Applied Chemistry, Jozsef Attila University, Szeged, Hungary, May 4, 1978.
- "Selective Deuteration of Acetylene Over Palladium Catalyst", Seminar at Institute of Isotopes, Hungarian Academy of Sciences, Budapest, Hungary, May 8, 1978.
- "Catalytic Hydrodechlorination of Pesticides", Spring Meeting of Hungarian Catalysis Club, Kecsemet, Hungary, May 11-12, 1978.
- "A Kinetic Model for the Formose Reaction", presented at Sixth Joint US-USSR Symposium on Chemical Catalysis, June 19-23, Cherry Hill Inn, N.J., (A.H. Weiss, R.F. Socha, M.M. Sakharov)
- "Food and Liquid Fuel from Coal", Interview for "The Third Millenium", Radio Series with Richard Kirkland, WTAG, Worcester, Mass., Feb. 9, 1979.
- "Hydroliquefaction of Cellulosic Materials", INTEC, Institute for Technological Development for the Chemical Industry, Santa Fe, Argentina, July 27, 1979.
- "Conversion of Solid Fuels to Liquids and Gases by Catalytic Hydrogenation", Workshop on Coal Conversion, MPI, Worcester, Mass., October 13, 1978.
- "University in the Desert", American Associates of Ben-Gurion University of the Negev, Worcester, Mass., Sept. 11, 1979.
- "Acetylene Deuteration in the Presence of  $^{14}\text{C}$  Ethylene", Proceedings of Joint Spring Symposium of New York

- and New England Catalysis Societies, Yale Univ., New Haven, Conn., Mar. 14, 1979.
- "Selective Hydrogenation of Acetylene to Ethylene", Second International Meeting on Petrochemical Technology, Universidad Nacional del Sur, Bahia Blanca, Argentina, July 16, 1979.
- "Resource Recovery from Pesticides", EPA Pesticide Disposal R&D Symposium, Reston, VA, Sept. 6-7, 1978.
- "Formaldehyde Condensation to Glycolaldehyde Over Zeolites", 6th North American Meeting of the Catalysis Society, Chicago, IL, Mar. 18-22, 1979.
- "Seminario de Catalisis, Programa de Naciones Unidas para el Desarrollo", Universidad Nacional de Sur, Bahia Blanca, Argentina, 11-12 August 1980; "Industrial Needs in Catalysis - Research Which Should Be Done in Universities and in Industry" (A.H. Weiss).
- "Basic Principles of Gas Chromatography", 2-day mini course (in Spanish), presented at Indupa Corp., Cinco Saltos, Argentina, July 7-8, 1980; at Petroquimica Bahia Blanca, Bahia Blanca, Argentina, July 24-25, 1980; at Gas del Estado, Buenos Aires, Argentina, July 29-30, 1980; at Research Institute for Chemical Industry, Beijing, China, August, 1981.
- "Interactions of Industry and Academia for Research in Catalysis", presented at Petroquimica General Mosconi, Ensenada, Argentina, Aug. 28, 1980.
- "Catalytic Hydroliquefaction of Cellulose Materials", presented at COPPE, Dept. of Chemical Engineering, Federal University of Rio de Janeiro, Brazil, May 21, 1982.
- "Chemical Process Development", 6-week course presented at Research Institute for Chemical Industry, Beijing, China, August-September, 1981.
- "Surface Diffusion Effects in Pd/Al<sub>2</sub>O<sub>3</sub> Catalyzed Acetylene Hydrogenation", First Annual Research Symposium of the Catalysis Society of New England, Worcester Polytechnic Institute, Worcester, MA, Nov. 29, 1983.
- "Selectivity Phenomena in Acetylene Hydrogenation", Presented at Institute of Chemical Physics, Moscow, USSR, 8 June 82, Institute of Catalysis, Akadengorodok, Novosibirsk, USSR, 14 June 82, Hungarian Hydrocarbon Institute, Szazhalombatta, Hungary, June 1982.
- "Selectivity Control in CCl<sub>4</sub> Hydrogenation Using Nickel Zeolites", Presented at Hungarian Academy of Sciences, Central Institute of Chemistry, Budapest, June 1982.
- "Selectivity Characterization of DDT Hydrogenation", Presented at Hungarian Academy of Sciences, Central Institute of Chemistry, Budapest, June 1982.
- "Quantitative Measurement of Adsorbed Species on Pd/Al<sub>2</sub>O<sub>3</sub> During Acetylene Deuteration", US Hungary Workshop for Surface Science and Catalysis, Budapest, July 8-12, 1984.
- "Surface Diffusion During Acetylene Deuteration", AIChE 1984 Spring National Meeting, Anaheim CA, May 20-23, 1984.
- "Synthetic Crude Oil and the Twentieth Century Energy Picture", WPI Outstanding Research and Creative Scholarship Award Lecture, WPI February 28, 1985.
- "Selective Hydrogenation of Acetylene in the Presence of Ethylene", Presented at University of New Hampshire, Dept. of Chemical Engineering, Spring 85 Seminar Series, Durham, NH, March 14, 1985.
- "Acetylene/Ethylene Hydrogenation Structure Sensitivity on Dispersed Pd", Ninth North American Meeting of the Catalysis Society, Houston, Texas, March 20, 1985.
- "Deactivation, Oligomer Formation, and Structure Sensitivity during Acetylene Hydrogenation" at the 1985 Joint Spring Symposium of the Metropolitan New York-New England Catalysis Societies, Yale University, March 13, 1985.
- Mini-Course "Industrial Practice of Kinetics and Catalysis" at PETKIM Corp. Petrochemical Complex, Yarimca, Turkey, January, 1986.
- "The Role of Synthetic Crude Oil in the World Petroleum Market of the Year 2000" Award Lecture at Worcester Polytechnic Institute, April 1985; at Institute of Industrial Chemistry, Ho Chi Minh City, Viet Nam, February, 1986.
- "Research on Catalytic Hydrogenation of Acetylene in Ethylene" at Institute of Industrial Chemistry, Ho Chi Minh City, Viet Nam, February, 1986.
- "Structure Dependent Hydrodechlorination and Oligomerization of Carbon Tetrachloride over NiY Zeolites" at Institute of Chemistry, Hanoi; at Institute of Industrial Chemistry, Ho Chi Minh City, Vietnam, February, 1986.
- "Application of GC/MS and Isotopic Techniques in Catalysis Research", Plenary Lecture, Sixth Danube Symposium on Chromatography, Varna, Bulgaria, October, 1987.
- "Breathing Device to Protect Against CO, Lachrymators, and Toxics in Smoke". Babson Entrepreneurial Exchange Business Plan Forum, Babson College, Babson Park, MA, November, 1986.