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ANALYSIS OF THE VOLATILE COMBUSTION
PRODUCTS OF VINYL PLASTICS

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The use of plastics at elevated temperatures in confined spaces has created an interest in the possible toxicity of their combustion products. We have examined pure and formulated vinyl plastics to determine the composition and toxicity of their combustion products.

Differential thermal analysis and thermal gravimetric analysis were used to determine the temperatures at which chemical and physical changes take place. The products of combustion were then determined qualitatively using infrared spectroscopy and a combination of gas chromatography and mass spectroscopy. Quantitative analyses were performed on the products produced under controlled combustion conditions.

A comparison of the products of the formulated and virgin resins is given, as well as some toxicity information resulting from animal exposures.

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INTRODUCTION

The use of plastics for applications that can result in high temperatures in confined spaces has made it necessary for the environmental health scientist to become knowledgeable of the nature and toxicity of the products of combustion of these plastics. The pyrolysis products of various polymers have been reported by others^(1,2,3,), but much of this work has been carried out in inert atmospheres for the purpose of gaining information about polymer structure. Those workers concerned with the combustion of vinyl chloride polymers examined these plastics to determine primarily the amounts of HCl, CO₂, CO and other gross products given off and the temperatures at which they were produced. Five such papers were published recently in German publications⁽⁴⁻⁸⁾.

In 1963, we began a program* to determine the volatile combustion products of various plastics⁹ and to carry out animal exposure studies to determine the toxicity of these products. The combination of analytical data and acute toxicity studies will allow the determination of whether the compounds shown to be present can account for the overall toxicity of the decomposition products or whether synergistic effects may also be a factor to be taken into consideration. A prior knowledge of the physical nature and chemical composition of these pyrolytic products will also provide a necessary guide for animal exposures, both as to the extent of exposure and to the possible nature of the toxic effects.

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This paper describes our results in the examination of polyvinyl chloride polymers and plastics. This particular group was selected first because of its wide application in electrical insulation and construction materials, second, because of extensive work done in the pyrolysis of the basic polymers by others, and third, because only limited knowledge is available on the quantities of compounds formed in combusting plastic products of this type under various combustion conditions⁽¹⁰⁾. The procedure used in our work consisted of two parts. The first part was directed toward a qualitative and quantitative analysis of the products of combustion. The second was concerned with the determination of the toxicity of the combustion products. All combustion took place in controlled amounts of air.

The analytical portion of the study was carried out in three phases:

- 1) The temperatures at which chemical and physical changes take place in a controlled air supply were determined.
- 2) The compounds liberated at these temperatures were identified or characterized.
- 3) The quantities of the products were determined either at the temperatures covering each decomposition step or for a sample collected over the entire combustion process.

The temperatures at which changes take place were determined by differential thermal analysis (DTA) and thermogravimetric analysis (TGA). In the second phase of the analysis, which involved identification of the compounds liberated at the decomposition temperatures, two different approaches were taken. The gases collected from either the TGA apparatus or combustion furnace were analyzed directly for the major compounds by infrared absorption spectroscopy or mass spectroscopy. For positive identification of the minor constituents, it was necessary to collect the gases from a larger sample than the 200 mg that can be handled

by the TGA apparatus. To do this, a combustion furnace with controlled temperature and air supply was used to carry out the combustion on a ten-fold scale (2g) but under the same conditions as in the TGA apparatus. The gaseous products were either collected in two phases (compounds boiling below -74°C and above -74°C) or were collected as a single gas sample and separated further by gas chromatography. The individual chromatographic peaks were collected by condensation at liquid air temperature, and these fractions were analyzed by mass spectroscopy.

The third phase, the quantitative analysis or the identified products, was carried out by infrared spectroscopy for the principal constituents and by gas chromatography for the minor constituents.

In the toxicity portion of the study, rats were exposed to the volatile thermal decomposition products of the plastics in small chambers. The products were generated in the same combustion furnace used in the analytical study. As in the analytical study, the individual exposures were made using the same combustion temperature range and heating rate, so that the exposure conditions could be correlated with the analytical data. The toxicity data is described in another paper.

Four polymers produced by two companies were analyzed, as were three formulations using three of these polymers. These polymers are as follows:

Polymer A: A polyvinyl chloride homopolymer.

Polymer B: Similar to A but a later production.

Polymer C: Similar to A & B, but produced by another company.

Copolymer D: A copolymer of vinyl chloride and vinyl acetate in the ratio of 85 to 15 respectively.

Plastic E: A formulation commonly used for wire insulation using Polymer C.

Plastic F: A formulation used for floor tiles, using copolymer D.

Plastic G: A wire insulation formulation; using polymer B.

With one exception, the polymers and formulations were standard commercial materials furnished by the polymer manufacturers. The last product, Plastic G, was formulated for us in a development lab of one manufacturer, using a "typical" wire insulation formula.

RESULTS:

Breakdown Process. Differential thermal analysis (DTA) was used to determine the temperatures at which chemical and physical changes take place. With this apparatus, we obtained a record as shown in Figure 1 for Polymer C when heated in an excess of air. This record shows the heat absorbed (from an endothermic change) (down) or liberated (from an exothermic change) (up) as ΔT plotted against the temperature of the sample. Of significance here is the endothermic peak with a maximum at about 300°C, which (according to Cobler) results from the release of the chlorine atoms in the polymer; unfortunately it is obscured here in the start of the continually increasing exothermic peak from 300°C to 600°C, at which temperature the samples is completely combusted. The dehydrochlorination peak varies in position by $\pm 20^\circ\text{C}$, and as this variation seems to be erratic and independent of the sample, it is assumed that it is associated with some experimental parameter, such as sample packing, etc.

Figure 2 shows the DTA record of plastic E which was formulated from polymer C. The only gross difference is the steeper slope in the exothermic peak at 325°C. Because of the limited amount of interpretation that we could extract from the curves, the information derived from the DTA technique was not as helpful to our study as was thermogravimetric analysis, where one obtains a recording of weight loss with temperature. Figure 3 shows a TGA record for Polymer C. Here one finds a rapid weight loss at 300°C, corresponding to the endothermic peak in the DTA record. On collecting the combustion gases up to 300°C and analyzing them by infrared absorption, it was found that the 60% weight loss was almost entirely due to the removal of chlorine in the form of

hydrogen chloride gas, and by calculation it appeared that the amount corresponded to almost all of the chlorine atoms in the polymer. Above 300°C, the TGA record shows a slower but gradually increasing rate of weight loss up to 600°C, corresponding to the exothermic peak in the DTA record. It will be noted that this weight loss appears to take place in five stages: The first is the rapid loss up to 280°, the second, a decreasing rate of loss up to 350°, the third, a slow constant rate of loss to 430°, the fourth, a more rapid rate of loss to 510°, and finally, a faster rate of loss for the remainder of the sample. These particular temperature ranges are used later (Table IV) in describing the change in composition of the combustion products with the temperature.

Figure 4 shows a similar record for Plastic E, which contains Polymer C. It will be noted that the height of the 300° step, attributed in Figure 2 to the removal of chlorine, is as high here, although this plastic contains only 57% of the polymer. The remainder of the weight loss is due to the boiling-off of the plasticizer, a phthalate which has a boiling point of about 280°C.

Figure 5 is the TGA record of the Copolymer D, and it can be seen that its weight loss proceeds quite the same as the previous polymer, except that here the initial weight loss is due to both the removal of chlorine atoms and acetate groups. Figure 6 is of Plastic F, the floor tile formulation that contains about 35% of Polymer D. This formulation contains a considerable amount of inorganic minerals, such as asbestos, which is the reason for the limited amount of weight loss up to 600°C.

QUALITATIVE ANALYSIS:

If one analyses the products of combustion by infrared spectroscopy, collecting the total products in gas form and introducing them into long-path gas cells, absorption bands of HCl, CO₂, CO, and C₆H₆ will be found, along with other bands in the 3000 cm⁻¹ region, indicating the presence of compounds containing C-H groups. It was evident from this that the identification of

other compounds should be carried out by separating them from the mixture and collecting them in individual quantities that would permit identification by infrared or mass spectroscopy. For this, gas chromatography was used, using sufficiently large columns to permit the introduction of up to 30 ml of air containing combustion products. To separate the low boiling compounds, i.e. those boiling at temperatures less than 0°C , a Porapak Q column was used, while to separate the higher boilers, a column of 5% Squalane on Chromosorb P was used. On the column outlet of the chromatograph is a stream splitter which passes one hundredth of the gas through a hydrogen flame detector. The remaining 99 parts emerge from the column through a two-way valve so that it can be diverted into a U-tube when a particular compound is emerging. The U-tube is filled with glass beads and is cooled with liquid air to condense out everything except the carrier gas, which is He. The U-tube and its cooling flask is then transferred to the inlet system of the mass spectrometer.

As indicated earlier, HCl , CO , CO_2 , and C_6H_6 were identified in the gross product by infrared spectroscopy. Other low boiling compounds were separated on the Porapak column. Figure 7 shows the separation of the first 8 compounds. These are primarily the parafins and olefins up through butane. The peaks are identified in Table I according to peak number. These peaks were identified by using the collection technique described to transfer the compound to the mass spectrograph. The mass spectrographic identification was then cross-checked by injecting the pure compound on the chromatograph to establish that its elution time was the same as the collected peak.

Higher boiling compounds were separated using the squalane column. A chromatogram of this column is shown in Figure 8. Here, in addition to the straight chain parafins and olefins, one finds both branched and cyclic compounds. These are again identified in Table I.

There are a minimum of 58 volatile products of combustion, totaling the three compounds identified by direct infrared analysis

and 52 chromatographic peaks. This is given as a minimum figure, because at least three of the peaks represent more than one compound. Of this minimum figure of 58, we have identified 44 compounds. Of another six, we have determined the molecular weight and established that they are olefins, but because of the similarity in the molecular weights and the limited mass spectra reference data, a positive identification has been difficult. The other eight compounds are higher boilers and are present in very small quantities, i.e. less than 30 µg/g, and therefore are of limited interest from the standpoint of toxicity. This qualitative picture was quite similar for all PVC polymers and formulations tested, with only a few differences found in the higher-boiling products, and this is discussed in the next section.

QUANTITATIVE ANALYSIS:

As indicated earlier, to obtain large amounts of combustion products both for the analytical work and later toxicity tests, a controlled atmosphere combustion furnace was designed and built. The furnace has a Vycor gas-tight core which is supplied air from a tank of purified air. The outlet of this core is connected to a U-tube submerged in a cooling bath for condensing out some of the emerging compounds. Others pass through or by-pass the tube and are collected in a plastic bag. The furnace is controlled by a commercial programmer-controller. Using this apparatus, we can heat larger samples of the plastic with controlled temperature and air supply to carry out the combustion under the same conditions as the TGA apparatus. One can establish that the products are the same by comparing the gas chromatogram of the furnace products with the chromatogram obtained from the TGA combustion products over the same weight-loss range. The products from the combustion furnace can be collected in several temperature or time fractions, depending on the collection method.

One of our "ground rules" from the start was that we would only be concerned with the "volatile products" of combustion, defining as volatile those compounds boiling up to 130°C. As a result, we were not concerned with the collection of higher boiling

compounds that either remained in the combustion boat or were deposited in the exit end of the combustion tube, although we attempted to keep an account of the weight of this remainder to assure that the volatile fraction was all accounted for. As a result, although the TGA record of Plastic E (Figure 4) shows a weight loss due to the boiling off of the phthalate plasticizer, this compound is not listed in our quantitative results. In our quantitative work, various parameters were examined that could affect the quantities of the various compounds of combustion, and these are reported as follows:

1. The variation in quantity within a class of compounds and between classes of compounds for the polymers.
2. Quantitative changes with varying air supply.
3. Quantitative changes with temperature.
4. Quantitative changes with varying heating rates.
5. Quantitative changes between the plastics and their polymers.

All the quantitative work was done on the 22 compounds present in the greatest quantities.

1. Variations between combustion compounds of the polymers:

As a uniform condition for intercomparing the polymers and formulations of the polymers, the following combustion conditions were adopted:

The air supply was 60 c.c. of air a minute, which when integrated over the entire run would result in about twice the amount of oxygen necessary to convert all of the carbon to carbon dioxide. However, this is not true for any particular time in the combustion process, in that first, the carbon is not available to form carbon dioxide until the higher temperatures are reached, and second, the air flow pattern is such that all of its oxygen is not in the immediate vicinity of the sample. The plastics were heated, (after an initial heating from room temperature) from 200°C to 600°C at a rate of 3°C degrees a minute.

Table II shows the volatile products of combustion of the Sample B polymer. The quantities of these products are quite

representative of the other two homopolymers. Also in this table are the same products from the Sample D copolymer. All quantities given are in mg of compound per gram of polymer. It will be noted that in the case of Sample B, the chlorine is almost completely accounted for in the form of HCl gas (582 mg vs 584 possible).

*0.001
2.5m =
500 ppm of
air
0.05% max
of sample in
vcl 92*

The only other chlorine compounds found, methyl chloride and vinyl chloride, are present in quantities less than 1 mg. Some investigators have reported finding phosgene intermittently in very small quantities (0.1 ppm) but, using detector tubes of this sensitivity, we have not found this compound in any of our tests. The next most abundant products are the carbon dioxide and the carbon monoxide, which are formed at the higher combustion temperatures. The next compound in quantity is benzene, where 35 mg/g are formed. Note that the quantities of these compounds in the copolymer are very similar, except that some of the HCl is replaced by acetic acid. Next in quantity and decreasing with increasing molecular weight are the straight chain aliphatics, starting with methane. The olefins and side-branched aliphatics are generally present in lesser quantities than the corresponding aliphatics. In these samples, the volatile combustion products account for approximately 100% of the original polymers, and no residue remained in the combustion boats.

2. Variations with amount of air.

One sample (Polymer A) was combusted under three air (or oxygen) conditions. The first was with the amount of air to provide a minimum amount of oxygen for complete combustion of all carbon to CO₂ (using 30 c.c. air per minute). The second was using about twice this amount (60 c.c. per minute) and the third air condition was with a large excess of oxygen.

The results are shown in Table III. The data shows that all of the hydrocarbons, except for benzene, decrease in quantity with increasing air. The benzene content seems to be independent of the air conditions. The only compound which increased was the vinyl chloride. Although this change in the amount of air affects

the quantity of hydrocarbons generated, surprisingly it had little effect on the quantity of CO and CO₂ generated, which showed no trends using these air flows. However, it should be mentioned that the quantities of CO₂ varied erratically in most of our combustion runs for some unknown reason.

Variations with temperature. Table IV shows the variation in quantities of products of combustion as a function of temperature. The products were collected in five fractions during a single heat run. The fractions were selected on the basis of the curve inflections on the TGA curve shown in Figure 3. The first temperature fraction, which is the one where most of the chlorine is removed, shows the immediate formation of benzene and a little toluene.

In the second fraction, 280-350°C, the first CO₂ and CO appear, the toluene continues to increase, but the benzene is already decreasing, and continues to decrease through the higher ranges. As one would expect, the CO₂ and CO reached their maximum at the higher temperatures.

Methane reached its maximum in the fourth step, but was still generated at the higher temperatures. The other straight chain aliphatics reached their maximum in the third step and were present in the last step in very small quantities. The olefins began to form in the first step, reached their maximum in the third, and did not appear in the last two fractions. Enough chlorine remained to form some HCl in the second step, but it was here that the maximum amount of vinyl chloride was formed.

Quantitative changes with varying heating rates:

The data on Table V is representative of what happens when the heating rate is increased considerably. Here one can see that an increase in heating rate results in an increase in hydrocarbon production, but it will also be noted that the unsaturated compounds increase by a greater amount than the saturates. As a result, in an exceptionally fast heating rate, the olefins will be present in greater quantities than the aliphatics. This is illustrated in the chromatogram shown in Figure 6, where the products

were collected from a run in which the controlling thermocouple burned out, with the result that a heating rate greater than $80^{\circ}\text{C}/\text{minute}$ was attained. Also to be noted is that at higher heating rates the production of CO_2 and CO decreases.

Variations between plastics and their polymers:

A comparison of the products of combustions of the three plastics with the products from their polymers is given in Table VI. Plastic E contains 57% of Polymer C, Plastic G 51% of Polymer B, and Plastic F 35% of Polymer D. One thing of note in Plastics E and G is that except for the aromatic compounds which are less, the other 15 hydrocarbons have all increased in quantity by factors ranging from 1.3 up to 8 times, with the average about 4 times. Likewise, the amount of vinyl chloride is about 5 times as great in these samples that contains only 50% of PVC polymer. It is possible that some of the increase in hydrocarbons may be attributable to the break-down of the phthalate plasticizer, although the extent of this contribution has not been established.

Different results are noted for a floor tile formulation (Plastic F) made from copolymer D. This product contains about $1/3$ copolymer D, but the hydrocarbon products generated, especially the saturated aliphatics and the benzene are considerably less than $1/3$ the amount generated in copolymer D. Likewise, the amount of HCl to CH_3COOH is only 20%, rather than the 33% expected. This product contains about 70% inert material, such as asbestos and calcium carbonate, which may play a part in inhibiting break-down of the polymer and the production of hydrocarbons. It should be stated that Plastic F has three compounds with boiling points in the vicinity of 120° that have not been identified, which are present in quantities of one to five mg/gram.

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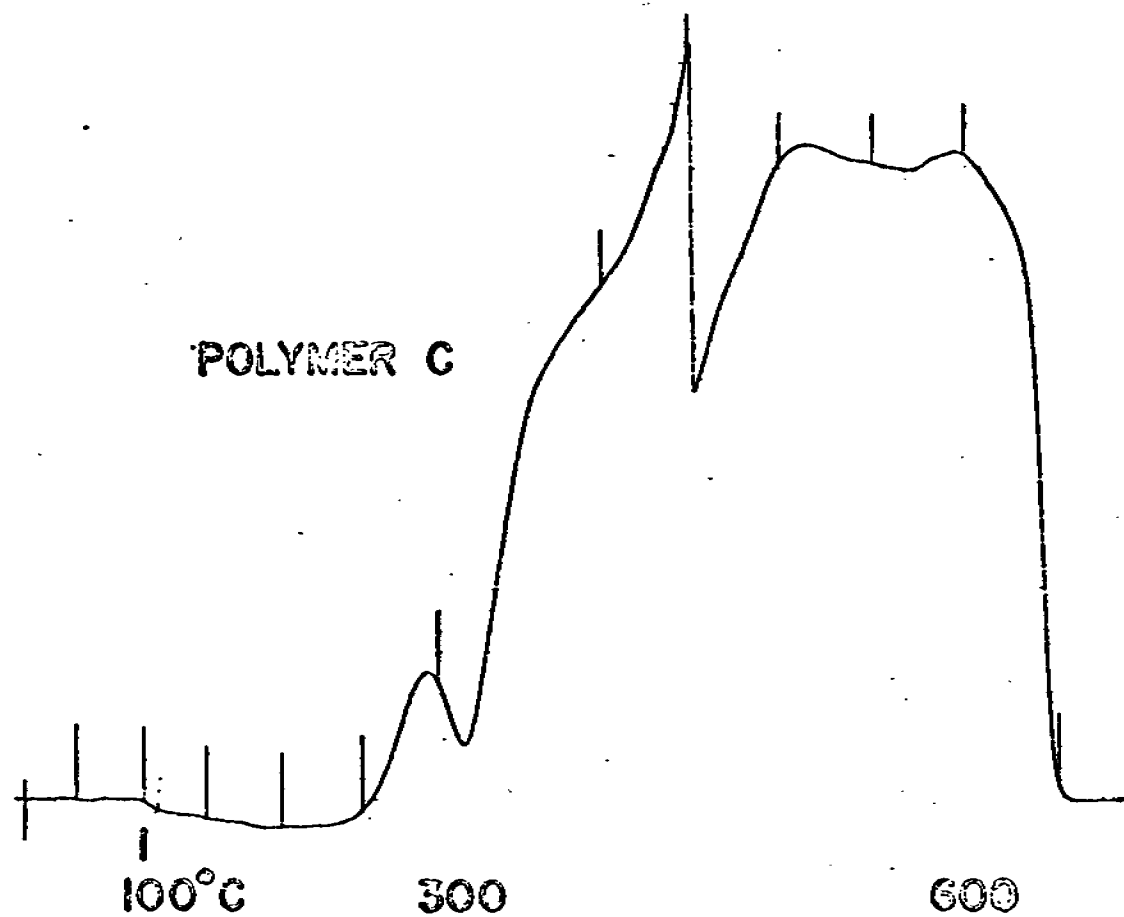


Figure 1 Differential thermal analysis of Polymer C

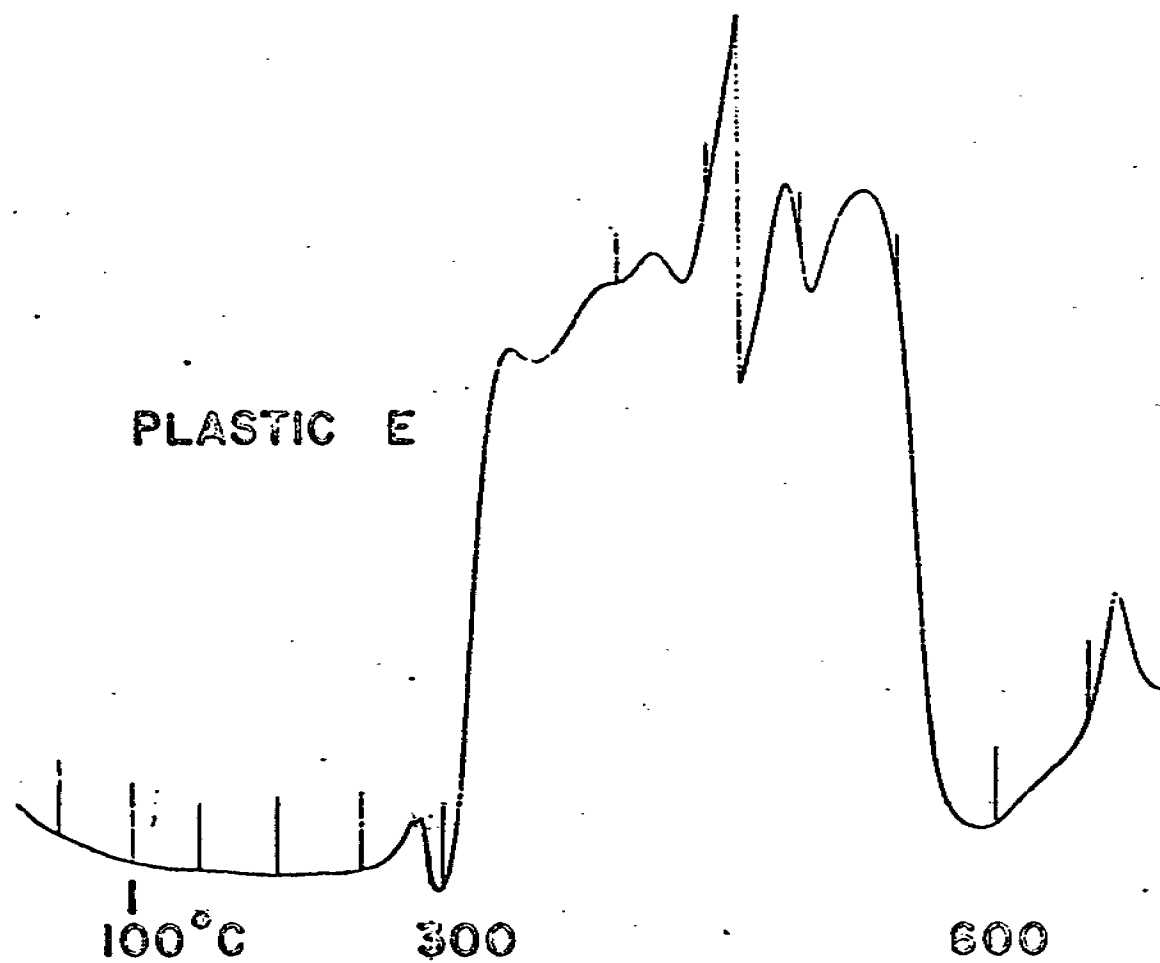


Figure 2 Differential thermal analysis of Plastic E

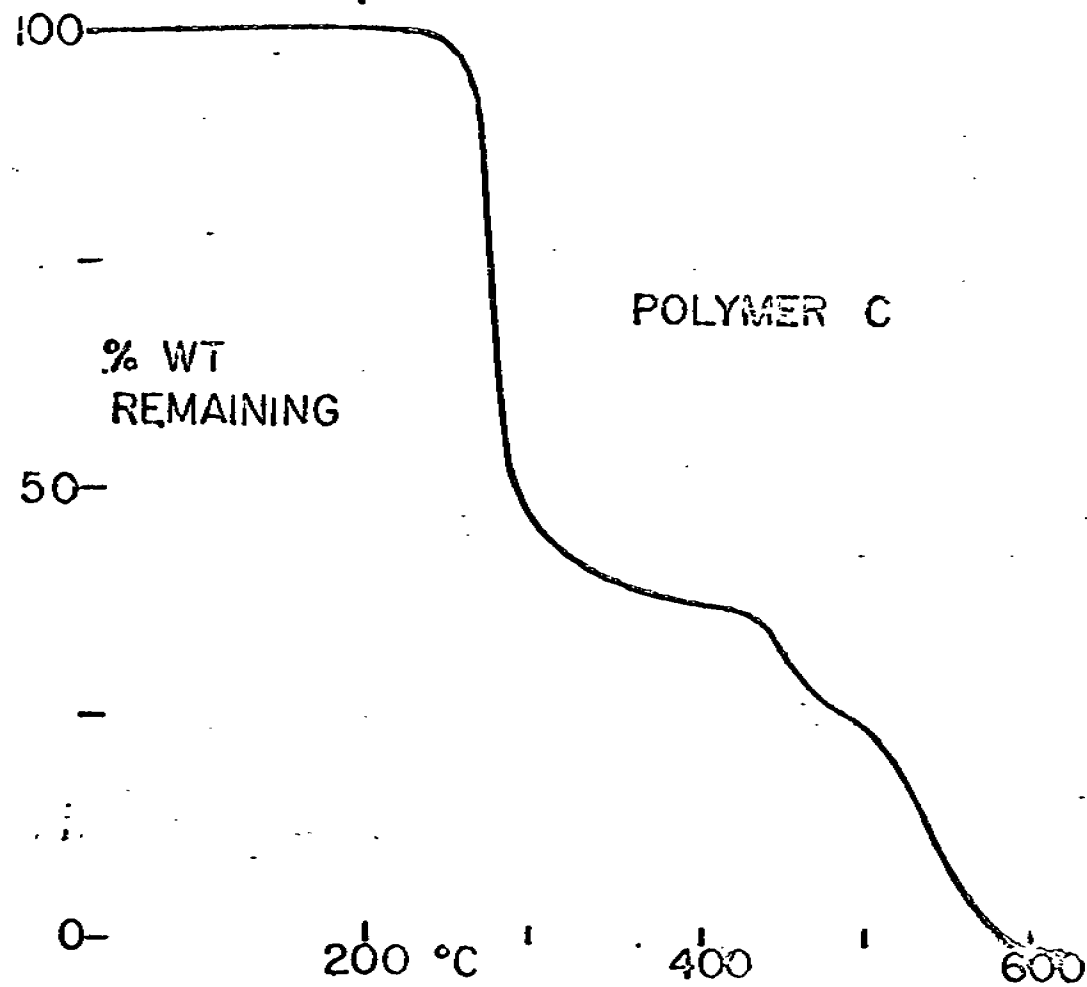


Figure 3 Thermogravimetric analysis of Polymer C

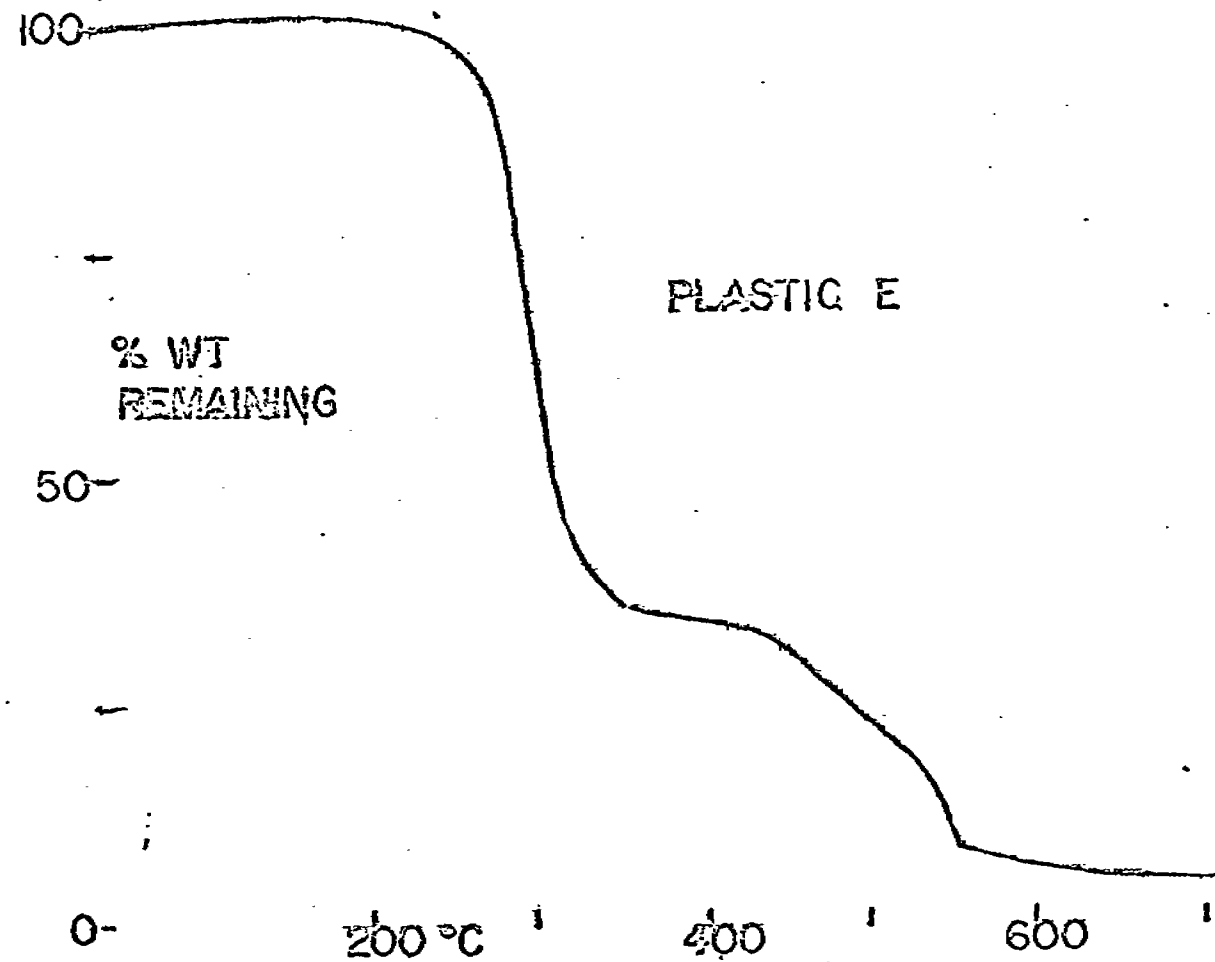


Figure 4 Thermogravimetric analysis of Plastic E

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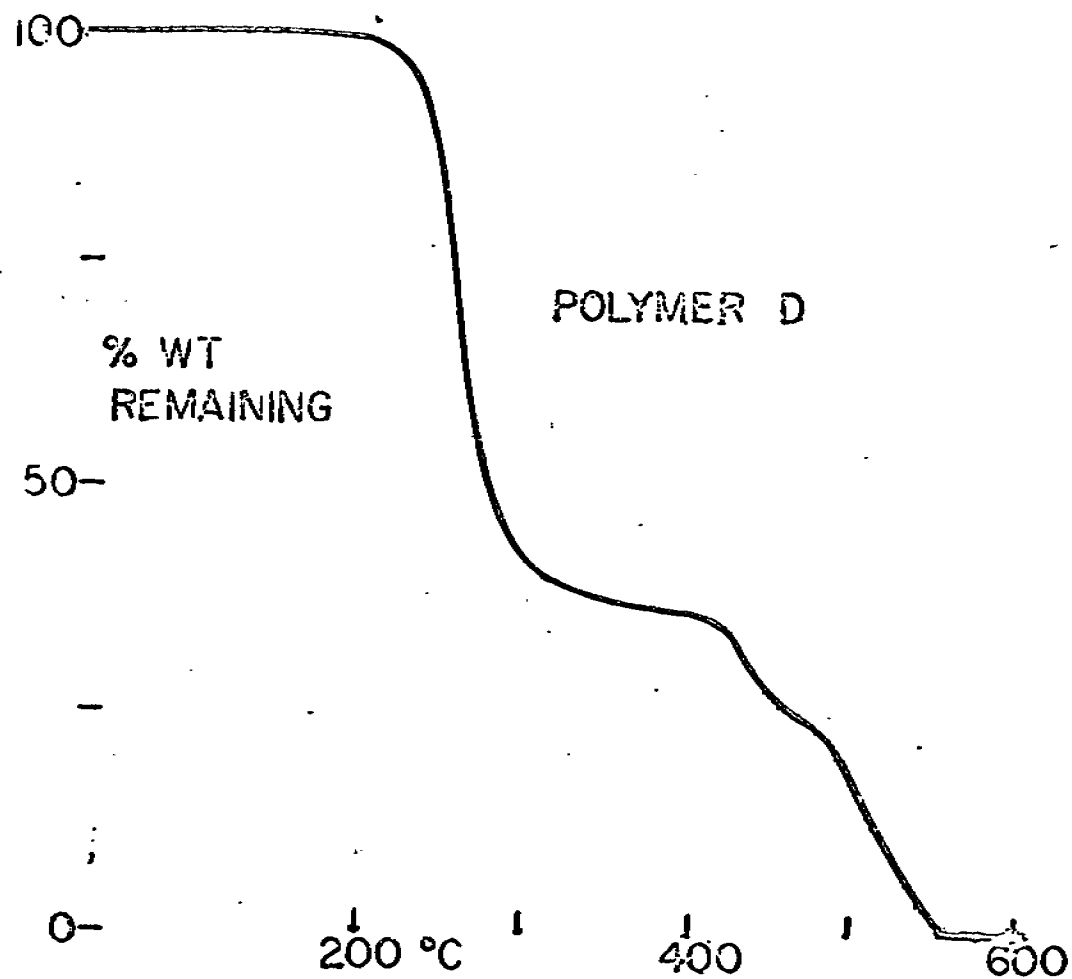


Figure 5 Thermogravimetric analysis of Copolymer D

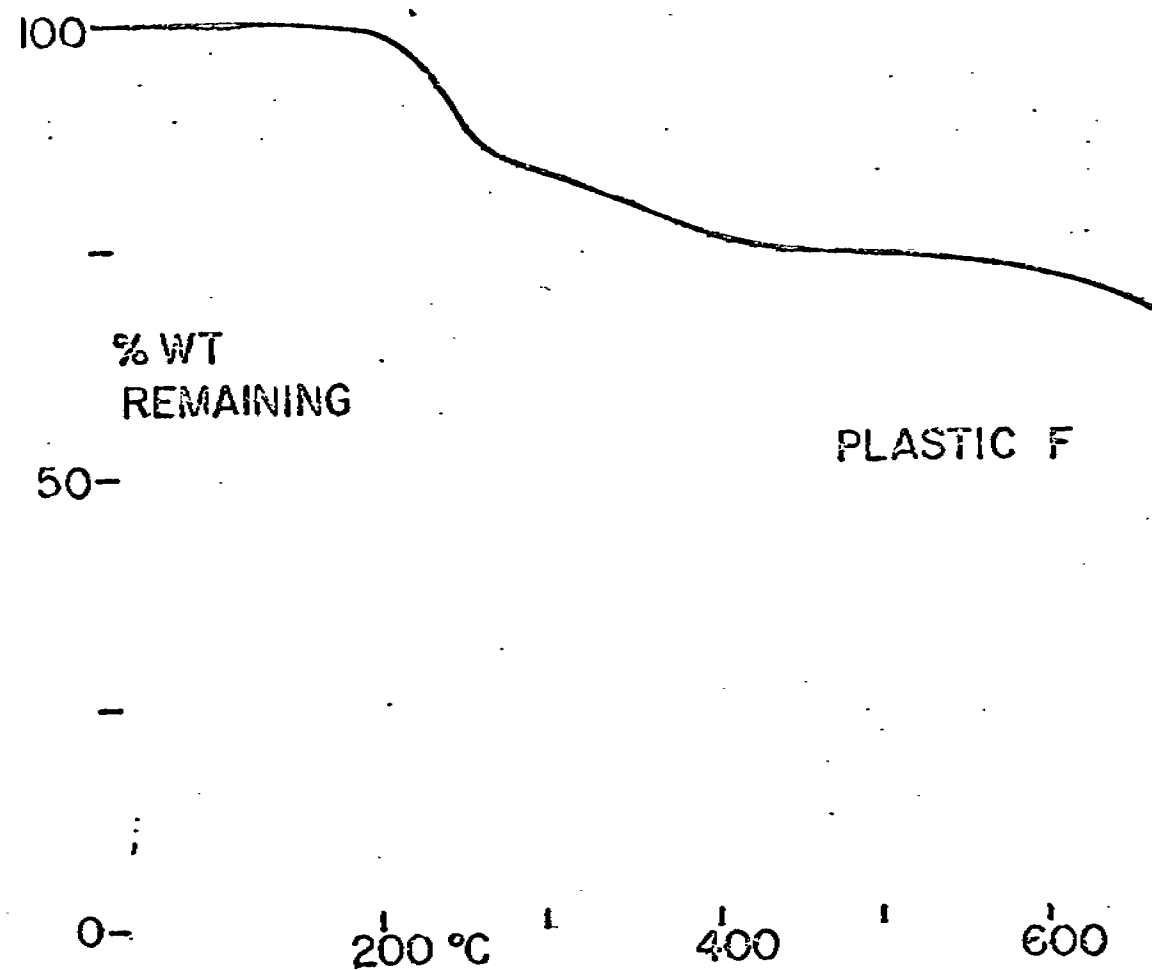


Figure 6 Thermogravimetric analysis of Plastic F

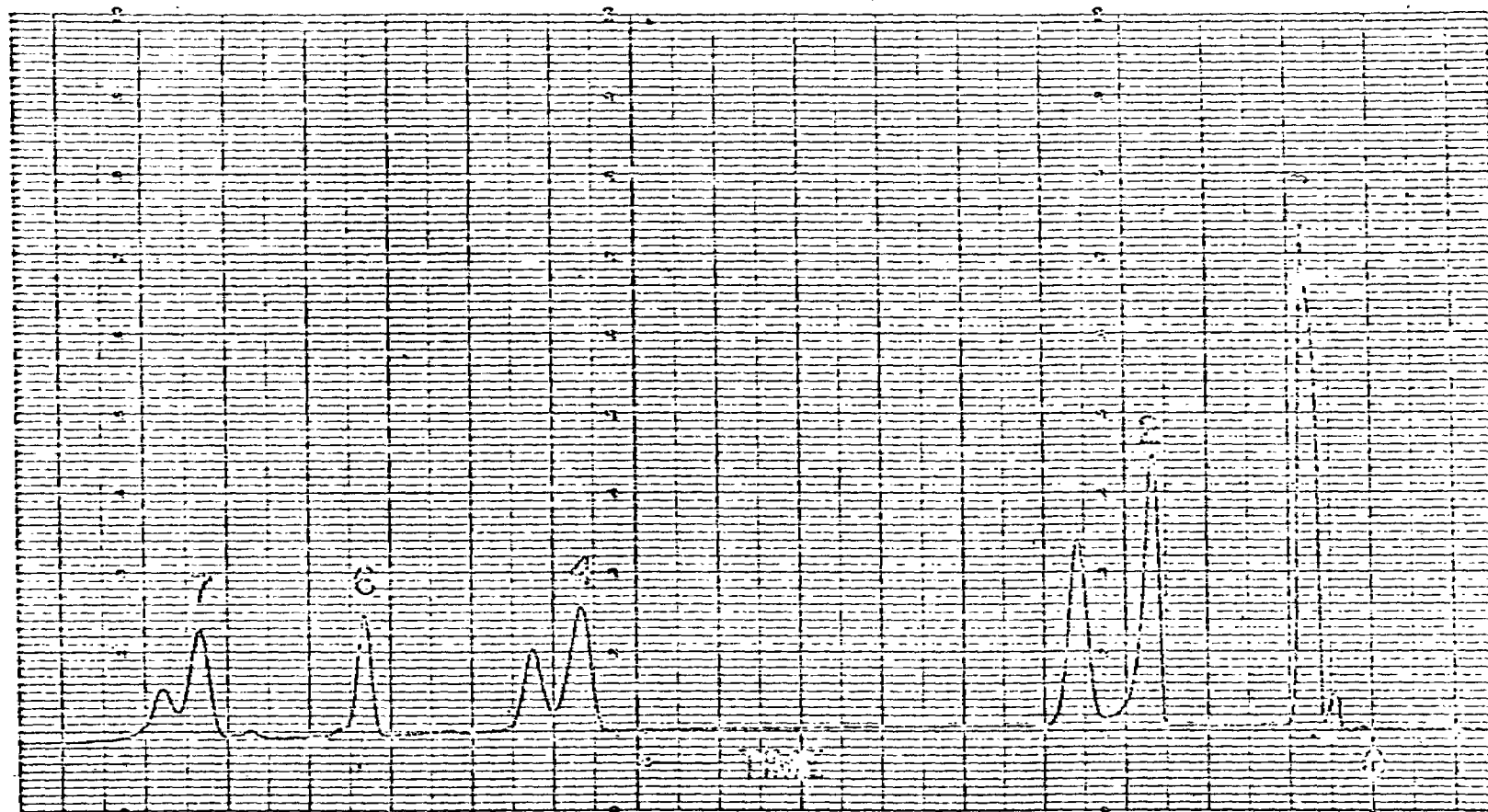


Figure 7 Chromatogram of low boiling compounds
using a Porapak Q column

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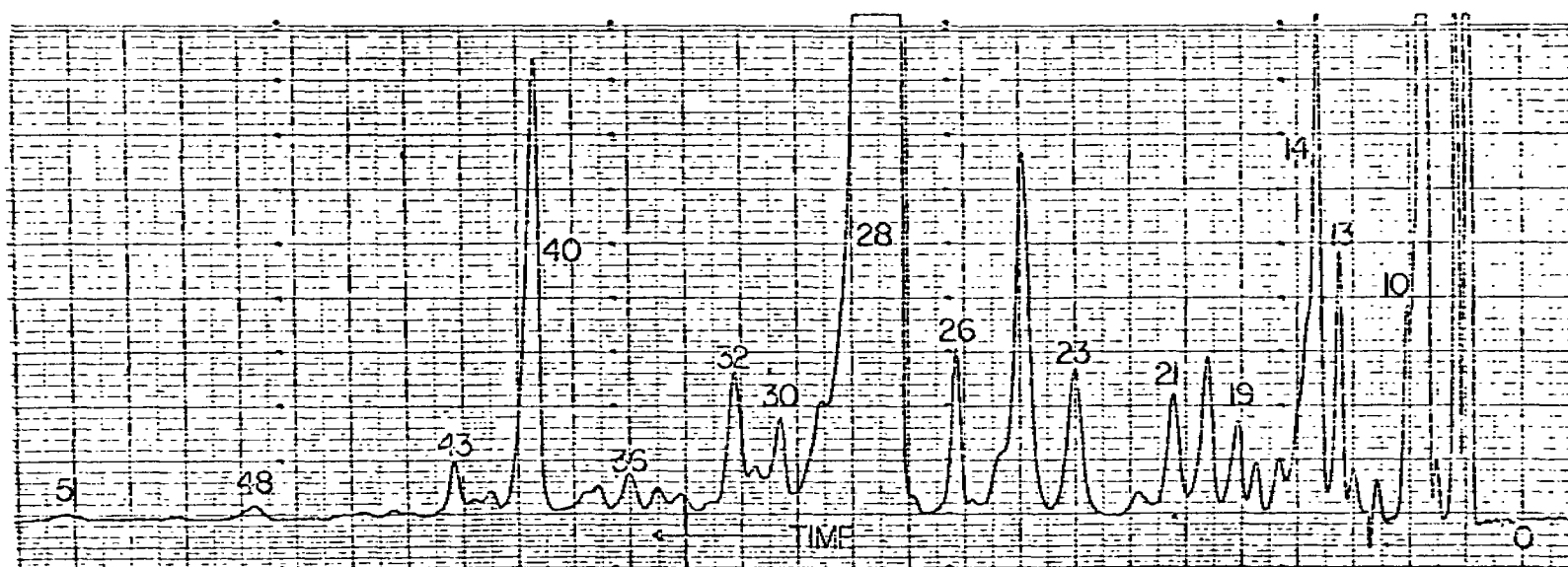


Figure 8 Chromatogram of higher boiling compounds
using a squalane column

Table I: Identification of Chromatogram Peaks

<u>Peak #</u>	<u>Identification</u>
air	
1	Methane
2	Ethylene
3	Ethane
4	Propylene
5	Propane (Methyl chloride)
6	Vinyl chloride
7	1-Butene (Isobutane - Butadiene)
8	Butane
9	trans-2-Butene
10	cis-2-Butene
11	3-Methyl-1-butene
12	Isopentane (1,4-Pentadiene)
13	1-Pentene
14	Pentane
15	cis- & trans-2-Pentene
16	
17	2-Methyl-2-butene
18	cis or trans-1,3-Pentadiene
19	cis or trans-2-Penten-4-yne
20	Cyclopentene
21	Cyclopentane
22	2-Methylpentane
23	1-Hexene
24	Hexane
25	2-Hexene
26	Methylcyclopentane
27	1-Methylcyclopentene
28	Benzene
29	
30	1-Heptene
31	An olefin, molecular weight = 96
32	Heptane
33	
34	an Ethylcyclopentene *
35	Methylcyclohexane
36	Ethylcyclopentane
37	An olefin, molecular weight = 96
38	an Ethylcyclopentene *
39	1-Methylcyclohexene
40	Toluene
41	at least two compounds here
42	
43	Octane
44	
45	
46	
47	
48	Ethylbenzene
49	p-Xylene
50	m-Xylene
51	o-Xylene

*Tentative

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Table II: Volatile Combustion Products
of Polymer B and Copolymer D

<u>Compound</u>	<u>Polymer B</u>	<u>Copolymer D</u>
HCl	583. $\frac{\text{mg}}{\text{g}}$	500. $\frac{\text{mg}}{\text{g}}$
Acetic Acid	---	96.
CO ₂	729.	923.
CO	442.	292.
Methane	4.6	4.4
Ethylene	0.58	0.60
Ethane	2.2	2.3
Propylene	0.47	0.56
Propane	0.84	0.88
Vinyl chloride	0.60	0.72
1-Butene	0.18	0.22
Butane	0.28	0.29
Isopentane	0.02	0.02
1-Pentene	0.06	0.09
Pentane	0.16	0.21
Cyclopentene	0.05	0.05
Cyclopentane	0.05	0.06
1-Hexene	0.05	0.08
Hexane	0.12	0.17
Methylcyclopentane	0.04	0.05
Benzene	36.	28.
Toluene	1.3	0.96

Table III: Variation of the Combustion Products
of Polymer A with Oxygen

Compound	<u>cc</u>	<u>cc</u>	25 <u>cc</u> min. air plus
	30 min. air	60 min. air	21 min. oxygen
CO ₂	861. $\frac{\text{mg}}{\text{g}}$	619. $\frac{\text{mg}}{\text{g}}$	814. $\frac{\text{mg}}{\text{g}}$
CO	357.	429.	401.
Methane	6.7	4.7	3.8
Ethylene	0.76	0.53	0.28
Ethane	2.6	2.1	1.7
Propylene	0.80	0.53	0.28
Propane	1.3	1.0	0.66
Vinyl chloride	0.51	0.59	0.66
1-Butene	0.25	0.18	0.06
Butane	0.53	0.31	0.15
Isopentane	0.02	0.02	0.01
1-Pentene	0.10	0.08	0.04
Pentane	0.26	0.20	0.11
Cyclopentene	0.07	0.05	0.03
Cyclopentane	0.08	0.07	0.03
1-Hexene	0.07	0.06	0.03
Hexane	0.16	0.14	0.09
Methylcyclopentane	0.06	0.05	0.03
Benzene	35.	31.	32.
Toluene	1.5	1.1	0.68

Table IV: Variation of Combustion Products
of Polymer A with Temperature

Compound	25-280°C	280-350°C	350-430°C	430-510°C	510-580°C
	$\frac{\text{mg}}{\text{g}}$	$\frac{\text{mg}}{\text{g}}$	$\frac{\text{mg}}{\text{g}}$	$\frac{\text{mg}}{\text{g}}$	$\frac{\text{mg}}{\text{g}}$
CO ₂	----	9.7	181.	244.	237.
CO	----	20.	46.	151.	181.
Methane	----	0.20	1.3	1.8	0.31
Ethylene	0.04	0.33	0.39	----	----
Ethane	----	0.12	0.94	0.41	----
Propylene	0.06	0.11	0.31	-----	----
Propane	----	0.08	0.44	0.11	----
Vinyl chloride	0.04	0.25	0.17	0.02	----
1-Butene	0.02	0.04	0.08	----	----
Butane	----	0.03	0.20	0.02	----
Isopentane	----	----	0.005	0.001	----
1-Pentene	----	0.01	0.03	----	----
Pentane	----	0.01	0.08	0.01	----
Cyclopentene	----	0.02	0.01	----	----
Cyclopentane	----	0.01	0.02	----	----
1-Hexene	----	0.01	0.02	----	----
Hexane	----	0.01	0.05	0.01	----
Methylclopentane	----	----	0.02	----	-----
Benzene	24.	6.6	0.35	0.16	----
Toluene	0.12	0.18	0.55	0.03	0.01

Table V: Variation of Combustion Products
of Polymer A with Heating Rate

<u>Compound</u>	<u>3°C/min.</u>	<u>50°C/min.</u>
	$\frac{\text{mg}}{\text{g}}$	$\frac{\text{mg}}{\text{g}}$
CO ₂	619.	397.
CO	429.	269.
Methane	4.7	8.7
Ethylene	0.53	2.3
Ethane	2.1	3.5
Propylene	0.53	1.5
Propane	1.0	1.3
Vinylchloride	0.59	0.64
1-Butene	0.18	0.67
Butane	0.31	0.69
Isopentane	0.02	0.02
1-Pentene	0.08	0.18
Pentane	0.20	0.29
Cyclopentene	0.05	0.19
Cyclopentane	0.07	0.11
1-Hexene	0.06	0.13
Hexane	0.14	0.20
Methylcyclopentane	0.05	0.08
Benzene	31.	43.
Toluene	1.1	3.5

Table VI: Comparison of Combustion Products of the Plastics
with the Combustion Products of their Polymers

Compound	Polymer B	Plastic G	Polymer C	Plastic E	Copolymer D	Plastic F
HCl	583. $\frac{\text{mg}}{\text{g}}$	273. $\frac{\text{mg}}{\text{g}}$	584. $\frac{\text{mg}}{\text{g}}$	333. $\frac{\text{mg}}{\text{g}}$	500. $\frac{\text{mg}}{\text{g}}$	73. $\frac{\text{mg}}{\text{g}}$
Acetic Acid	--	--	--	--	96.	20.
CO ₂	729.	616.	730.	1182.	923.	456.
CO	442.	67.	403.	90.	292.	31.
Methane	4.6	6.6	5.8	6.8	4.4	0.30
Ethylene	0.58	2.3	0.33	2.0	0.60	0.13
Ethane	2.2	3.0	2.5	2.9	2.3	0.13
Propylene	0.47	2.0	0.56	1.4	0.56	0.11
Propane	0.84	1.7	1.1	1.4	0.88	0.10
Vinylchloride	0.60	3.3	0.52	2.6	0.72	0.30
1-Butene	0.18	1.1	0.28	0.58	0.22	0.06
Butane	0.28	1.1	0.39	0.74	0.29	0.05
Isopentane	0.02	0.15	0.02	0.04	0.02	0.01
1-Pentene	0.06	0.35	0.11	0.15	0.09	0.01
Pentane	0.16	0.58	0.27	0.38	0.21	0.02
Cyclopentene	0.05	0.14	0.58	0.07	0.05	0.004
Cyclopentane	0.05	0.16	0.07	0.09	0.06	0.003
1-Hexene	0.05	0.24	0.09	0.18	0.08	0.01
Hexane	0.12	0.49	0.25	0.35	0.17	0.01
Methylcyclopentane	0.14	0.14	0.07	0.09	0.05	---
Benzene	36.	10.	29.	11.	28.	0.86
Toluene	1.3	0.94	1.1	1.0	0.96	0.04
Residue*	---	159.	---	61.	---	709.

*Residue is what remained in combustion boat. It does not include products which condensed at the end of the combustion tube.