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Bartlesville Energy Technology Center
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CONTENTS

Page

FIGURES

TABLES

TRENDS IN MOTOR GASOLINES: 1942 - 1981

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Ella Mae Shelton[1], M. L. Whisman[2], and Paul W. Woodward[3]

ABSTRACT

Trends in motor gasolines for the years of 1942 through 1981 have been evaluated based upon data contained in surveys that have been prepared and published by the Bartlesville Energy Technology Center (BETC). These surveys have been published twice annually since 1935 describing the properties of motor gasolines from throughout the country. The surveys have been conducted in cooperation with the American Petroleum Institute (API) since 1948. Various companies from throughout the country obtain samples from retail outlets, analyze the samples by the American Society for Testing and Materials (ASTM) procedures, and report data to the Bartlesville center for compilation, tabulation, calculation, analysis and publication. A typical motor gasoline report covers 2400 samples from service stations throughout the country representing some 48 companies that manufacture and supply gasoline. The reports include trend charts, octane plots, and tables of test results from about a dozen different tests.

From these data in 77 semiannual surveys, a summary report has thus been assembled that shows trends in motor gasolines throughout the entire era of winter 1942-1943 to the present. Trends of physical properties including octane numbers, antiknock ratings, distillation temperatures, Reid vapor pressure, sulfur and lead content are tabulated, plotted and discussed in the current report. Also included are trend effects of technological advances and the interactions of engine design, societal and political events and prices upon motor gasoline evolution during the 40 year period.

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INTRODUCTION

The Bartlesville Energy Technology Center--first as a Bureau of Mines field station of the Department of Interior, later as a research center for the Energy Research and Development Administration (ERDA), and currently as a technology center for the Department of Energy--has an extensive background in assembling information on the quality of petroleum fuels marketed in the United States. Except for two years during World War II (WW II), surveys of motor gasoline have been assembled and distributed twice annually since 1935 (*1, 2, 3, 4, 5, 6, 7, 8, 9*).

These surveys are currently conducted in cooperation with the American Petroleum Institute (API) which provides partial funding and technical data for the surveys. Reports are prepared from test data supplied by company contributors and these data provide comparative information on refiners' fuels which are being currently marketed.

For the API fuel surveys, various companies from across the country obtain samples from retail outlets, analyze the samples by ASTM procedures, and report data to BETC for compilation, tabulation, calculation, analysis and report preparation. A typical motor gasoline report covers 2400 samples from service stations throughout the country representing some 48 companies that manufacture and supply gasoline. The report includes trend charts, octane plots and tables of test results from several different tests. Similar reports are provided for aviation turbine fuels, diesel fuels, and heating oils. The aviation turbine fuels reports include data from about 20 analytical procedures.

More specifically, the semiannual motor gasoline surveys include charts indicating the trends of selected properties of motor fuels since 1949, although data were accumulated as early as 1920. Octane distribution charts for unleaded, leaded regular, and leaded premium grades of gasoline are presented in a typical report. The report shows calculated antiknock (octane) index (R+M)/2 averages obtained for gasolines sold in this country.

The purpose of this report is to summarize the trends in motor gasoline over a longer time period than cooperative work covers in a single report. This report shows trends of motor gasoline since 1942 evaluated in terms of octane number, distillation range, volatility, sulfur, lead, price, and correlations with engine design as indicated by compression ratios during these 40 years. The role that refining technology has played in these trends is also discussed.

TREND PARAMETERS

One of the more obvious ways of measuring trends in a commodity such as motor gasoline is to show changes in the physical properties and relate these properties to societal trends. In this study, a few physical properties have been selected to measure changes over a 40 year period since World War II. These include octane number, volatility, distillation temperatures, lead content and sulfur content. Each of these properties and test procedures are subsequently discussed.

Physical Properties

Octane Number

Octane number is related to the ability of a gasoline to prevent detonation during the combustion process in a spark ignition engine. Leadalkyl antiknock additives influence the octane quality of gasoline as does the chemical composition of the gasoline itself.

Research Octane Number (RON); and Motor Octane Number (MON) are established in the laboratory by running the fuel in a single-cylinder test engine under prescribed operating conditions. The combination of these laboratory fuel ratings in the expression "(R+M)/2" is an attempt to estimate Road Octane Number (RdON) or antiknock characteristics of the fuel. RdON is believed to describe how a fuel would perform in an engine under road operating conditions.

Octane requirements of vehicles decrease as altitude increases because of the reduction in mixture density (air/fuel ratio) caused by reduced atmospheric pressure. However, altitude does not affect octane requirements of all cars uniformly. In general, the decrease in octane requirement is larger for lower octane requirement vehicles.

Research octane number data in this report were determined by Method D 908 until the summer of 1971 when the test method was changed to D 2699, Knock Characteristics of Motor Fuels by the Research Method (*10*).

Motor octane number data were determined by Method D 357 until 1971 when the test method was changed to D 2700, Knock Characteristics of Motor and Aviation Fuels by the Motor Method (*10*).

In these methods the octane number is determined by comparing the knocking tendency of a gasoline to that for blends of ASTM reference fuels of known octane number under standard operating conditions. The knock test unit consists of a single-cylinder engine of continuously variable compression ratio with suitable loading, accessory equipment and instrumentation. The motor method requires critical adjustment of the fuel-air ratio to produce a standard knock intensity condition.

Volatility

Vapor pressure by either the Reid method as described in ASTM Method D 323 (*11*) Vapor Pressure of Petroleum Products (Reid Method), or Method D 2551 Vapor Pressure of Petroleum Products (Micromethod) are both used to measure the volatility of motor gasoline. Only Reid method data are used in this report, however. The Reid vapor pressure differs from the true vapor pressure of the sample due to a small amount of sample vaporization and the presence of water vapor and air in the confined space. Results are reported in pounds-force per square inch at 100° F.

Gasoline, like all petroleum products, is a complex mixture of many hydrocarbons which vary both in proportion and boiling points. Owing to this fact, the volatility of a gasoline is a complex function of the partial pressures of thousands of compounds. One way, then, to evaluate the volatility of a gasoline is by a vapor pressure determination such as ASTM D 323.

Volatility is second only to octane number in importance as a fuel property. In general, the petroleum industry has tailored the volatility of fuels to the seasonal variation of weather, so that fuels with suitable volatility for starting and warmup are generally available. The main difficulty encountered is that the marketing of too volatile fuels in the summertime brings about difficulties in hot-fuel handling, such as in engine idling, hot starting, and vapor lock. Engine malfunctions associated with vapor lock are difficult for the customer to diagnose.

Air-conditioning which has become widely adopted by buyers of cars during the 40 year time element of this report, has had a significant impact upon automotive design and fuel specification tailoring. Air-conditioned cars have been developed to meet a volatility tolerance criterion and special measures, such as larger cooling and electrical systems have been employed. Higher under-hood temperatures are encountered in cars with air conditioning as heat is dissipated by the air-conditioning condenser. This heat results in higher fuel system temperatures which leads to vapor lock problems unless fuel distribution designs are modified to tolerate higher under-hood temperatures.

Distillation

Still another technique for defining volatility of gasoline is by determining the distillation ranges of various fractions of the fuel. The ASTM distillation test [ASTM D 86, Distillation of Petroleum Products (*11*)] provides a measure, in terms of volatility, of the relative proportions of all the hydrocarbon components of a gasoline. The ASTM specification designates the maximum temperatures at which 10%, 50%, and 90% of the fuel shall be evaporated under closely defined conditions of the prescribed test method and the maximum end point. These distillation characteristics, along with vapor pressure and V/L ratio characteristics, define and control: starting, warm-up, acceleration, vapor lock, crankcase dilution, and, in part, fuel economy and carburetor icing.

The 10% evaporated temperature should be low enough to ensure ready starting under normal temperature conditions. Generally it should be lower in the winter than in the summer, but it is obvious that gasoline used in vehicles such as buses, which are kept in warm garages in the winter, and are never allowed to cool while in service, do not require gasoline with as low a 10% evaporated temperature as do the majority of privately owned passenger cars.

Winter warm-up and driveaway operation is influenced by the volatility indicated at both the 10% and 50% ASTM distillation temperatures, but to a greater degree by the 50% temperature. Consequently gasolines having the same 10% and 90% evaporated temperatures may vary considerably in warm-up and acceleration quality because of differences in the boiling temperatures of the intermediate components. The 90% evaporated and end point temperatures should be low enough to preclude excessive dilution of the crankcase lubricating oil.

Generally, the empirical results obtained by use of the ASTM D 86 distillation method have been found to correlate with automotive equipment performance factors and with other characteristics of petroleum products related to volatility.

Lead

There are two acceptable techniques for determining lead in motor gasoline. These include Method D 2547, Lead in Gasoline, Volumetric Chromate Method and Method D 2599, Lead in Gasoline by X-ray Spectrometry (*12*). Method D 526, Lead in Gasoline, Gravimetric Method for leaded gasolines was discontinued as an ASTM standard in 1976 although this latter test method was used to obtain most of the data in this report.

Essentially, these methods determine the total lead content which originates from leadalkyl antiknock additives. The concentration of lead is reported in grams of lead per gallon. Appropriate conversion factors can be used to convert grams of lead per U. S. gallon to ml per U.S. gallon, as tetraethyllead and tetramethyllead.

Sulfur

Sulfur in motor gasoline was determined by Method D 90 until about 1957 when the method was changed to Method D 1266, Sulfur in Petroleum Products (Lamp Method) (*11*).

In the lamp technique described in Method D 1266, the sample is burned in a closed system using a lamp and an artificial atmosphere. Oxides of sulfur are absorbed and oxidized to sulfuric acid. Sulfur as sulfate is then determined by titration.

Sulfur compounds, particularly mercaptans, impart a disagreeable odor to gasoline and have a detrimental effect upon the long term storage stability characteristics of a fuel. Sulfur also reduces the effectiveness of lead as an antiknock additive.

Engine Compression Ratio

In a spark ignition engine, the quality of the gasoline and the performance of the engine are so closely interrelated that it is difficult to discuss them in isolation. The power output and the fuel economy are highly dependent upon the compression ratio, and this in turn depends upon the antiknock quality of the fuel and on combustion chamber design.

In order to understand the basics of engine design it is important to have an understanding of the combustion process. Combustion can be normal or abnormal. Normal combustion occurs in a spark-ignited automotive engine when a mixture of gasoline and air burns in a controlled fashion within the combustion chamber. A flame created at the spark plug advances into the unburned mixture so that the flame front propagates throughout the chamber until it is quenched near the cylinder wall. The reaction between gasoline and oxygen liberates energy that causes a rise in temperature. This temperature rise is primarily responsible for the pressure rise that drives the piston. Part of this energy is converted to usable work by pushing against the piston top. The remainder is lost through heat to the coolant and in the exhaust gases.

Prior to legislation of exhaust emissions, engine designers tried to optimize combustion for maximum power and fuel economy. Exhaust emission control has become a dominant consideration in fuel-engine systems and it has caused design changes which often result in loss of both power and efficiency. With an even more recent emphasis on fuel economy, and with the development of catalytic exhaust emission controls, engines are once again being designed to optimize fuel economy.

The size of the combustion chamber relative to the volume displaced by the piston establishes the compression ratio of the engine. The piston displacement of a cylinder is the volume swept by the piston during one stroke and is equal to the cross-sectional area of the cylinder multiplied by the length of the stroke. The larger volume above the piston at the lowest point in its stroke divided by the combustion-chamber volume when the piston is at its highest point is the compression ratio of the engine. The larger volume is the sum of the piston-displacement volume and the combustion-chamber volume. The compression ratio may thus be expressed as the ratio of the sum of the piston-displacement volume and the combustion-chamber volume. It is the ratio of the volume of the combustion chamber and cylinder when the piston is at bottom dead center to the volume when the piston is at top dead center. Compression ratio is the most important factor affecting the theoretical efficiency of the engine cycle. Because increased compression ratio is the most basic way to improve efficiency, the automobile engine has tended toward higher compression ratios until recent years.

DISCUSSION

Data from reports previously cited which have been collected, compiled, calculated, tabulated and published by the Bartlesville center of the Department of Energy (Bureau of Mines and ERDA) over the past 40 years have been extracted and included in this report.

Table 1 contains some selected averaged physical properties of leaded regular motor gasoline over the period of 1942 through 1981 and these data are plotted in Figures 1, 2, 3, and 5. Table 2 is a similar tabulation for leaded premium gasoline and these data are plotted in Figures 1, 2, 3, and 6. Table 3 contains weighted average compression ratio data based on U. S. production for each automobile model year, and they are plotted in Figure 4.

These latter data are intended to show a comparison of engine design changes to trends in motor gasoline. Table 4 contains price data for leaded regular gasoline as well as the price of U.S. crude oil to demonstrate the correlation between crude oil price and gasoline price as well as the correlation between gasoline price and other trend parameters. These data are plotted in Figure 7.

The trends to be found in these data since 1942 cannot be completely evaluated without some consideration of technology advancements during this and previous eras. One can postulate that engine design created markets for improved gasolines with higher octane number and volatility but the development of these markets have been highly dependent upon refining technology which permitted keeping pace with automobile advances. Technology developments therefore, constitute a major part of the following discussion relating to trend parameters. Nelson (*13*) has excellently summarized the history of this era.

TABLE 1. — Average data for leaded regular motor gasoline, 1942-81.

Season and Year	Report No.	Sulfur ASTM D1266 wt %	Lead, ASTM D2547 g/gal	Octane Number			RVP, ASTM D323 lb	Distillation, ASTM D86 Temp. °F (corrected to 760 mm Hg) Percent Evaporated		
				Research ASTM D2699	Motor ASTM D2700	R + M / 2		10	50	90
Winter 1942-43	RI 3716	0.072	-	76.8	72.5	74.7	10.3	122	226	331
Summer 1943	RI 3745	.077	-	77.1	72.0	74.6	7.9	139	239	337
Winter 1943-44	RI 3758	.085	-	76.4	71.7	74.1	9.4	130	242	345
Summer 1944	RI 3796	.093	-	74.9	71.1	73.0	7.7	143	254	348
Winter 1944-45	RI 3820	.092	-	74.2	70.2	72.2	9.2	133	245	348
Summer 1945	RI 3883	.097	-	73.3	69.7	71.5	7.7	145	251	351
Winter 1945-46	RI 3959	.081	-	81.7	75.9	78.8	9.8	125	229	338
Summer 1946	RI 4063	.072	-	79.3	74.4	76.9	7.8	139	233	336
Winter 1946-47	RI 4146	.077	1.10	80.1	75.0	77.6	10.1	125	227	334
Summer 1947	RI 4248	.092	1.46	80.2	75.1	77.7	8.0	139	235	339
Winter 1947-48	RI 4354	.091	1.33	80.2	75.3	77.8	10.1	126	229	335
Summer 1948	RI 4444	.099	1.58	80.1	75.2	77.7	8.0	138	238	343
Winter 1948-49	RI 4567	.092	1.35	80.5	75.6	78.1	10.2	125	230	337
Summer 1949	RI 4644	.097	1.70	81.9	76.4	79.2	8.1	137	237	345
Winter 1949-50	RI 4702	.084	1.53	82.4	77.1	79.8	10.4	122	226	336
Summer 1950	RI 4765	.087	2.04	83.5	78.2	80.9	8.3	134	232	341
Winter 1950-51	RI 4809	.092	1.91	83.7	78.8	81.3	10.5	122	224	335
Summer 1951	RI 4854	.095	1.60	82.5	77.6	80.1	8.3	135	232	341
Winter 1951-52	RI 4901	.092	1.45	83.1	78.1	80.6	10.5	122	223	334
Summer 1952	RI 4963	.097	1.89	83.6	78.4	81.0	8.2	135	232	341
Winter 1952-53	RI 5000	.092	1.85	84.0	79.1	81.6	10.5	121	224	336
Summer 1953	RI 5041	.091	2.19	84.2	79.3	81.8	8.2	134	234	343
Winter 1953-54	RI 5066	.088	1.99	84.7	80.0	82.4	10.6	120	223	336
Summer 1954	RI 5111	.092	2.24	85.5	80.3	82.9	8.3	133	230	342
Winter 1954-55	RI 5146	.088	1.86	86.2	80.8	83.5	10.8	120	219	334
Summer 1955	IC 7746	.078	2.11	87.4	81.6	84.5	8.6	130	222	338
Winter 1955-56	IC 7763	.072	2.03	88.1	82.4	85.3	10.9	117	214	333
Summer 1956	IC 7979	.073	2.17	88.8	82.6	85.7	8.6	129	220	338
Winter 1956-57	IC 7796	.063	1.95	89.1	83.1	86.1	11.1	116	210	331
Summer 1957	PPS 3	.067	2.14	89.8	83.2	86.5	8.7	129	218	340
Winter 1957-58	PPS 5	.067	1.87	90.0	83.4	86.7	11.1	115	209	337
Summer 1958	PPS 8	.061	1.77	90.2	83.4	86.8	8.7	127	217	342
Winter 1958-59	PPS 10	.059	1.58	90.6	83.6	87.1	11.2	114	207	337
Summer 1959	PPS 12	.061	1.87	91.4	83.9	87.7	8.6	128	217	344
Winter 1959-60	PPS 15	.056	1.69	91.7	84.1	87.9	11.3	114	207	338
Summer 1960	PPS 17	.059	1.86	91.8	84.0	87.9	8.7	126	213	343
Winter 1960-61	PPS 20	.053	1.62	91.9	84.2	88.1	11.4	113	206	338
Summer 1961	PPS 22	.054	1.87	92.0	84.2	88.1	8.8	127	214	342
Winter 1961-62	PPS 25	.048	1.60	92.2	84.4	88.3	11.5	112	203	336
Summer 1962	PPS 27	.053	2.02	92.3	84.5	88.4	8.9	126	212	341
Winter 1962-63	PPS 30	.051	1.79	92.4	84.6	88.5	11.5	112	202	336
Summer 1963	PPS 33	.050	2.06	92.6	84.7	88.7	8.9	125	211	341
Winter 1963-64	PPS 35	.052	1.83	92.8	84.8	88.8	11.6	112	202	338
Summer 1964	PPS 37	.049	2.16	92.8	84.9	88.9	8.9	125	210	341
Winter 1964-65	PPS 40	.047	1.97	93.0	85.1	89.1	11.6	111	201	337
Summer 1965	PPS 43	.049	2.22	93.2	85.2	89.2	9.0	124	207	341
Winter 1965-66	PPS 45	.047	2.01	93.3	85.3	89.3	11.7	110	200	338
Summer 1966	PPS 48	.045	2.31	93.3	85.4	89.4	9.0	124	209	341
Winter 1966-67	PPS 50	.047	2.13	93.7	85.9	89.8	11.8	110	200	338
Summer 1967	PPS 53	.048	2.43	93.8	85.8	89.8	9.1	122	208	341
Winter 1967-68	PPS 55	.041	2.10	93.8	85.9	89.9	12.0	108	199	335
Summer 1968	PPS 58	.042	2.45	93.8	86.0	89.9	9.1	123	208	339
Winter 1968-69	PPS 60	.043	2.13	93.8	86.3	90.1	12.1	108	200	336
Summer 1969	PPS 63	.042	2.48	93.8	86.1	90.0	9.1	123	208	340
Winter 1969-70	PPS 66	.043	2.26	93.8	86.3	90.1	12.1	109	202	335
Summer 1970	PPS 68	.042	2.43	93.8	86.3	90.1	9.1	123	207	339
Winter 1970-71	PPS 70	.039	2.02	93.9	86.4	90.2	12.1	108	197	335
Summer 1971	PPS 73	.043	2.22	94.0	86.3	90.2	9.0	122	206	339
Winter 1971-72	PPS 75	.044	1.88	94.0	86.5	90.3	12.1	108	199	336
Summer 1972	PPS 78	.042	2.04	94.1	86.4	90.3	9.2	122	208	339
Winter 1972-73	PPS 80	.038	1.80	93.9	86.4	90.2	12.2	108	200	334
Summer 1973	PPS 83	.040	2.01	93.5	86.1	89.8	9.3	121	211	342
Winter 1973-74	PPS 85	.038	1.67	93.4	86.0	89.7	13.1	107	200	329
Summer 1974	PPS 88	.039	1.90	93.4	85.9	89.7	9.6	120	211	340
Winter 1974-75	PPS 75/1	.038	1.58	93.4	86.1	89.8	12.0	108	202	332
Summer 1975	PPS 76/1	.043	1.85	93.4	86.0	89.7	9.6	120	210	339
Winter 1975-76	PPS 76/3	.041	1.62	93.4	86.0	89.7	13.0	105	200	332
Summer 1976	PPS 77/1	.043	2.04	93.3	86.0	89.6	9.6	120	211	342
Winter 1976-77	PPS 77/3	.040	1.71	93.2	86.1	89.7	12.4	107	202	335
Summer 1977	PPS 78/1	.043	2.00	93.2	85.9	89.6	9.7	121	211	343
Winter 1977-78	PPS 78/3	.038	1.56	93.2	85.7	89.5	12.4	107	201	334
Summer 1978	PPS 79/1	.040	1.71	93.2	85.7	89.5	9.7	119	210	341
Winter 1978-79	PPS 79/3	.042	1.65	93.2	85.9	89.6	12.3	106	202	338
Summer 1979	PPS 80/1	.039	1.87	92.8	85.7	89.3	9.7	119	208	342
Winter 1979-80	PPS 80/3	.042	1.20	92.5	85.5	89.0	12.3	106	200	335
Summer 1980	PPS 81/1	.049	1.21	92.6	85.2	88.9	9.9	118	206	343
Winter 1980-81	PPS 81/3	.042	.94	92.8	85.4	89.1	12.4	107	200	334

TABLE 2. — Average data for leaded premium motor gasoline, 1942-81.

Season and Year	Report No.	Sulfur ASTM D1266 wt %	Lead, ASTM D2547 g/gal	Octane Number: Research ASTM D2699	Octane Number: Motor ASTM D2700	Octane Number: R + M / 2	RVP, ASTM D323 lb	Distillation, ASTM D86 Temp. °F (corrected to 760 mm Hg) Percent Evaporated: 10	50	90
Winter 1942-43	RI 3716	0.053	-	85.2	79.6	82.4	10.0	123	216	317
Summer 1943	RI 3745	.063	-	85.4	79.1	82.3	7.7	138	226	324
Winter 1943-44	RI 3758	.078	-	81.7	75.8	78.8	9.6	128	238	342
Summer 1944	RI 3796	.099	-	80.5	75.0	77.8	7.7	141	250	352
Winter 1944-45	RI 3820	.095	-	80.5	75.1	77.8	9.0	132	241	348
Summer 1945	RI 3883	.083	-	79.7	74.9	77.3	7.6	142	243	346
Winter 1945-46	RI 3959	.057	-	87.7	80.9	84.3	10.0	123	218	326
Summer 1946	RI 4063	.061	-	84.7	78.3	81.5	7.8	139	226	329
Winter 1946-47	RI 4146	.061	1.48	85.0	78.5	81.8	10.1	124	220	327
Summer 1947	RI 4248	.075	1.86	85.9	79.2	82.6	7.8	137	226	331
Winter 1947-48	RI 4354	.073	1.85	86.2	79.4	82.8	10.2	124	218	327
Summer 1948	RI 4444	.078	1.99	86.1	79.5	82.8	8.0	136	228	335
Winter 1948-49	RI 4567	.076	1.88	86.5	79.7	83.1	10.4	121	219	330
Summer 1949	RI 4644	.076	2.15	88.0	80.4	84.2	8.0	135	227	338
Winter 1949-50	RI 4702	.074	2.02	89.0	81.2	85.1	10.5	120	216	331
Summer 1950	RI 4765	.079	2.36	90.0	82.0	86.0	8.2	132	224	336
Winter 1950-51	RI 4809	.079	2.29	90.3	82.5	86.4	10.4	121	216	334
Summer 1951	RI 4854	.083	1.95	89.7	81.7	85.7	8.2	133	223	339
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Summer 1955	IC 7746	.070	2.49	95.0	85.4	90.2	8.6	128	213	335
Winter 1955-56	IC 7763	.060	2.34	95.6	86.0	90.8	11.0	116	209	332
Summer 1956	IC 7979	.063	2.50	96.4	86.2	91.3	8.6	128	219	337
Winter 1956-57	IC 7796	.051	2.38	96.7	86.8	91.8	11.0	115	209	330
Summer 1957	PPS 3	.049	2.54	97.6	87.4	92.5	8.8	128	219	332
Winter 1957-58	PPS 5	.049	2.45	98.0	87.8	92.9	11.0	114	210	328
Summer 1958	PPS 8	.046	2.48	98.4	88.4	93.4	8.8	126	220	330
Winter 1958-59	PPS 10	.040	2.48	98.9	88.9	93.9	11.2	114	212	327
Summer 1959	PPS 12	.038	2.49	99.1	89.1	94.1	8.7	128	221	328
Winter 1959-60	PPS 15	.036	2.43	99.2	89.4	94.3	11.2	114	211	326
Summer 1960	PPS 17	.034	2.43	99.2	89.7	94.5	8.8	127	220	328
Winter 1960-61	PPS 20	.033	2.31	99.2	89.9	94.6	11.3	113	211	324
Summer 1961	PPS 22	.034	2.36	99.2	90.0	94.6	8.9	127	219	326
Winter 1961-62	PPS 25	.031	2.30	99.3	90.1	94.7	11.3	113	210	322
Summer 1962	PPS 27	.031	2.57	99.3	90.3	94.8	8.9	127	218	323
Winter 1962-63	PPS 30	.028	2.55	99.5	90.5	95.0	11.5	113	210	322
Summer 1963	PPS 33	.028	2.65	99.6	90.6	95.1	8.9	126	218	324
Winter 1963-64	PPS 35	.030	2.56	99.6	90.8	95.2	11.6	112	210	321
Summer 1964	PPS 37	.029	2.78	99.7	90.8	95.3	9.0	126	217	327
Winter 1964-65	PPS 40	.027	2.69	99.8	91.0	95.4	11.7	111	210	322
Summer 1965	PPS 43	.029	2.86	99.8	91.1	95.5	9.1	125	217	326
Winter 1965-66	PPS 45	.027	2.77	99.8	91.3	95.6	11.9	111	210	323
Summer 1966	PPS 48	.025	2.85	99.8	91.3	95.6	9.0	125	217	324
Winter 1966-67	PPS 50	.026	2.75	99.8	91.7	95.8	11.8	111	210	323
Summer 1967	PPS 53	.025	2.89	99.9	91.7	95.8	9.1	124	218	326
Winter 1967-68	PPS 55	.023	2.72	99.9	91.9	95.9	12.1	108	208	320
Summer 1968	PPS 58	.023	2.87	99.9	91.9	95.9	9.2	124	216	324
Winter 1968-69	PPS 60	.031	2.69	99.8	92.2	96.0	12.2	109	208	322
Summer 1969	PPS 63	.022	2.89	99.9	92.0	96.0	9.2	123	216	327
Winter 1969-70	PPS 66	.020	2.71	99.8	92.2	96.0	12.1	109	210	323
Summer 1970	PPS 68	.021	2.81	99.8	92.2	96.0	9.2	124	217	323
Winter 1970-71	PPS 70	.023	2.60	99.8	92.2	96.0	12.1	109	210	321
Summer 1971	PPS 73	.022	2.67	99.8	92.3	96.1	9.2	124	218	323
Winter 1971-72	PPS 75	.026	2.43	99.8	92.3	96.1	12.1	109	209	321
Summer 1972	PPS 78	.020	2.52	99.8	92.2	96.0	9.3	123	217	324
Winter 1972-73	PPS 80	.023	2.34	99.6	92.2	95.9	12.1	109	209	319
Summer 1973	PPS 83	.026	2.42	99.3	91.9	95.6	9.5	121	215	325
Winter 1973-74	PPS 85	.025	2.21	99.1	91.7	95.4	12.0	109	209	318
Summer 1974	PPS 88	.027	2.32	98.9	91.5	95.2	9.7	122	217	327
Winter 1974-75	PPS 75/1	.026	2.10	98.9	91.6	95.3	11.8	110	210	321
Summer 1975	PPS 76/1	.029	2.23	98.9	91.4	95.2	9.8	121	216	325
Winter 1975-76	PPS 76/3	.027	2.19	98.9	91.4	95.2	12.8	106	208	321
Summer 1976	PPS 77/1	.028	2.51	98.9	91.4	95.2	9.8	121	217	330
Winter 1976-77	PPS 77/3	.027	2.28	98.8	91.4	95.1	12.2	108	210	326
Summer 1977	PPS 78/1	.028	2.50	98.7	91.2	95.0	10.0	120	217	331
Winter 1977-78	PPS 78/3	.028	2.15	98.8	91.0	94.9	12.3	108	210	328
Summer 1978	PPS 79/1	.032	2.00	98.2	90.4	94.3	9.9	119	216	331
Winter 1978-79	PPS 79/3	.025	2.01	98.0	90.3	94.2	12.1	107	209	331
Summer 1979	PPS 80/1	.028	2.27	97.6	89.8	93.7	10.0	117	215	337
Winter 1979-80	PPS 80/3	.022	1.65	97.2	89.3	93.3	11.8	108	210	330
Summer 1980	PPS 81/1	.034	1.41	97.0	88.6	92.8	10.1	118	212	334
Winter 1980-81	PPS 81/3	.016	1.49	97.3	89.2	93.3	11.4	116	208	324

TABLE 3. — Compression ratios of U. S. automobile engines.

Year	Compression Ratio [1]	Year	Compression Ratio [1]
1942	6.6	1962	9.0
1943	- [2]	1963	9.2
1944	- [2]	1964	9.3
1945	- [2]	1965	9.4
1946	6.8	1966	9.4
1947	6.8	1967	9.5
1948	6.9	1968	9.4
1949	7.0	1969	9.5
1950	7.0	1970	9.4
1951	7.1	1971	8.7
1952	7.2	1972	8.4
1953	7.4	1973	8.3
1954	7.6	1974	8.2
1955	8.0	1975	8.2
1956	8.5	1976	8.2
1957	9.1	1977	8.2
1958	9.5	1978	8.2
1959	9.2	1979	8.3
1960	9.0	1980	8.3
1961	8.9	1981	8.3

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[1] Source National Petroleum News, Factbook Issue, various years, (weighted averages).

[2] New cars not produced during these years.

TABLE 4. — Price information for leaded regular gasoline and U. S. crude oil.

Year	Motor Gasoline Price in current U. S. dollars, Cents per gallon [1]	Avg. Annual wellhead Price of U. S. Crude Oil in current U. S. dollars, Dollars per 42 gal. barrel [1]
1947	23.1	1.93
1948	25.9	2.60
1949	26.8	2.54
1950	26.8	2.51
1951	27.2	2.53
1952	27.4	2.53
1953	28.7	2.68
1954	29.0	2.78
1955	29.1	2.77
1956	29.9	2.79
1957	31.0	3.09
1958	30.4	3.01
1959	30.6	2.90
1960	31.1	2.88
1961	30.8	2.89
1962	30.6	2.90
1963	30.4	2.89
1964	30.4	2.88
1965	31.2	2.86
1966	32.1	2.88
1967	33.2	2.92
1968	33.7	2.94
1969	34.8	3.09
1970	35.7	3.18
1971	36.4	3.39
1972	36.1	3.39
1973	38.8	3.89
1974	[2] 53.2	6.74
1975	[2] 56.7	7.56
1976	[2] 59.0	8.14
1977	[2] 62.2	8.57
1978	[2] 62.7	8.96
1979	[2] 85.7	12.51
1980	[2] 110.1	[3] 21.19
1981	[2] 131.1	[3] 31.77

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[1] 1980 Annual Report to Congress, DOE/EIA-0173(80)/2 Vol. 2 (of 3), and Basic Petroleum Data Book Pet. Ind. Statistics, v. 1, No. 2, API, 2101 L Street Northwest, Washington, D. C. 20037.

[2] Bureau of Labor Statistics, Washington, D. C.

[3] Monthly Energy Review, DOE/EIA-0035(82/03), Washington, D. C.

Historical Considerations

As the demand for gasoline increased during the first two decades of the 20th century, gasoline ceased to be a by-product of crude oil and more of the kerosene cut began to be included with the gasoline fraction. By 1913 even this spiking became inadequate to supply the increasing market for gasoline and a shortage threatened the further development of the automobile. Fortunately, the first commercial cracking process, the Burton process, was developed about this time to convert heavier oils, particularly the gas oils (which boiled just above kerosene) into gasoline by subjecting them to temperatures of around 750° F (399° C) and a pressure of about 100 pounds. As a result of this and many later improvements in cracking processes, which have been described by Nelson (*13*), gasoline yields have increased to about 50 percent of the crude oil that is processed, a figure well over twice the amount of hydrocarbons of suitable boiling point found in average crude oil.

As engine designers sought greater efficiency through higher compression ratios, they encountered increasing trouble with engine "knock", a rapid detonation occurring toward the end of each combustion cycle. The shape of the gasoline molecules was found to be very important in determining the knocking tendency of gasoline. Straight-chain molecules knock much more readily than branched or ring-shaped molecules, especially of the saturated type naturally present in crude oil. It soon became evident that the extent to which the compression ratio, and hence the efficiency, of gasoline engines could be increased depended on changing the kind of molecules present in gasoline.

It was in 1921 that Midgley (*14*) discovered the antiknock properties of tetraethyllead (TEL). But it also was learned that TEL alone caused massive combustion chamber deposits. He went on to show that combinations of TEL with an organic compound of a halide minimized these deposits. Later, other leadalkyl compounds including tetramethyl- and tetrapropyl- also proved to be effective antiknocks. The lead that is used now in some regular grade gasolines contains leadalkyl compounds and an ethylene dichloride-ethyl dibromide scavenger package.

Lead antiknock compounds or packages vary somewhat in effectiveness depending on composition of the base gasoline. In a typical gasoline, adding 0.8 milliliters per liter (3 ml/gal) of TEL increases the antiknock quality about seven research octane numbers. About half of the increase is obtained on addition of the first 0.2 ml/l (1 ml/gal). With the advent of catalytic converters for exhaust emission control, lead could no longer be tolerated since its combustion products tend to coat the catalyst surface, rendering it inactive. Barring a change in current legislation, lead will be essentially phased out of motor gasoline in the U.S. by the end of the 1980s.

During the period of 1925 to 1935, the petroleum refining industry profited by the application of advanced chemical engineering practices. During this period, vacuum distillation was developed. Although vacuum distillation techniques had been known previously, it was during this period that fractionating-tower design was advanced to permit continuous vacuum-distillation systems as opposed to batch heating techniques.

In the years of 1929 to 1935, the demand for high antiknock gasoline resulted in the development of vapor-phase cracking plants, gasoline-reforming units, and an increasing use of cracking plants. The hydrogenation process was developed but was not widely used yet because of unfavorable economics.

Vacuum distillation was widely applied to the manufacture of certain petroleum products and tetraethyllead was adopted as a means of improving the antiknock properties of motor fuels.

In the period between 1935 to 1941, propane, butane, and unsaturated hydrocarbons, found in cracking-still gas were utilized in polymerization, dehydrogenation, and alkylation processes. Polymerization, of olefins into "poly" gasoline was practiced at nearly all large cracking plants. The Houdry catalytic cracking process was introduced. Although these cracked gasolines were unstable in long-term storage, refiners delayed the formation of gum by the use of oxidation-inhibiting chemicals. Colored gasolines were generally accepted by the public and the properties of lube oils were being enhanced with additives during this time period.

With this background in the basic technical developments during the years prior to WW II, it is possible to better understand some of the trends that we shall see for motor gasoline during the years between 1942 and the present.

1942-1947

Catalytic cracking, as well as thermal cracking, has been widely used since 1942. Catalytic cracking differs from thermal cracking mainly in the introduction of an adsorbent-type catalyst which holds the asphaltic or tarlike products of cracking on the surface of the catalyst in the form of coke. Only distilled charging stocks are employed. Generally without some molecular rearrangement, gasolines produced from paraffin-base oils knocked badly in automotive engines while gasoline from naphthenic crude oils was high antiknock and could often be sold directly as premium-grade motor fuel.

The period from 1942 to 1947 saw an increased demand for diesel fuel oil and domestic distillate fuel oil. The urgency during World War II hastened the manufacture of high melting point waxes and numerous chemicals were manufactured from petroleum on a large scale including toluene, glycerol, butadiene, styrene, isopentane and isooctane (in the form of alkylate for aviation gasoline). Figure 1 shows the changes in octane numbers for both leaded regular and premium gasolines in years starting in the winter of 1942-1943. It will be noted that during the WW II years, there was a decided down-turn in the octane rating of motor gasoline. This was due, in part, to the large demand for aviation gasolines. Aviation fuel, which represents a "heart cut" of the motor gasoline boiling range produced the net result of raising the boiling range of motor gasoline. Robbing the crude oil of hydrocarbons especially suited to aviation gasoline resulted in motor gasoline with not only a lower octane number but also reduced volatility as shown by vapor pressure data presented in Figure 2. Figure 3 contains distillation data which graphically testifies to the change in molecular composition and the effect upon distillation patterns of motor gasoline during these WW II years.

Other technological factors that shaped the trends in motor gasolines during the years of WW II were the Houdry, Thermofor, Fluid, or Hydroforming catalytic cracking processes which were employed in all large refineries, and catalytic desulfurization of gasolines which was widely used. The production of 100 octane aviation gasoline reached 500,000 barrels per day in 1945 but decreased rapidly after the war.

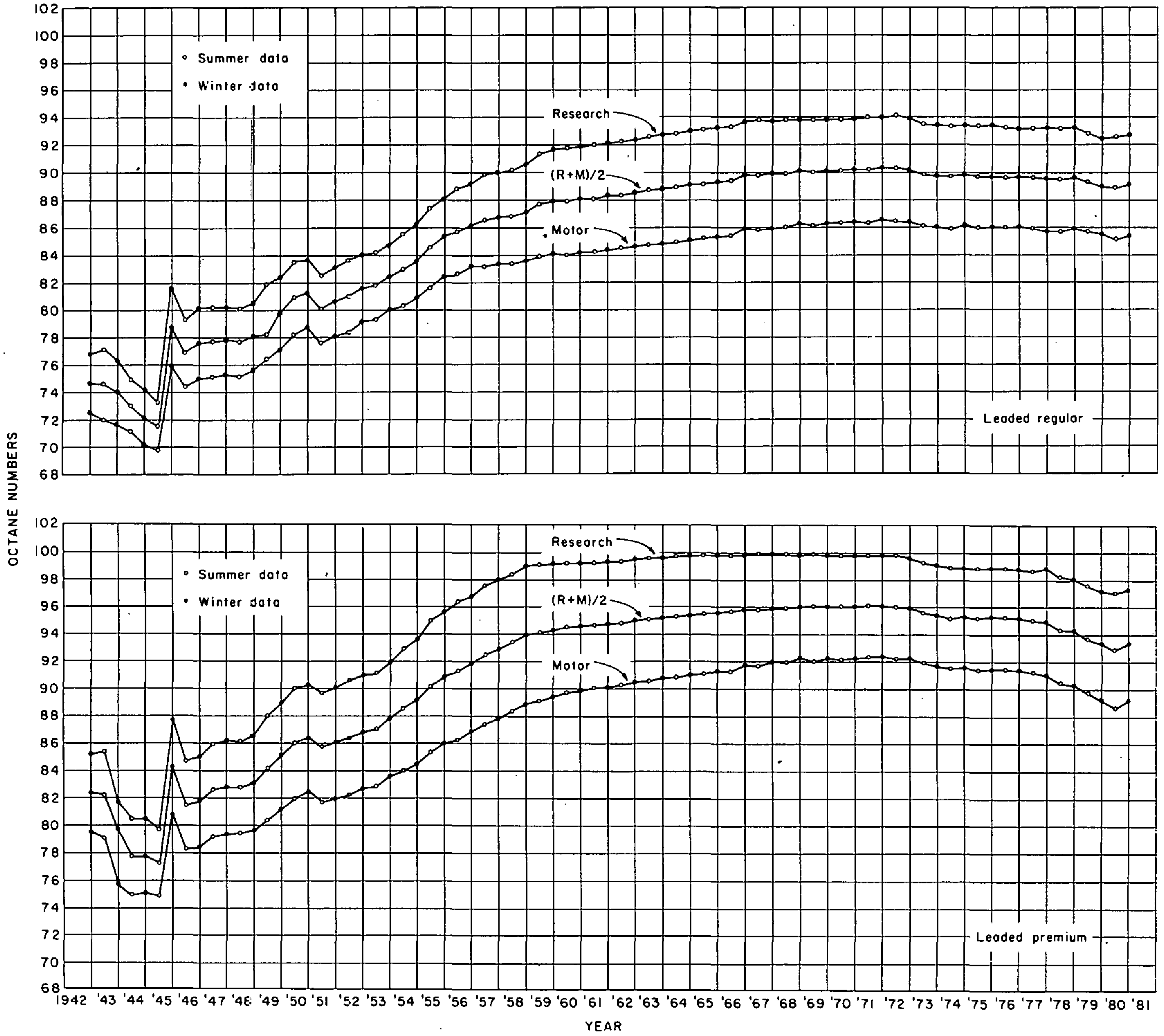

FIGURE 1. — Trends in octane numbers for leaded regular and leaded premium grade motor gasolines.

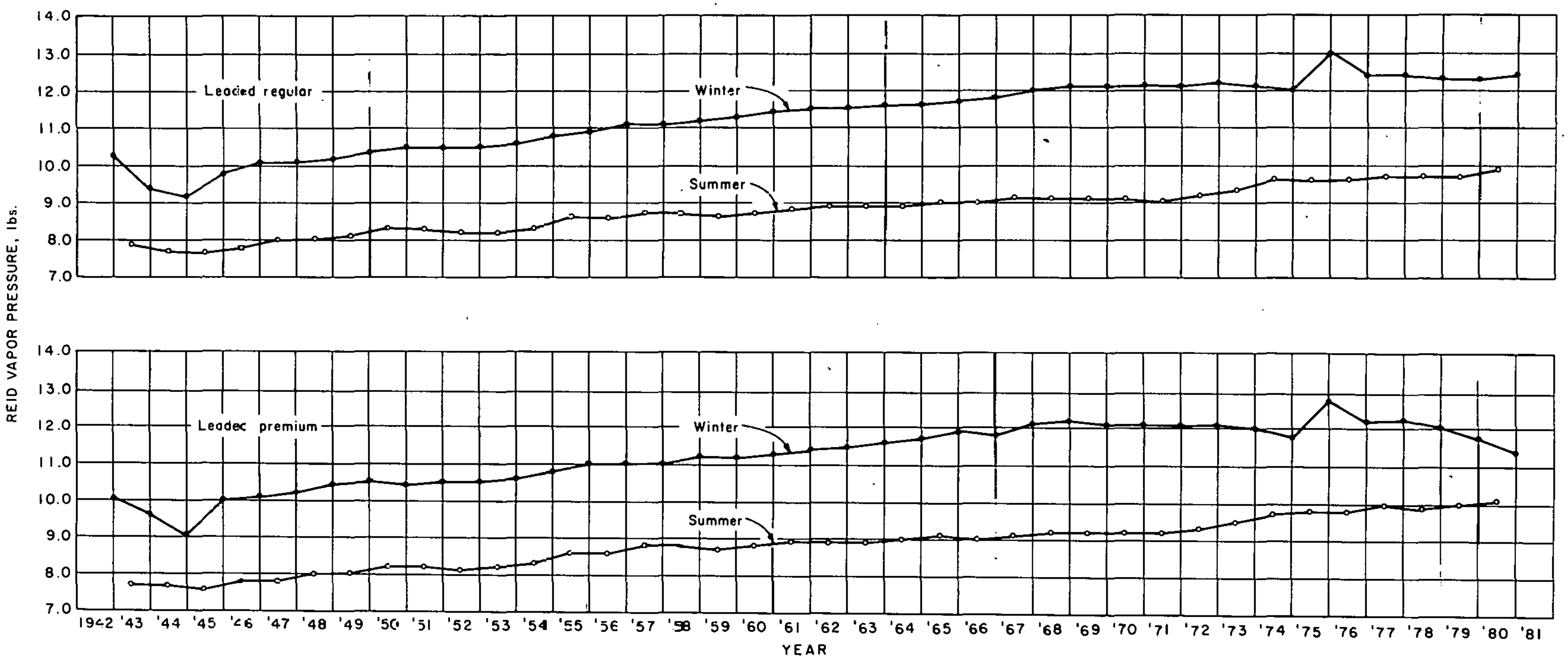

FIGURE 2. — Trends in Reid vapor pressure for leaded regular and leaded premium grade motor gasolines.

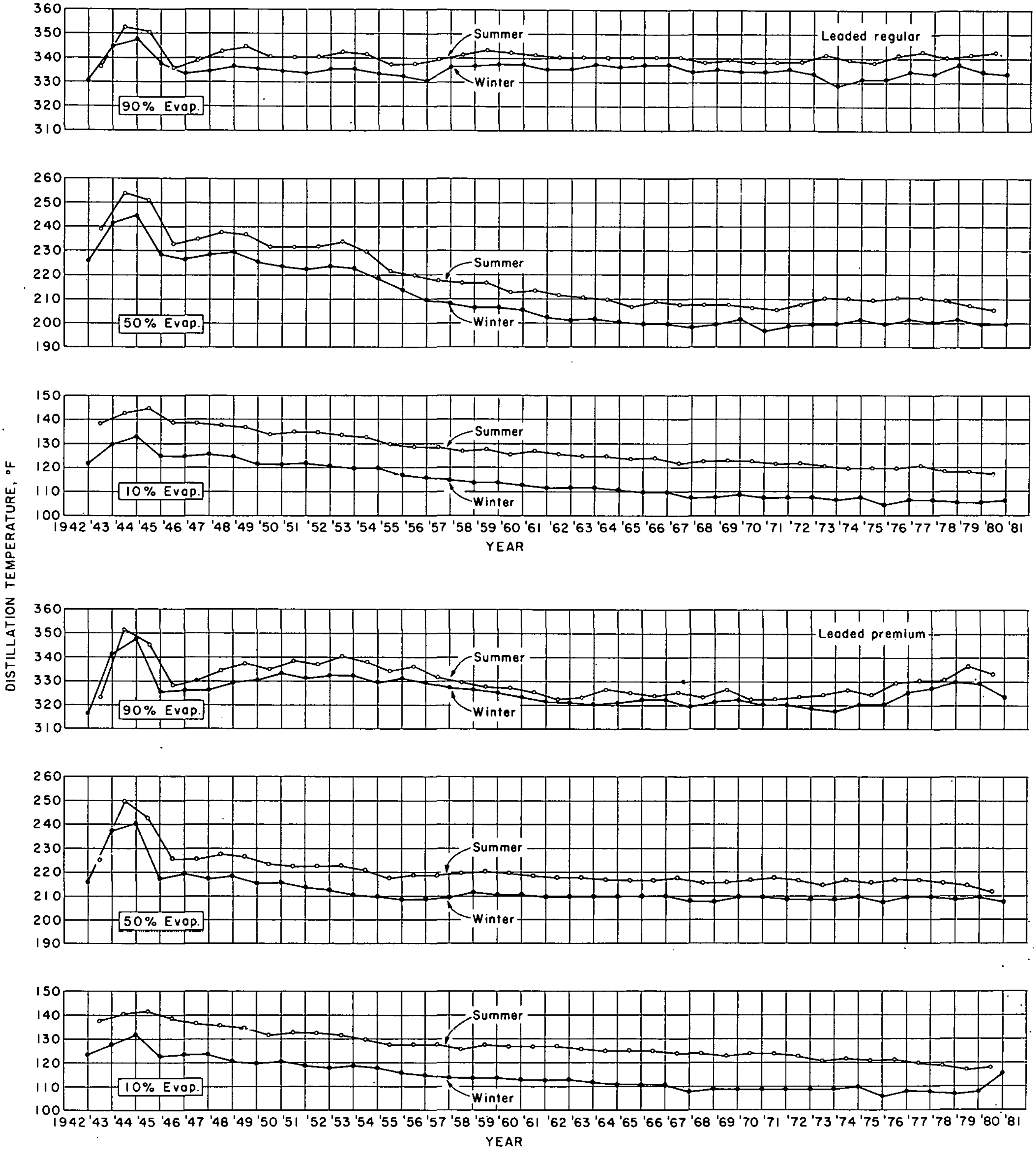

FIGURE 3. — Trends in distillation temperature for leaded regular and leaded premium grade motor gasolines.

Perhaps it is an over simplification, but one of the greatest trend-producing factors of these years was the use of technology to change molecules in crude oil by the processes of cracking and reforming to produce more fuel from a barrel of crude oil. By the end of WW II about 60% of the average motor fuel was composed of synthetic molecules, and aviation gasoline was more than 90% synthetic. By the 1960s most motor gasoline was fully 80% synthetic. This illustrates forcibly the revolution in refining methods brought about by the advent of cracking. The discovery that the cheap hydrocarbons in petroleum could be readily changed in composition and structure led also to a rapidly growing petrochemical industry, which makes a wide variety of chemicals for solvents, plastics, fibers, and synthetic rubber from petroleum or natural gas.

1948-1957

After the war, petrochemical manufacture increased tremendously, synthetic rubber was more widely used than natural rubber, and sulfur from refinery and natural gases became a significant amount of total sulfur production. The development of jet and turbine aircraft engines caused a rapid increase in jet fuel manufacture so that the middle distillate portion of petroleum was in great demand for distillates, diesel fuel, jet fuel, and rocket fuel. The first truly catalytic processes to be applied to the bulk-scale treatment of petroleum was introduced as platforming (a contraction of the term "platinum-reforming") or similar platinum catalyst reforming processes. Starting from 1950, catalytic reforming increased and by 1955 there was nearly a million barrels per day of product. Practically all refineries had installed the capability to do catalytic reforming and adequate supplies of benzene and toluene were thus assured because the platinum-refined gasolines were rich in aromatics.

By the 1960s the average octane number of U. S. gasoline had risen to about 91 for the regular grade and 99 for the premium grade, as compared with an octane number of 55 or below before the advent of cracking. Military aviation gasoline reached the 100 octane level just before World War II, and still better fuels were later developed. Their antiknock quality was stated in terms of performance numbers, which indicated the knock-free power obtainable in an engine of suitable compression ratio as a percentage of the power obtainable from pure isooctane. The widely used grade of aviation gasoline had a performance number of 115 under cruising conditions and 145 under take-off conditions. However, further substantial increases in antiknock quality promised to be quite expensive. During the same period the compression ratios of new automobile engines went up from an average of 4.4 in 1925 to an average of 9.5 in 1958, with an improvement in the efficiency of gasoline utilization of about 60%. The average power generated per cubic inch of engine displacement increased from 0.234 horsepower to 0.779 in the same period.

The years following WW II saw the beginning of the automobile era in the United States. Cars, which were not manufactured during the war, were suddenly in great demand and the mobility of the American public became legend. The trend in automobile design was toward larger, roomier, faster and more comfortable riding vehicles. This called for larger engines with more horsepower. For the sake of efficiency, compression ratios were increased. Figure 4 shows the compression ratio on a weighted average for all engines in a given model year of American origin. These compression ratios are admittedly of little use other than to indicate trends because of the large number of engines that must be averaged to produce an average compression ratio. For example, in 1967, 14.3 percent of the total cars had compression ratios between 8.1 and 8.9; 51.1 percent had compression ratios between 9.1 and 9.9; 34.3 percent had ratios

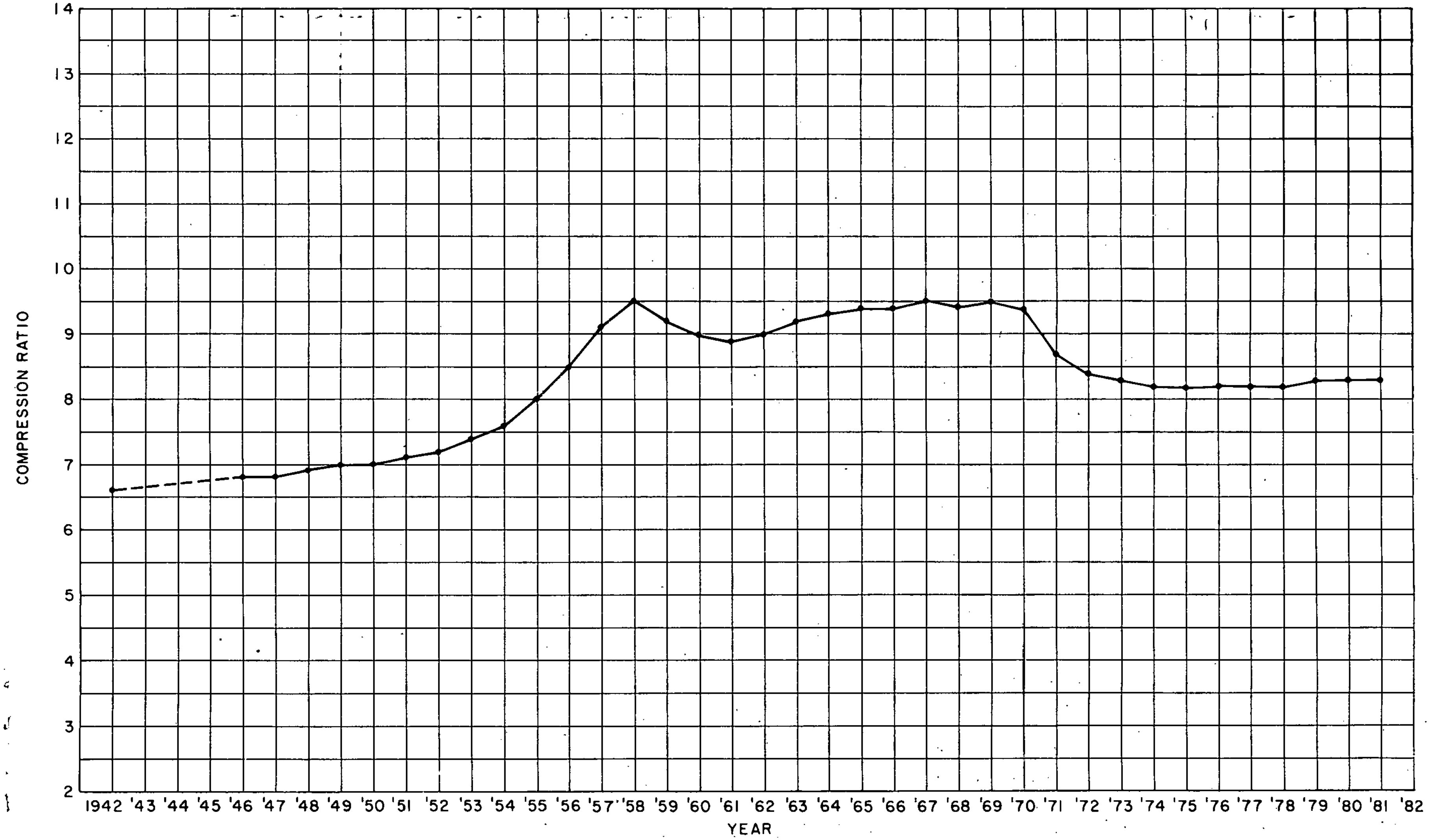

FIGURE 4. — Trends of average compression ratios for engines built in the United States.

between 10.1 and 10.9; and only 0.3 percent were between 11.1 and 11.9 compression ratios. The compression ratio data used in this report was compiled by the National Petroleum News (*15, 16, 17, 18*). Compression ratios started to increase in about 1949 and continued to rise until about 1957 when the weighted average leveled off between 9.0 and 10.0.

Other technological developments during this period included sweetening of petroleum products by means of inhibitors rather than by chemical treatment. The increasing percentage of sulfur in newly discovered oils in that period led to the development of several hydrogenation methods of desulfurizing gas oil and distillate materials. Premium gasoline of 100 Research Octane Number was first marketed in 1956 and many alkylation plants were installed in maintaining the so-called "octane race". Figure 1 shows how octane numbers increased during this period. The volatility of gasolines marketed showed improvement in a slow and consistent pattern as demonstrated by data in Figure 2. With the press for aviation gasoline largely in the past and with the capability for catalytically cracking and reforming, the distillation temperatures for motor gasolines no longer depended upon the abundance of straight-run gasoline. Although the upper end of the boiling range remained fairly constant after the WW II years, more lower-boiling components were included in motor gasoline as shown by the 10% and 50% evaporated curves of Figure 3. This reflected the effort to improve both winter warm-up, driveaway operation and low-temperature starting ease.

Advanced desulfurization techniques developed during this period had a definite effect upon the sulfur in motor gasoline as shown in Figures 5 and 6. The average sulfur content of leaded regular gasoline which was near 0.09 percent by weight in 1945 through 1953 was cut nearly in half by the year 1958.

Lead, as an antiknock additive, was naturally being increased during a period when higher octane ratings were desired and when engine design tended toward more power. Trends in lead content are to be seen in Figures 5 and 6.

An important observation that should be made regarding technology during the era which has been discussed above is that in 1919 refiners' output of gasoline represented only about 25 percent of the input of crude oil and these were, for the most part, very good crude oils. Whereas in 1958, largely because of the evolution of new processing methods, refiners were able to produce 44.9 percent gasoline from similar crude oil and the product was of much higher quality.

1958-1970

The 1960s will probably be best remembered by this and future generations as the period of regulation of the automobile. It was a time when the numbers of vehicles and users became so large in critical geographic areas that exhaust emissions turned clean atmospheres into almost unbreathable mixtures with unburned hydrocarbons, nitrogen oxides, and carbon monoxide. These exhaust gas emissions in high density population areas of the U.S. coupled with industrial atmospheric emissions made regulation by state and federal governments mandatory.

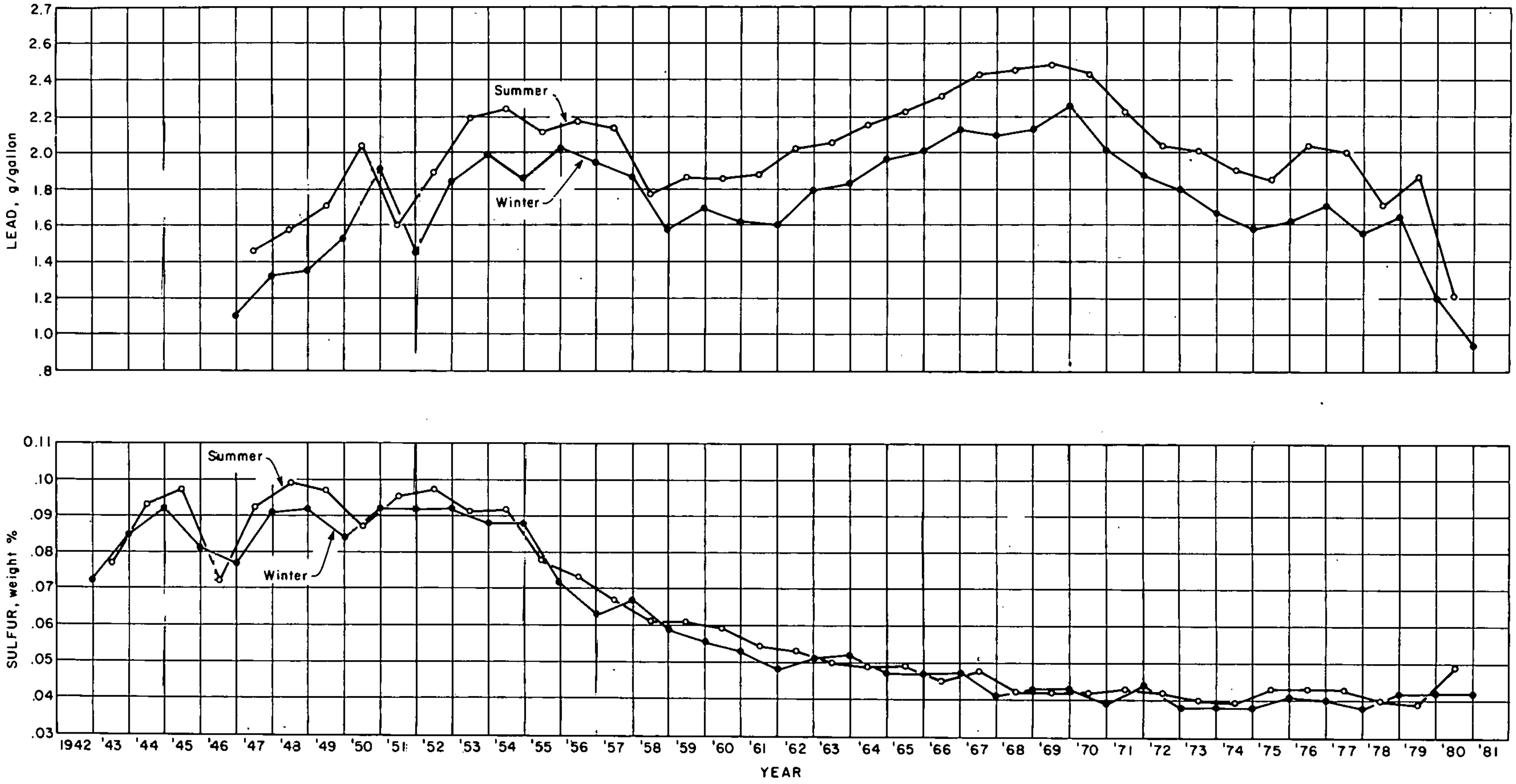

FIGURE 5. — Trends of lead and sulfur content of leaded regular grade motor gasoline.

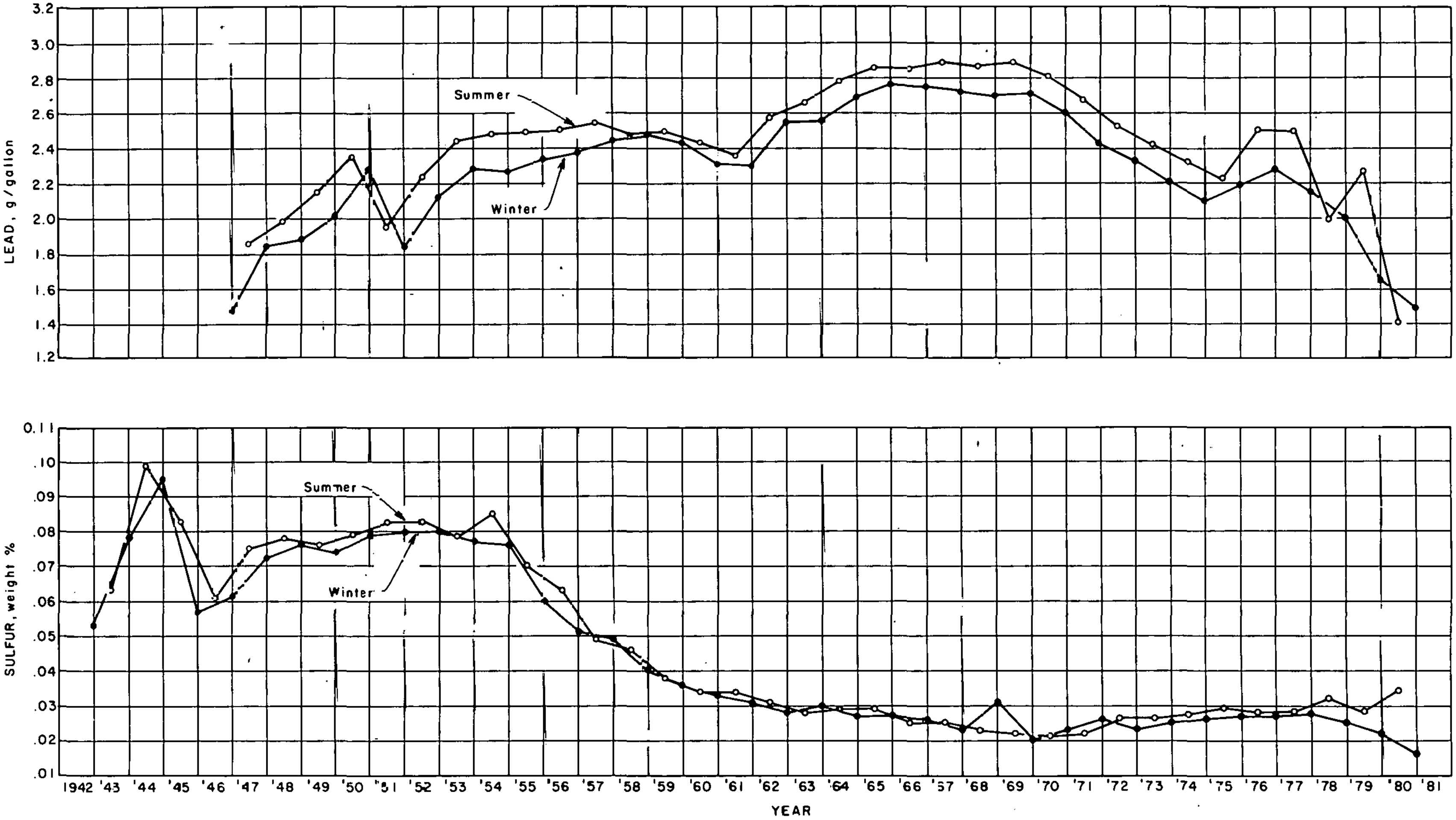

FIGURE 6. — Trends of lead and sulfur content of leaded premium grade motor gasoline.

Atmosperic contaminants present in strong enough concentration to pose possible threat to life, or suspected cases of disease or acute poisoning became apparent in the 1960s in areas such as the Los Angeles basin in southern California. The urgency of the problem gave rise to the development of the catalytic converter (muffler) for automobiles to reduce the noxious emissions, but these converters which were used only on new automobiles were quickly poisoned and rendered ineffectual by the lead additive present in gasoline. Additionally, the suspicion that airborne lead as a toxic material could be directly absorbed through the lungs as people breathe or settle out of the air to contaminate dirt which may be consumed by children was added evidence to support the view that through these routes, airborne lead could contribute to excessive exposure in adults and children. Both factors contributed to legislation that is destined to ultimately eliminate the use of leadalkyls in motor gasolines.

Octane number continued to increase slowly throughout the 1960s although it was becoming apparent that the internal combustion engine, without some major innovations, was reaching a point where further increases in size and horsepower were impractical as were further attempts to increase efficiency through higher compression ratios. The volatility of motor gasolines continued to stabilize throughout the 1960s (Figure 2) and the boiling range of these fuels had reached an optimum balance to provide quick starting in winter and avoid vapor lock problems in the summer.

The amount of leadalkyl additivies to motor gasoline peaked near the end of the 1960 period while at the same time sulfur content dropped to historical lows as the result of improved desulfurization technology (Figures 5 and 6).

Compression ratios reached a measure of stability between the years of 1957 and 1969 ranging from 9.0 to 9.5 in a weighted average of all U.S. built engines.

1971-1981

If the 1970s are to be historically related to motor gasoline evolution it will be in terms of shortages. The oil embargo of 1973 which temporarily halted the importation of foreign crude oil to U.S. markets brought gasoline shortages to the American public that were not only a great inconvenience but threatened to radically alter life styles closely tied to mobility since the end of WW II. Although America had once possessed huge resources of crude oil that seemed inexhaustible, production of domestic crude proved inadequate to meet demands during the 1960s resulting in increasing imports of foreign crude. The eventual embargo by the Organization of the Petroleum Exporting Countries (OPEC) started a trend in the U.S. toward conservatism based upon short supplies and skyrocketing gasoline prices. These resulting high gasoline prices changed the American's appetite for large gas-guzzling automobiles and thus the compact and subcompact automobiles from both foreign manufacturers and American origin became a trend of the times. Environmental factors which mandated the phase-out of lead additives also brought unleaded gasoline to the market. The necessity for unleaded gasoline brought an apparent end to the octane numbers race and virtually eliminated leaded premium gasoline from the marketplace as older cars requiring premium fuels became obsolete. However, unleaded premium gasolines are now available in the marketplace. Petroleum shortages have resulted in limited use of alcohol as an automotive fuel and these same shortages promise to introduce shale and coal-derived fuels to the market place within the decade of the 1980s.

Examination of Figure 1 shows that octane numbers have decreased modestly since 1971 but further dramatic decreases appear unlikely. The volatility of leaded regular gasoline has not created a new trend as the result of the move to smaller automobiles. There has been some decrease, however, in the volatility of leaded premium grade motor gasoline. Since leaded premium has largely been phased out of existence, the trends appear, at this point, to be non-significant.

The boiling points of motor gasolines as indicated by distillation temperatures in Figure 2 appear to be consistent with trends established in the 1960s and thus we are seeing little change in this property.

The lead content, of course, as shown in Figures 5 and 6 continues to drop rapidly as mandated by legislation. The gasoline pool, which contained 2.3 grams of lead per gallon in 1970 was reduced to 1.6 grams in 1975, to 1.0 grams in 1980 and is expected to reach virtually zero level based on gradual elimination of vehicles burning leaded fuels.

Sulfur content of gasolines continues low although much of the foreign crude oil currently imported for fuel manufacture is "sour" and requires extensive desulfurization.

Compression ratios appeared to level off in about 1972 near a weighted average level of 8.2 and have remained very constant for about 10 years. Without some astounding innovation in engine design technology or trends away from smaller engines, the need for fuel efficiency based on shortages and prices will probably stabilize compression ratios for the near-term.

The price for leaded regular grade motor gasoline which remained in the range of 25 to 36 cents per gallon from 1948 through 1972, a period of some 24 years. Gasoline prices suddenly rose to over 60 cents per gallon between 1972 and 1978 responding to the increased costs of crude oil. These data are shown in Figure 7. Deregulation of petroleum prices produced similar upward price pressures and the price for gasoline was near $1.10 per gallon on a national average in 1980. Domestic crude oil at the wellhead (no transportation charges attached) rose from $3.00 per barrel in 1968 to only $3.40 in 1972, a period of four years. The embargo of 1973, however, triggered a jump to $9.00 per barrel in five years and another jump to over $12 in one more year (1979). The current price for OPEC oil is about $34 per barrel despite the current world-wide "oil glut" and the price is expected to remain high with domestic crude oil following foreign pricing trends.

It is obvious from Figure 7 that gasoline price trends have been dictated by domestic crude oil prices which in turn have been affected by foreign crude oil prices. The trend showed slight signs in late 1981 of slowing its upward spiral. This has resulted to a large extent from conservation measures, increased domestic production, and over-production by some foreign countries.

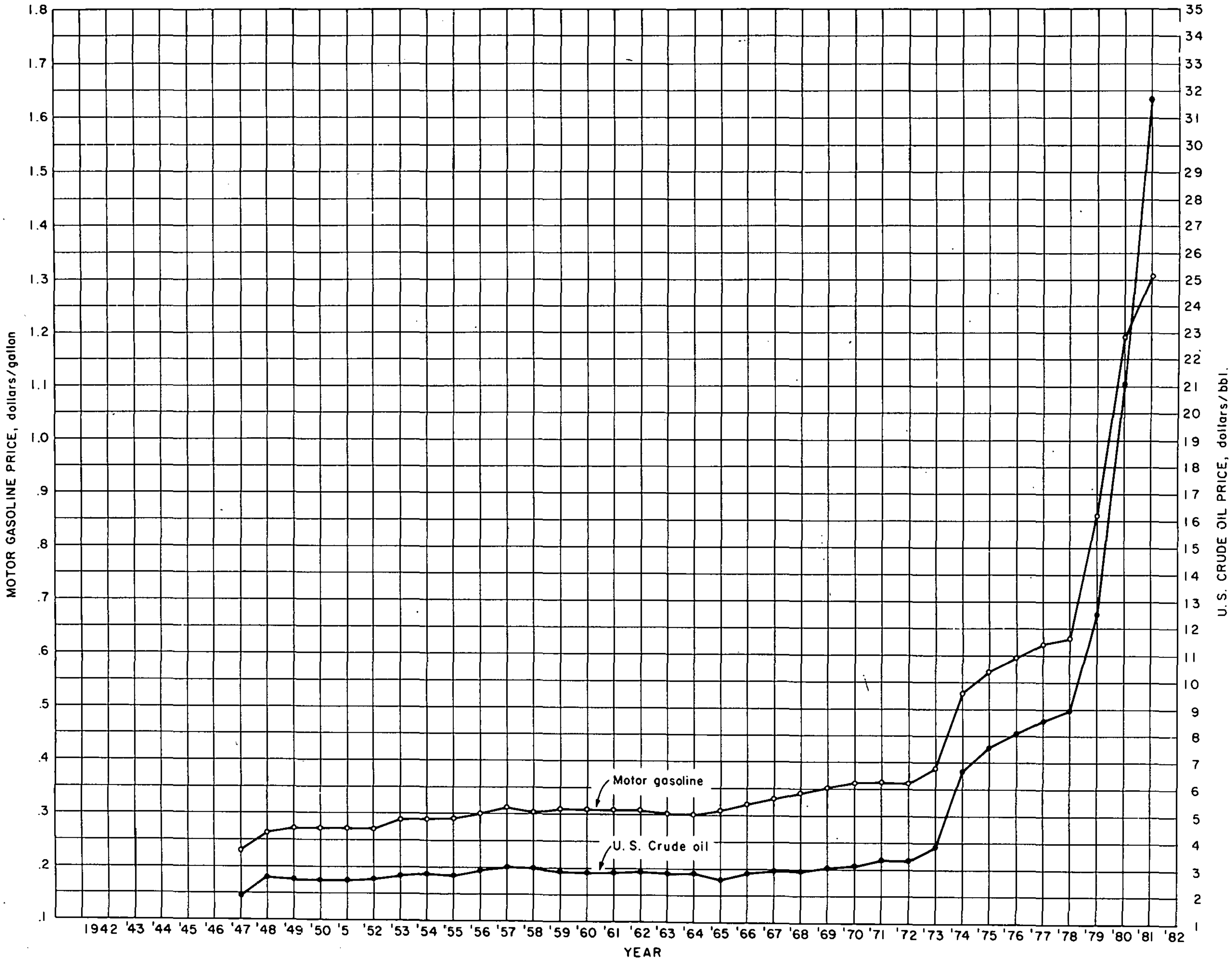

FIGURE 7. — Trends of prices for leaded regular motor gasoline and U. S. crude oil.

SUMMARY AND CONCLUSIONS

Some very general observations that can be made in regard to motor gasoline trends over the past 40 years are:

- The trends for leaded regular and leaded premium gasolines have been parallel.
- Trends have been the result of societal, political, and technological interactions.
- It does not appear feasible to extrapolate trends for more than a few years past actual data availability.
- Regulation of automotive design characteristics and shortages of crude oil will probably have the largest effects in the near-term in setting trends for future motor gasolines.

More specifically, trends in octane numbers included a drop during the WW II years because of the introduction of new processing technology and because some of the middle gasoline distillate was siphoned off to use for other strategic purposes associated with the war effort. This included the manufacture of enormous quantities of aviation gasoline and the pressing need for petrochemicals manufactured from toluene, styrene, and some other compounds. At the end of the war, though, the octane number suddenly spurted upward then settled down to a 10 year upward trend as engines became larger and more powerful. The years between 1960 and 1975 saw a period of stability in octane number and the past six years (1975-1981) have produced a small decline in octane numbers as automobiles and engines have become smaller and as inferior grade crude oils are being used more commonly in the manufacture of motor gasoline.

Octane number is a partial function of lead content and there has been a striking similarity between trends in lead content and octane number in the period of 1942 to 1981. For example, a peak in the average lead content in 1950-1951 corresponded to a similar rise in octane number for those same years. Generally, as lead has been reduced in gasoline by mandate, starting in 1975, the octane number has shown a slight decrease. Some of the contribution that lead makes to higher octane number has been compensated by blending of hydrocarbons with higher natural antiknock properties. Although lead content appears to be slightly higher in summer gasolines than in winter, the difference is not significantly high to be manifested in a similar higher octane number bias.

Since more volatility is needed in winter gasolines for easier cold-engine starting and less volatility is desirable in summer gasolines to reduce vapor lock problems, these requirements are seen as trends in distillation and vapor pressure data. Summer gasolines have a higher 10%, 50%, and 90% distillation temperature than do winter gasolines. This trend is a result of seasonal refinery adjustments. These winter/summer differences in distillation temperatures make an effective difference in volatility as indicated by Reid vapor pressure changes of about two pounds.

The use of some motor gasoline components during WW II for aviation gasoline and chemical manufacture resulted in higher 10%, 50%, and 90% evaporated distillation temperatures in 1943 and 1944. The vapor pressure in the winter gasoline of those years was also lower by about two pounds.

Improved refining technology, a trend from aviation gasoline to jet fuel and demands for gasolines tailored for larger, faster engines resulted in a trend toward lower gasoline boiling ranges between 1950 and 1960. The period between 1960 and 1975 saw no significant changes in volatility of motor gasolines but the increased use of lower quality crude oil for the manufacture of gasoline plus other factors have tended to raise and narrow the boiling point range of gasolines since 1975.

Sulfur in gasoline is objectionable because of odor and sulfur's adverse effect upon the long term storage stability of the product. It also reduces the effect of lead upon octane number and therefore low sulfur in motor gasoline is desirable. The level of sulfur in gasoline is generally a function of the sulfur content of the crude oil and the processing technology used to produce the gasoline. Higher boiling materials contain more sulfur, thus sulfur tends to be slightly higher in summer gasolines than in winter gasolines.

Sulfur in gasoline has been dramatically reduced over the years by improved desulfurization technology. Sulfur was higher in the WW II years because of the generally higher boiling range of materials in motor gasoline and a lack of good and effective sweetening technology.The increased use of hydrotreating and hydrofining since the late 1950s has caused a marked decline in total sulfur content of gasoline.

Lead content which originates as a leadalkyl antiknock additive to motor gasoline has been influenced by demands of engines for antiknock characteristics, requirements for higher octane number as engines increased in size and compression ratio, and environmental management since 1975. These recent environmental regulations and the trend toward smaller cars with smaller engines has produced a decrease in total lead content in motor gasoline. Actually, lead reached a maximum in about 1970 and has been decreasing since that time. The decrease has been more dramatic since 1975. It is believed that lead will be virtually nonexistent in motor gasoline by the end of this decade as the number of newer automobiles using unleaded gasoline continue to increase and as older cars which burn leaded fuel continue toward obsolescence.

Immediately following the war years of WW II, the American public turned its eyes toward the automobile to an extent unprecedented in the world's history. The race was soon on to produce larger, faster and more comfortable cars for a society that abandoned public transportation for the sake of independent mobility. Automobile design trends resulted in larger and more powerful engines. Power was needed for more than just speed as Americans accepted and provided a ready market for air conditioning, sound equipment, automatic transmissions, power brakes, and even power seats, windows and headlights. As engines grew to accomodate the optional extras on cars, the compression ratios increased in an effort for higher operating efficiency. The upward trend in compression ratios did not become graphically obvious before about 1952. A peak was reached in about 1958 with a leveling trend in compression ratio in the period between 1960 and 1970. Compression ratios then dropped as unleaded gasolines with lower octane numbers were mandated by exhaust emission constraints. Compression ratios have been constant since 1972 with the weighted national average about 8.2.

The trends in prices for motor gasolines have been upward since the end of WW II. However, the rate of increase for both domestic crude oil and gasoline, which seem to run parallel, was very modest through about 1970. The big surge toward higher prices started in about 1971 as short supplies became more apparent and as more foreign crude was imported, but it was not until after the embargo of 1973 that prices escalated dramatically. The current trend appears to be upward. Crude oil prices have increased by approximately 900 percent over the 1969 price and motor gasoline prices have increased by about 300 percent during the same period.

Perhaps one of the most dramatic motor gasoline trends is the rapid demise of leaded premium grade motor gasoline as American automobile manufacturers have discontinued the manufacture of engines that specify this fuel and older cars that use premium fuel are gradually being eliminated through obsolescence. The other startling trend, of course, is the rapid decline in the use of leadalkyls as antiknock additives. Currently, the beneficial properties of lead on octane number is being compensated by the use of hydrocarbons with natural antiknock qualities. It is more expensive to manufacture gasoline with equal antiknock qualities without lead additives than with lead additives. Perhaps this fact will lead to the eventual development of an additive with lower toxicity that will have the same or improved enhancement of antiknock properties of motor gasoline.

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