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3,955,938	511976	Graham et al.	441305
3,957,901	511976	Chapman	
3,980,448	911976	Haemmerle et al.	44/63
3,988,122	1011976	Rosenthal et al.	441452
4,017,268	411977	Gilley	44152
4,022,589	511977	Alquist et al.	
4,045,092	811977	Keller	302166
4,112,889	911978	Harpman	123125 B
4,118,425	1011978	Herbetman	
4,180,036	1211979	Wolf	1231122 E
4,194,886	311980	Ripple	44170
4,205,960	611980	Bryant	44/68
4,211,639	711980	Jackson	2081188
4,214,876	711980	Garth et al.	441404
4,215,997	811980	Sandy	441367
4,220,120	911980	Jackson et al.	
4,231,756	1111980	King	44153
4,244,703	111981	Kaspaul	44156
4,294,587	1011981	Burns	
4,295,861	1011981	Burns	
4,295,862	1011981	Burns	
4,297,172	1011981	Kyle	203119
4,312,636	111982	Singerman	441447
4,313,738	211982	Parlman et al.	441447
4,319,981	311982	Singerman	441447
4,321,061	311982	Parlman	441447
4,321,063	311982	Burns	441447
4,322,304	311982	Parlman et al.	441447
4,324,569	411982	Klimczak	441447
4,336,032	611982	Kupka et al.	44/56
4,339,245	711982	Burns	44156
4,341,529	711982	Burns	44156
4,347,062	811982	Born et al.	44/68
4,372,752	211983	Lamy	
4,378,230	311983	Rhee	44151
4,378,231	311983	Burns	
4,387,257	611983	Burns	585114
4,388,081	611983	Burns	441443
4,417,904	1111983	Burns et al.	60/39
4,420,930	1211983	Beuther et al.	60/39
4,429,173	111984	Hutson et al.	60/39
4,437,436	311984	Graiffe	60/39
4,444,567	411984	Burns et al.	60/39

Related U.S. Application Data

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- [52] U.S. Cl. . **208/17**
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References Cited

U.S. PATENT DOCUMENTS

H1305	511994	Townsend et al.	441449
Re. 20,596	1211937	Taylor et al.	441449
1,409,404	311922	Ramage	441449
2,032,330	211936	Roberts et al.	196111
2,142,937	111939	Deanesly et al.	196111
2,190,480	211940	Nichols, Jr. et al.	196111
2,204,215	611940	Greensfelder et al.	196111
2,209,904	711940	McCulloch et al.	196111
2,401,983	611946	Stanley et al.	196111
2,407,716	911946	Marschner	196111
2,407,717	911946	Marschner	196111
2,409,157	1011946	Schulze et al.	196111
2,411,582	1111946	McCulloch	196111
2,495,648	111950	Voge et al.	196111
2,593,561	411952	Herbst et al.	44/69
2,857,254	1011958	Thomas	44/63
2,939,836	611960	Koome et al.	44/62
2,944,003	711960	Ritedisnlj et al.	44/63
2,968,609	711961	Lutz	2081100
3,002,917	1011961	Hamilton	208179
3,009,789	1111961	Jordan et al.	208179
3,009,791	1111961	Emrick	208179
3,034,878	511962	McCall et al.	208179
3,156,640	1111964	Hart	208179
3,385,680	511968	Feld et al.	208179
3,391,077	711968	Osborne	2081256
3,658,690	411972	Graven	
3,685,502	811972	Oberdorfer, Jr.	1231119 R
3,753,670	811973	Strang et al.	441432
3,758,401	911973	Bridgford et al.	208178
3,765,848	1011973	Brent	44/51
3,785,790	111974	Strang	44166
3,795,495	311974	Howland et al.	44/66
3,836,342	911974	Shang et al.	44/66
3,873,276	311975	Haemmerle et al.	44/63
3,886,759	611975	McNamee	44/63
3,894,849	711975	Polss	44163
3,902,870	911975	Rollmann et al.	44/6
3,903,194	911975	Hutson, Jr. et al.	44/6
3,904,508	911975	Whyte, Jr. et al.	4416
3,920,698	1111975	Haemmerle et al.	44/63

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

213136	511952	Australia	208117
466511A	111992	European Pat. Off.	

OTHER PUBLICATIONS

1989-1990 ARCO EC-1 an EC-P (Exhibits 27, 28, 29, 30 and 11877 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca. Case No. CV-95-2379 KMW (JRx).

(List continued on next page.)

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[57] ABSTRACT

By controlling one or more properties of a gasoline fuel suitable for combustion in automobiles, the emissions of NOx, CO and/or hydrocarbons can be reduced. The preferred fuel for reducing all three such emissions has a Reid Vapor Pressure no greater than 7.5 psi (0.51 atm), essentially zero olefins, and a 50% D-86 Distillation Point greater than about 180° F. (82° C.) but less than 205° F. (96.1° C.)

58 Claims, 9 Drawing Sheets

U.S. PATENT DOCUMENTS

4,455,909	611984	Burns	60/39
4,468,233	8/1984	Bruderreck et al.	60/39
4,474,580	1011984	MacKenzie et al.	44/68
4,501,596	211985	Burns	441341
4,508,617	411985	Montgomery	441341
4,525,174	611985	Croudace	441341
4,571,439	211986	Keyworth	441341
4,579,990	411986	Keyworth	441341
4,600,408	711986	Jessup et al.	441341
4,602,919	711986	Jessup et al.	441341
4,607,129	811986	Lee	441341
4,647,292	311987	Jessup et al.	441341
4,647,368	311987	McGuiness et al.	441341
4,684,373	811987	Vataru et al.	44/63
4,699,629	1011987	Croudace et al.	441429
4,720,288	111988	Croudace et al.	
4,737,159	411988	Phillips	441419
4,743,273	511988	Croudace et al.	441418
4,773,916	911988	Croudace et al.	441440
4,781,728	111988	Jessup et al.	
4,797,134	111989	Vataru	44166
4,804,389	211989	Johnston et al.	44/70
4,812,146	311989	Jessup	585114
4,818,250	411989	Whitworth	
4,824,552	411989	Nagasawa	208117
4,844,717	711989	Croudace et al.	441418
4,851,601	711989	Fukuda et al.	
4,852,992	811989	Nasu	44/50
4,873,389	1011989	Avidan et al.	2081188
4,884,531	1211989	Degan, Jr. et al.	
4,895,640	111990	Jackson	2081188
4,896,636	111990	Pfefferle	2081188
4,899,014	211990	Avidan et al.	2081188
4,953,332	911990	Talbert	2081188
5,004,850	411991	Wilson	585/1
5,015,356	511991	Talbert	208116
5,032,144	711991	Jessup et al.	441384
5,041,208	811991	Patridge et al.	
5,113,803	511992	Hollrah et al.	
5,288,393	211994	Jessup et al.	208116
5,593,567	111997	Jessup et al.	208116
5,653,866	811997	Jessup et al.	208116

OTHER PUBLICATIONS

"GM Still Wants Costly Light Gasoline" *Oil & Gas Journal*, Oct. 2, 1972, pp. 44-46 (Exhibit 876 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

"GM Bids for Radically New Gasoline." *Oil & Gas Journal*, Jan. 17, 1972, pp. 953-954 (Exhibit 11,801 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Adams, "New Technology Complements an Aliphatic Route for Future Gasolines," published by API. Proceedings—Division of Refining-1973-Philadelphia, Penn., May 14-17, 1973 (Exhibit 10,283 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

CRC Report No. 454, "Effect of Altitude Changes on Octane Number Requirement of Late Model Cars," Oct. 1973 (Exhibit 1240 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

ARCO Reformulated Gasoline "Reformulated Gasoline for Clean Air, An ARCO Assessment," by K. L. Boekhaus et al., for "Roads to Alternative Transportation Fuels" 2nd Biennial U. C. Davis Conference on Alternative Fuels, Jul. 12, 1990 (Exhibit 1333 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

CRC Report No. 477, "1973 Fuel Rating Program Part I: Road Octane Performance in 1973 Model Cars," Feb. 1975 (Exhibit 6221 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

CRC Report No. 493, "1976 CRC Octane Number Requirement Survey," Jul. 1977 (Exhibit 6224 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

CRC Report No. 449, "1975 CRC Fuel Rating Program: Road Octane Performance in 1975 Model Cars," Oct., 1977 (Exhibit 6225 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Stebar SAE 720934, "New Emphasis on Fuel Volatility—Effects on Vehicle Warmup with Quick-Release Chokes," 1972 (Exhibit 6284 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Date et al., SAE 770811, "Road Octane Number Trends of Japanese Passenger Cars," 1977 (Exhibit 6401 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Marbach et al., SAE 790204, "A Novel Laboratory Method for Evaluating Induction System Deposits in Gasoline Engines," Feb. 26-Mar. 2, 1979 (Exhibit 6410 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

ARCO LOD and LOD 2 (Exhibits 7036, 7048, and 7056 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Lieder, "The Impact on Fuels of the 1990 Clean Air Act Amendments," National Petroleum Refiners Association, FL-90-110, presented at the NPRA National Fuels and Lubricants Meeting, Nov. 1-2, 1990, Houston, Texas (Exhibit 7813 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Piel and Thomas "Ethers: A Key Ingredient for Reformulated Gasoline," *The National Conference on Octane Quality and Reformulated Gasoline*, Mar. 29, 1990 (Exhibit 11844 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Ockerbloom, "Reformulation of Gasoline Impact on Basic Petrochemical Aromatics—An Early Appraisal," *The National Conference on Octane Quality and Reformulated Gasoline* Mar. 29, 1990 (Exhibit 11844 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Piel, "Ethers Will Play Key Role in "Clean" Gasoline Blends," *Oil & Gas Journal*, pp. 40-44 Dec. 4, 1989 (Exhibit 7476 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Colucci, "What Can the Oil Industry Do in the 1990s—An Auto Man's Perspective," GMR-7010, F&L-893, Presented to API Forum Apr. 25, 1990 Dearborn, Michigan (Exhibit 7073 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

"Automotive Fuels for the 1990's—Challenges and Opportunities" by Joseph M. Colucci, Research Publication, General Motors Research Laboratories, GMR-6589, F&L-882 to be presented at DeWitt and Company-Petrochemical Review Seminar, Houston, TX, Mar. 30, 1989.

- "Vehicle Evaporative and Exhaust Emissions as Influenced by Benzene Content of Gasoline" by Donald E. Seizinger, William F. Marshall, Frank W. Cox, and Martin W. Boyd, National Institute for Petroleum and Energy Research, NIPER-151, DE86 010603, Apr. 16, 1986.
- "The Effect of Aromatics Content on Nox Emissions" by Annette Reid Guerrero and James M. Lyons, Toxics and Fuels Section, Mobile Source Division, California Air Resources Board, Mar., 1990.
- "The Effect of Gasoline Aromatics on Emissions of Nitrogen Oxide in Vehicle Exhaust", by J. A. Gething, Chevron Research and Technology Company, Richmond, CA, Apr. 19, 1990.
- "Reformulated Gas No Help in Older Cars" by Matthew L. Wald, The New York Times, appearing in Orange County Register, Dec. 19, 1990.
- "Clean Gasoline" ARCA EC-1 Gasoline.
- "Nationwide Gasoline Compositions" (MVMA and SWRI Surveys, 1988).
- "Reformulated Gasoline" Industry Scoreboard.
- "Regular Compositions" Average Results for 9 RVP Season.
- "Premium Compositions" Average Results for 9 RVP Season.
- "The Talbert Information Package" by Talbert Fuel Systems, Inc., dated Dec. 3, 1990.
- "A Study of Factors Influencing the Evaporative Emissions From In-Use Automobiles," API Publication No. 4406, Apr., 1985, American Petroleum Institute.
- "The Effect of Fuel Volatility Variations on Evaporative and Exhaust Emissions," API Publication 4310, May, 1979, Prepared for the American Petroleum Institute by Exxon Research and Engineering Company.
- NIPER-143-PPS-86/1, "Motor Gasolines, Summer 1985," by C. L. Dickson et al., Work performed by the American Petroleum Institute and the U. S. Department of Energy, National Institute for Petroleum and Energy Research, Bartlesville, Oklahoma, Jun. 1986.
- "Petroleum Refinery Engineering," by W. L. Nelson, Fourth Edition, McGraw Hill Book Company, Inc., 1958, pp. 34 and 138.
- "Future Automotive Fuels," by Ellis, Automotive Engineering, Jun. 1972, pp. 36-41.
- BERC/RI-76/15, "Experimental Results Using Methanol and Methanol/Gasoline Blends as Automotive Engine Fuel," by J. R. Allsup, Published by Bartlesville Energy Research Center, Energy Research and Development Administration, Bartlesville, Oklahoma Jan. 1977, pp. 1-7.
- HESD Report No. 35-32030, "Emissions and Vehicle Performance with Lower RVP Fuels," prepared for American Petroleum Institute by Automotive Testing Laboratories, Inc., Jan. 1988.
- Report of Investigations 7291, "Influence of Volatile Fuel Components on Vehicle Emissions," by B. H. Eccleston et al., United States Department of the Interior, Bureau of Mines, 1970.
- "NPC: U. S. Refiners Near Top Gasoline Capacity," Oil & Gas Journal, Oct. 13, 1986, p. 30.
- Pp. 47-50 from the Oil & Gas Journal, Jun. 18, 1990.
- "Motor Fuels, Performance and Testing," William A. Gruse, Reinhold Publishing Corp., 1967, p. 104.
- "A New Approach to Blending Octanes," Proceedings American Petroleum Institute, Section III-Refining, New York, NY, vol. 39, Healy, Jr., et al. (1959), pp. 132-192.
- "Carbon Monoxide Linked to Heart Failure in Elderly," The Orange County Register, Oct. 10, 1995, one page.
- Morton Lippmann, "Health Effects of Ozone: A Critical Review," The Journal of the Air & Waste Management Association, vol. 39, No. 5, May 1989, pp. 672-695.
- "Health Effects of Ozone: Critical Review Discussion Papers," The Journal of the Air & Waste Management Association, vol. 39, No. 9, Sep. 1989, pp. 1185-1194.
- F. L. Potter, "Clean Air Act History Marked by Battle, Compromise," Fuel Reformulation, vol. 1, No. 1, Sep./Oct. 1991, pp. 22-25.
- J. E. Peeples, "A Brave New World for Fuel Reformulation," Fuel Reformulation, vol. 1, No. 1, Sep./Oct. 1991, pp. 27-31.
- D. R. Lawson, P. J. Groblicki, D. H. Stedman, G. A. Bishop and P. L. Guenther, "Emissions from In-Use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program," The Journal of the Air & Waste Management Association, vol. 40, No. 8, Aug. 1990, pp. 1096-1105.
- B. H. Eccleston and R. W. Hurn, "Comparative Emissions From Some Leaded and Prototype Lead-Free Automobile Fuels," United States Department of the Interior, Bureau of Mines, Report of Investigations 7390, 1970, pp. 1-24.
- R. K. Stone and B. H. Eccleston, "Vehicle Emissions vs. Fuel Composition," API-Bureau of Mines- Part II, 1969, pp. 651-690.
- "Motor-Fuel Composition and Photochemical Smog," API Publication 4247, Final Report (Part I), Apr. 1975.
- "Motor-Fuel Composition and Photochemical Smog," API Publication 4247, Reference Data Report (Part 2), Apr. 1975.
- "Gasoline Consumption by State, 1991," National Petroleum News, vol. 84, No. 7, Mid-Jun. 1992, p. 94.
- Brown, J. E., Greenlee, K. W., Tindall, E. M., "Octane Numbers of Pure Hydrocarbon Blends and Their Relationship to Precombustion Reactions," American Petroleum Institute's Division of Refining, vol. 42, [III] (1962).
- Knaus, J. A., Lockerbie, T. E., Buerstetta, F. D., and Warren, T. W., "Road Octane Improvement-A Basis For Process Evaluation," presented at the Thirteenth Southwest Regional Meeting of the American Chemical Society, Tulsa, Oklahoma, Dec. 5-7, 1957.
- Anglo-Iranian Oil Co., Ltd. Et al., "High-Octane Aviation Fuel by the Sulfuric-Acid Alkylation Process," presented at the Twentieth Annual Meeting of the American Petroleum Institute in Chicago, Illinois, Nov. 9-17, 1939.
- Mulac, J. C., McCafferty, R. L., and Meyer, W.A.P., "Carburetor Evaporation Losses-Volatility and Reactivity," presented at the 31st Mid-Year Meeting of the American Petroleum Institute's Division of Refining, Houston, Texas, May 11, 1966.
- Zwicker, S. L., "Vapor Emission Controls," National Petroleum Refiners Association, FL-85-89. Presented at the 1985 Fuels & Lubricants Meeting, Houston, Texas, Nov. 7-8, 1985.
- Duffy, L. J., Everett, N. R., Sevcik, J. J., and Piehle, F. J., "Keeping The Lead Out of Unleaded Gasolines," Proceedings of the American Petroleum Institute's Division of Refining, 1972. Presented at the 37th Mid-Year Meeting of the American Petroleum Institute's Division of Refining, New York, New York, May 8-11, 1972.
- "New Gas for Older Cars Will Cut Air Pollution," Chemical & Engineering News, Aug. 21, 1989, p. 8.
- "Effect of Automotive Emission Requirements on Gasoline Characteristics," ASTM STP 487, pp. 1-31, 1970.

- CRC 434, "Octane Number Requirement Survey," Sep. 1970, cover page, title page and pp. 4-5 and 75-78.
- CRC Report No. 445, "Influence of Leaded and Unleaded Fuels on Octane Requirement Increase in 1971 Model Cars," 20 Car Pilot Program at Southwest Research Institute, Mar. 1971, pp. 1 to 7, 17, 81-84, & 86.
- CRC Report No. 451, "Influence of Leaded and Unleaded Fuels on Octane Requirement Increase in 1971 Model Cars, Phase 1: 1970-1971 CRC Road Rating Program," May 1972, Revised Sep. 1972, pp. 6, 7, 19, 96 to 98, 102 & 103.
- CRC Report No. 455, "Evaluation of a High Temperature Driveability Test Procedure," Jun. 1973 pp. 1-3, 8-10, 39 & 40.
- CRC 464, "Octane Number Requirement Survey 1972," Sep. 1973, cover page, title page and pp. 6 and 86-92.
- CRC Report No. 467, "Octane Number Requirement Survey 1973," May 1974, pp. 1-4, 6, 75, 76, 96, 97, & Table C-1.
- CRC Report No. 476, "Octane Requirement Increase in 1973 Model Cars, Phase II: 1973 CRC Road Rating Program," Feb. 1975, pp. 1-4, 45, 46, 48, & 49.
- CRC Report No. 479, "Octane Number Requirement Survey 1974," Aug. 1975, pp. 1-4, 6, 67, 68, 69a, 85 & 85a.
- CRC 486, "Driveability Performance of 1975 Passenger Cars at Intermediate Ambient Temperatures-Paso Robles," May 1976, cover page, title page and pp. 5-6 and 20-21.
- CRC Report No. 488, "1975 CRC Octane Number Requirement Survey," Aug. 1976.
- CRC Report No. 497, "1977 CRC Octane Number Requirement Survey," Jun. 1978, pp. 1-5, 117, 118 & 143.
- CRC Report No. 500, "1977 CRC Altitude Program," Feb. 1979, pp. 1-3, 76 & 77.
- CRC Report No. 510, 1978 Fuel Rating Program: Road Octane Performance in 1978 Model Cars, Aug. 1979, pp. 1-3, 17, & 18.
- CRC Report No. 515, "1979 CRC Octane Number Requirement Survey," Apr. 1980, pp. 1-5, C2-C5, D5, and D6.
- CRC Report No. 519, "1980 CRC Octane Number Requirement Survey," Jan. 1981, pp. 1-6, C3-C5, D5, and D6.
- CRC Report No. 520, "1980 CRC Fuel Rating Program: Road Octane Performance in 1980 Model Cars," Jul. 1981, pp. 1-3, 17-19, B-6, & B-9.
- CRC Report No. 523, "1981 CRC Altitude Octane Requirement Program," Dec. 1981, pp. 1-4, and D1-D4.
- CRC Report No. 525, "1981 CRC Octane Number Requirement Survey," Aug. 1982, pp. 1-7, C1, C4, D2, D3, and D6.
- CRC Report No. 533, "1982 CRC Octane Number Requirement Survey," Jul. 1983, pp. 1-7, C1, C4, D4, D5, and D8.
- CRC Report No. 539, "1983 CRC Octane Number Requirement Survey," Aug. 1983, pp. i, 3, 7-11, 19, C1, C4, D4, D5, and D8.
- CRC Report No. 541, "1982 CRC Fuel Rating Program: Road Octane Performance of Oxygenates in 1982 Model Cars," Jul. 1985, pp. 1-4, and 13-15.
- CRC Report No. 544, "1984 CRC Octane Number Requirement Survey," Dec. 1983, the Abstract page, and pp. 3, 4, 7-11, 19, C1, C4, D7 and D10.
- CRC Report No. 548, "1985 CRC Octane Number Requirement Survey," Oct. 1986, pp. i, 1-6, C1, C3, D5, & D8.
- CRC Report No. 553, "1986 CRC Octane Number Requirement Survey," Aug. 1987, pp. i, 1-4, 6, C1, C3, D5, & D8.
- CRC Report No. 561, "1987 CRC Octane Number Requirement Survey," Aug. 1988, pp. i, 1-7, C1, C3, & D8.
- CRC Report No. 563, "1987 CRC Octane Number Requirement Rating Workshop," Sep. 1988, pp. I, 1-4, 7, & 8.
- CRC Report No. 566, "1988 CRC Octane Number Requirement Survey," Aug. 1989, pp. i, 1-4, 6, 7, C1, C3, D3, D6, and D7.
- CRC Report No. 567, "1989 CRC Octane Number Requirement Rating Workshop," Oct. 1989, pp. 1-7.
- CRC Report No. 570, "1989 CRC Octane Number Requirement Survey," Aug. 1990, the Abstract page, and pp. 1-5, 7, 8, D3, D6, D7, Table C-1, and Table C-3.
- CRC Report No. 575, "1990 CRC Octane Number Requirement Survey," Jul. 1991, pp. i, 1-3, 5, 6, C1, C3, D7, D10, and D11.
- CRC Report No. 578, "Effect of Volatility and Oxygenates on Driveability at Intermediate Ambient Temperatures," Mar. 1992.
- CRC Project No. CM-79-71, "Analysis of 1971 Road Rating Data: Unleaded Gasolines in 1971 Cars, Phase II: 1970-71 CRC Road Rating Program," Coordinating Research Council, Inc., Jun., 1973.
- "Initial Findings of the 1989 CRC Cold-Start and Warm-Up Driveability Program," Yakima, Washington, CRC Project No. CM-118-89, Jun. 1990, with cover letter dated Jun. 13, 1990, by Beth Evans, Technical Project Coordinator to the Members of the CRC-Automotive Committee and the CRC-Volatility Group, Jun. 13, 1990.
- CRC Project No. CM-118-86/87, "CRC Low- and Intermediate-Temperature Driveability Program Using Gasoline Alcohol Blends," Prepared by the Analysis Panel for the 1986/87 CRC Intermediate- and Low-Temperature Driveability Program, Jan. 1990, p. 22 (Table III), and B-7.
- CRC Project No. CM-125-78, "Performance Evaluation of Alcohol-Gasoline Blends in 1980 Model Automobiles," Jul. 1982, p. C-13.
- Letter from Coordinating Research Council signed by Beth Evans, dated May 19, 1989, addressed to Unocal Corporation (four pages).
- Letter from Coordinating Research Council signed by Beth Evans, dated Nov. 21, 1988, addressed to Members of the CRC Automotive Committee with an attachment entitled "1989 CRC Program on the Effect of Volatility on Driveability at Intermediate Ambient Temperatures" (Nov. 1988).
- Letter from Alan Zengel to the Members of the CRC Volatility Group, dated Dec. 20, 1988, with attachment letter from Joseph Colucci to Alan Zengel dated Dec. 12, 1988. One page memo from E. H. Schanerberger of Ford Motor to Beth Evans of CRC, dated Jan. 11, 1989.
- Cover letter from Beth Evans to the Members of the CRC Volatility Group dated Feb. 7, 1989, with a four page letter attachment from Scott Jorgensen to Alan Zengel.
- Two page letter from A. M. Horowitz to Shirley Bradich dated Mar. 7, 1989 and entitled "Automotive Vehicle Fuel, Lubricant and Equipment Committee".
- Internal, three page Unocal corporate memorandum by Tim Wusz to Gerald Wessler dated Mar. 28, 1988 (apparently misdated, sic Mar. 28, 1989).
- Letter from R. M. Reuter of Texaco, Inc., dated Mar. 29, 1990 addressed to Participants in the 1989 CRC Driveability Program-Yakima.
- "Unconfirmed Minutes of the Meeting of the Volatility Group of the Automotive Vehicle Fuel, Lubricant, and Equipment Research Committee" for CRC Project No. CM-118-90, dated Oct. 23, 1990.
- "Unconfirmed Minutes of the Meeting of the Volatility Group of the Automotive Vehicle Fuel, Lubricant, and Equipment Research Committee" for CRC Project No. CM-118-91, dated Oct. 9, 1991.

- "Effect of Volatility on Driveability at Intermediate Ambient Temperatures," (CRC Project No. CM-118-89) (Not to be published), prepared by the CRC Volatility Group of Coordinating Research Council, dated Jan. 1992.
- "Released Reports," Jan. 1994, Coordinating Research Council, Inc., Atlanta, Ga.
- "Carburetor Evaporation Losses," by Wentworth, SAE Paper No. 12B presented Jan. 1958 at the SAE Annual meeting (pp. 146-156) in Vehicle Emissions, Society of Automotive engineers, Technical Progress Series, vol. 6, 1964.
- Davis, H. P., Uyehara, O. A., and Myers, P. S., "The Effects of Knock On The Hydrocarbon Emissions Of A Spark-Ignition Engine," SAE Technical Paper Series, 690085, International Automotive Engineering Congress, Detroit, Michigan, Jan. 13-17, 1969.
- Nelson, E. E., "Hydrocarbon Control For Los Angeles By Reducing Gasoline Volatility," SAE Technical Paper Series, 690087, International Automotive Engineering Congress, Detroit, Michigan, Jan. 13-17, 1969.
- Duke, L. C., Lestz, S. S., and Meyer, W. E., "The Relation Between Knock and Exhaust Emissions Of A Spark Ignition Engine," SAE Technical Paper Series, 700062, Automotive Engineering Congress, Detroit, Michigan, Jan. 12-16, 1970.
- McKinney, C. M. and Blade, O. C., "Bureau of Mines-API Survey of Aviation Gasolines, 1969," SAE Technical Paper Series, 700228, National Business Aircraft Meeting, Wichita, Kansas, Mar. 18-20, 1970.
- Carr, R. C., Starkman, E. S., and Sawyer, R. F., "The Influence of Fuel Composition on Emissions of Carbon Monoxide and Oxides of Nitrogen," SAE Technical Paper Series, 700470, Mid-Year Meeting, Detroit, Michigan, May 18-22, 1970.
- Fleming, R. D., Eccleston, D. G., "The Effect of Fuel Composition, Equivalence Ratio, and Mixture Temperature on Exhaust Emissions," SAE Technical Paper Series, 710012, Automotive Engineering Congress, Detroit, Michigan, Jan. 11-15, 1971.
- SAE Paper No. 710136, "The Effect of Gasoline Volatility on Emissions and Driveability," by P. J. Clarke, 1971.
- SAE Paper No. 710138, "Passenger Car Driveability in Cool Weather," by J. D. Benson et al., 1971.
- SAE 710295, "Effect of Fuel and Lubricant Additives on Exhaust Emissions," Mixon et al., Inter-Industry Emission Control, SP-361, Jan. 11-15, 1971, coversheet, pp. 1207-1220.
- SAE Paper No. 710364, "Effects of Fuel Factors on Emissions," by S. S. Sorem, 1971.
- SAE Paper No. 710675, "Octane Requirement Increase in 1971 Model Cars with Leaded and Unleaded Gasolines," by H. A. Bigley, Jr. et al., 1971.
- SAE Paper No. 720700, "Mathematical Expressions Relating Evaporative Emissions from Motor Vehicles Without Evaporative Loss-Control Devices to Gasoline Volatility," by W. F. Biller et al., 1972.
- SAE Paper No. 720932, "The Effect of Gasoline Volatility on Exhaust Emissions," by P. J. Clarke, 1972.
- SAE Paper No. 720933, "Driveability Testing on a Chassis Dynamometer," by R. J. Wahrenbock et al., 1972.
- SAE Paper No. 730474, "An Evaluation of the Performance and Emissions of a CRF Engine Equipped with a Prechamber," by D. B. Wimmer et al., 1973.
- SAE Paper No. 730593, "Fuel Effects on Oxidation Catalysts and Catalyst-Equipped Vehicles," by A. H. Neal et al., 1973.
- SAE Paper No. 730616, Gasolines for Low-Emission Vehicles, by J. C. Ellis, 1973.
- SAE Paper No. 740520, "Cold Weather Driveability Performance of Late Model Cars," by A. M. Horowitz et al., 1974.
- SAE Paper No. 740694, "Fuels and Emissions-Update and Outlook, 1974," by R. W. Hurn et al., 1974.
- SAE Paper No. 750120, "Exhaust Emissions, Fuel Economy, and Driveability of Vehicles Fueled with Alcohol-Gasoline Blends," by N. D. Brinkman et al., 1975.
- SAE Paper No. 750419, "Methanol-Gasoline Blends Performance in Laboratory Tests and in Vehicles," by A. W. Crowley et al., 1975.
- SAE Paper No. 750451, "Establishment of OR1 Characteristics as a Function of Selected Fuels and Engine Families," by H. T. Niles et al., 1975.
- SAE Paper No. 750763, "Methanol/Gasoline Blends as Automotive Fuel," by J. R. Allsup, 1975.
- SAE Paper No. 750937, "Octane Number Increase of Military Vehicles Operating on Unleaded Gasoline," by J. D. Tosh et al., 1975.
- SAE 780588, "The Inter-Industry Emission Control Program-Eleven Years of Progress in Automotive Emissions and Fuel Economy Research," McCabe et al., pp. 1-7 (entire document).
- SAE Paper No. 780611, "Fuel Volatility Effects on Driveability of Vehicles Equipped with Current and Advanced Fuel Management Systems," by C. R. Morgan et al., 1978.
- SAE Paper No. 780651, "Hot Weather Volatility Requirements of European Passenger Cars," by R. F. Becker et al., 1978.
- SAE Paper No. 780653, "The Hot-Fuel Handling Performance of European and Japanese Cars," by B. D. Caddock et al., 1978.
- SAE Paper No. 780949, "The Effects of Refinery Gasoline Components on Road Octane Quality," by R. E. Burtner et al., International Fuels & Lubricants Meeting, Royal York, Toronto, Nov. 13-16, 1978.
- SAE Paper No. 790203, "The Effects of Fuel Composition and Fuel Additives on Intake System Detergency of Japanese Automobile Engine," by T. Nishizaki et al., 1979.
- SAE Paper No. 801352, "Evaluation of MTBE Gasoline by Japanese Passenger Cars," by Shintaro Miyawaki et al., 1980.
- SAE Paper No. 821211, "1980 CRC Fuel Rating Program—The Effects of Heavy Aromatics and Ethanol on Gasoline Road Octane Ratings," by M. J. Gorham et al., 1982.
- SAE Paper No. 830937, "Gasoline Volatility and Hot Weather Driveability of Japanese Cars," by E. Yoshida et al., 1983.
- SAE Paper No. 841386, "Hot and Cold Fuel Volatility Indexes of French Cars: A Cooperative Study of the GFC Volatility Group," by Le Breton et al., 1984.
- SAE Paper No. 852132, "Gasoline Vapor Pressure Reduction—an Option for Cleaner Air," by R. F. Stebar et al., 1985.
- Pendleton, P. O., "Automotive Gasoline Usage in Reciprocating Aircraft Engines," SAE Technical Paper Series, 871012, General Aviation Aircraft Meeting and Exposition, Wichita, Kansas, Apr. 28-30, 1987.
- SAE Paper No. 872111, "An Engine Dynamometer Test for Evaluating Port Fuel Injector Plugging," by F. Caracciolo et al., 1987.

- Croudace, M. C. and Jessup, P. J., "Studies of Octane Properties of Mixtures of Isomeric Hexanes," SAE Technical Paper Series, 881604, International Fuels and Lubricants Meeting and Exposition, Portland, Oregon, Oct. 10-13, 1988.
- "Are the Reductions in Vehicle Carbon Monoxide Exhaust Emissions Proportional to the Fuel Oxygen Content?" by J. A. Gething, J. S. Weistand, and J. C. Horn, SAE Technical Paper Series, 890216, AE International Congress and Exposition, Detroit, Michigan, Feb. 17-Mar. 3, 1989.
- "How Injector, Engine, and Fuel Variables Impact Smoke and Hydrocarbon Emissions with Port Fuel Injection" by Ather A. Quader, SAE Technical Paper Series, 890623 SAE International Congress and Exposition, Detroit, Michigan, Feb. 27-Mar. 3, 1989.
- W. F. Marshall and M. D. Gurney, "Effect of Gasoline Composition on Emissions of Aromatic Hydrocarbons," SAE Technical Paper Series, 892076, International Fuels and Lubricants Meeting and Exposition, Baltimore, Maryland, Sep. 25-28, 1989, pp. 1-10.
- SAE Paper No. 892090, "Changes in Reid Vapor Pressure of Gasoline in Vehicle Tanks as the Gasoline is Used," by A. D. Brownlow et al., 1989.
- "Engine Bench Evaluation of Gasoline Composition Effect on Pollutants Conversion Rate by a Three-Way Catalyst" by Michel F. Prigent, Brigitte C. Martin and Jean-Claude Guibet, SAE Technical Paper Serial, 900153, SAE International Congress and Exposition, Detroit, Michigan, Feb. 26-Mar. 2, 1990.
- "Effect on Gasoline Quality on Throttle Response of Engines During Warm-up" by Minoru Tomita, Masanori Okada, Haruyuki Katayama and Mashaiko Nakada, SAE Technical Paper Series, 900163, SAE International Congress and Exposition, Detroit, Michigan, Feb. 26-Mar. 2, 1990.
- SAE Paper No. 901114, "Volatility Characteristics of Blends of Gasoline with Ethyl Tertiary-Butyl Ether (ETBE)," by R. L. Furey, Government/Industry Meeting and Exposition Washington, D. C. May 1-4, 1990.
- "The Effect of Gasoline Aromatics Content on Exhaust Emissions: A Cooperative Test Program" by Jeff A. Gething, S. Kent Hoekman, SAE Technical Paper Series, 902073, International Fuels and Lubricants Meeting and Exposition, Tulsa, Oklahoma, Oct. 22-25, 1990.
- SAE 902094, "Effects of Gasoline Composition on Exhaust Emissions and Driveability," Hoshi et al., dated Oct. 22-25, 1990.
- R. H. Pahl and M. J. McNally, "Fuel Blending and Analysis for the Auto/Oil Air Quality Improvement Research Program," SAE Technical Paper Series, 902098, International Fuels and Lubricants Meeting and Exposition, Tulsa, Oklahoma, Oct. 22-25, 1990, pp. 1-11.
- SAE Paper No. 902129, "The Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions, Part II," by F. D. Stump et al., 1990.
- SAE Paper No. 902132, "Use of Ethyl-t-Butyl Ether (ETBE) as a Gasoline Blending Component," C. M. Shblom et al., 1990.
- "Distillation Adjustment: An Innovative Step to Gasoline Reformulation" by Jeff A. Gething, SAE Technical Paper 910382, 1991 SAE International Congress and Exposition, Detroit, Michigan, Feb. 25-Mar. 1, 1991.
- W. J. Koehl, J. D. Benson, V. Burns, R. A. Gorse, A. M. Hochhauser, and R. M. Reuter, "Effects of Gasoline Composition and Properties on Vehicle Emissions: A Review of Prior Studies-Auto/Oil Air Quality Improvement Research Program," SAE Technical Paper Series, 912321, International Fuels and Lubricants Meeting and Exposition, Toronto, Canada, Oct. 7-10, 1991, pp. 1-33.
- "An Overview of Unocal's Low Emission Gasoline Research Program" by P. J. Jessup et al., SAE 920801, Feb. 24-28, 1992.
- "California Sets Tough Auto Standards" by Jananne Sharpless in Fuel Reformulation published Nov./Dec. 1991, pp. 8-10.
- "Proposed Regulations for Low-Emission Vehicles and Clean Fuels", Staff Report, State of California Air Resources Board, Aug. 13, 1990.
- "Development of Ozone Reactivity Scales for Volatile Organic Compounds," William P. L. Carter, Statewide Air Pollution Research Center, APA Contract CR-814396-01-0, Apr., 1990, University of California, Riverside, CA 92521.
- "Southland Smog: Causes and Effects," the South Coast Air Quality Management District, two pages.
- Testimony, Dr. Robert Zweig, Meeting of California Air Resources Board, Nov. 21, 1991, Transcript pp. i, ii, 129-134 and 353.
- "Air Quality Designations and Classifications: Final Rule," Environmental Protection Agency, Federal Register, vol. 56, No. 215, Nov. 6, 1991, pp. 56695-56858.
- "1994 Air Quality," South Coast Air Quality Management District, two pages.
- "Reformulated Gasoline: Proposed Phase 1 Specifications," Technical Support Document, California Air Resources Board, Aug. 13, 1990.
- 40 CFR Part 86, Subpart B, "Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks: Test Procedures".
- Is Reformulated Gasoline A 'New' Gasoline, EPA-Office of Mobile Sources, Technical Overview, EPA 420-F-95, Apr. 1995.
- "CARB Says Phase 2 RFG Reduces Cancer Risk by 30%-40%," Octane Week, Sep. 18, 1995, p. 8.
- "Status of State Actions Regarding Ozone Nonattainment Areas: Likely Motor Fuels Options to be Submitted in State Implementation Programs," Octane Week, Nov. 8, 1993, pp. 7-8.
- Octane Week*, Special NPRA Convention Edition, Week of Mar. 26, 1990, vol. IV, No. 44, pp. 1-14.
- "EPA Administrator Points to Reformulated Fuels for Clean Air," Octane Week, vol. V, No. 6, Jun. 18, 1990, pp. 1 and 8.
- "Clean Air Act Now Law; Refiners Busy Responding," Octane Week, vol. V, No. 27, Nov. 19, 1990, pp. 1, 4, and 6.
- "API: Industry 'Committed,' But Emissions Data Lacking," Octane Week, vol. V, No. 25, Nov. 5, 1990, pp. 1, 7, and 8.
- "Phase II of Auto/Oil Will Include CNG, 'M100'," Octane Week, vol. V, No. 27, Nov. 19, 1990, pp. 1 and 3.
- "Initial Mass Exhaust Emissions Results from Reformulated Gasolines," Auto/Oil Air Quality Improvement Research Program, Dec. 1990.
- Progress Report to RPC, Data Analysis and Report Writing Subcommittee, A. M. Hochhauser, Jul. 26, 1990 (8 pages).
- R. A. Corbett, "Auto/Oil Progressing Toward Cleaner Fuel Compositions," Fuel Reformulation, vol. 1, No. 1, Sep./Oct. 1991, pp. 46-50.

- J. J. Wise, "Auto/Oil Program-Data and Knowledge—Growing Rapidly," *Fuel Reformulation*, vol. 2, No. 3, May/ Jun. 1992, pp. 64-69.
- "Emissions from Methanol Fuels and Reformulated Gasoline in 1993 Production Flexible/Variable Fuel and Gasoline Vehicles," *Auto/Oil Air Quality Improvement Research Program*, Technical Bulletin No. 13, Aug. 1994.
- "Auto/Oil Group Set to Release First Batch of Test Data," *Octane Week*, vol. V, No. 31, Dec. 17, 1990, pp. 1 & 4.
- "The Role of MTBE in Future Gasoline Production" By William J. Piel, *Energy Progress* (vol. 8, No. 4), Dec. 1988, pp. 201-204.
- "MTBE-The Refiner's Key to Future Gasoline Production" by William J. Piel, National Petroleum Refiners Association, AM-88-66, 1988 Annual NPRAM Meeting, San Antonio, Texas, Mar. 20-22, 1988.
- W. J. Piel and R. X. Thomas, "Oxygenates for Reformulated Gasoline," *Hydrocarbon Processing*, Jul. 1990, pp. 68-73. Publication No. 05-179263, Gasoline, Laid Open Jul. 20, 1993, Japanese Application No. 03-358562 filed Dec. 27, 1991.
- Publication No. 03-263493, Lead-Free High-Octane Gasoline, Laid Open Nov. 22, 1991, Japanese Application No. 02-63537 filed Mar. 14, 1990.
- Publication No. 03-229796, Fuel Oil Composition, Laid Open Oct. 11, 1991, Japanese Application No. 02-24005 filed Feb. 2, 1990.
- Publication No. 01-234497, Lead-Free High-Octane Value Gasoline, Laid Open Sep. 19, 1989, Japanese Application No. 63-59587 filed Mar. 14, 1988.
- Publication No. 01-131299, Fuel Composition For Use In Gasoline Engine, Laid Open May 24, 1989, Japanese Application No. 63-247245 filed Sep. 29, 1988.
- Publication No. 01-9293, Clear Gasoline, Laid Open Jan. 12, 1989, Japanese Application No. 62-162966 filed Jun. 30, 1987.
- Publication No. 63-317593, Unleaded Regular Gasoline, Laid Open Dec. 26, 1988, Japanese Application No. 62-154189 filed Jun. 20, 1987.
- Publication No. 63-317592, Production of High-Powered Fuel Oil, Laid Open Dec. 26, 1988, Japanese Application No. 62-153837 filed Jun. 19, 1987.
- Publication No. 63-317591, High-Powered Fuel Oil, Laid Open Dec. 26, 1988, Japanese Application No. 62-153836 filed Jun. 19, 1987.
- Publication No. 63-317590, Unleaded and High-Octane Gasoline, Laid Open Dec. 26, 1988, Japanese Application No. 62-153026 filed Jun. 19, 1987.
- Publication No. 63-289094, Lead-Free, High-Octane Gasoline, Laid Open Nov. 25, 1988, Japanese Application No. 62-123129 filed May 20, 1987.
- Publication No. 61-176694, Gasoline Composition, Laid Open Aug. 8, 1986, Japanese Application No. 60-17120 filed Jan. 31, 1985.
- Publication No. 61-166884, Fuel Composition for Gasoline Engine, Laid Open Jul. 28, 1986, Japanese Application No. 61-14308 filed Jan. 24, 1986.
- Publication No. 61-16985, Manufacture of Unleaded Gasoline of High Octane Value, Laid Open Jan. 24, 1986, Japanese Application No. 59-137525 filed Jul. 3, 1984.
- Publication No. 61-16984, Manufacture of Gasoline Mainly From Hydrocarbon of Boiling Point Lower Than 220" C. Such as Petroleum Naphtha or Naphtha-Cracked Gasoline, Laid Open Jan. 24, 1986, Japanese Application No. 59-138668 filed Jul. 4, 1984.
- Publication No. 60-130684, Fuel Composition, Laid Open Jul. 12, 1985, Japanese Application No. 58-237881 filed Dec. 19, 1983.
- Fuel and Energy Abstracts*, May 1990, Oil Gas J., May 1989, 87 (20), 35-40.
- Fuel and Energy Abstracts*, May 1990, Pure Appl. Chem., 1989, 61, (8), 1373-1378.
- Fuel and Energy Abstracts*, Mar. 1990, Oil Gas J., Apr. 1989, 87, (16) 44-48.
- Fuel and Energy Abstracts*, Sep., 1989, *Chem. Aust.*, 1989, 56 (3), 77-79.
- Fuel and Energy Abstracts*, Sep., 1989, Erdoel, Erdgas, Kohle, 1988, 104, (9), 368-371, (In German).
- Fuel and Energy Abstracts*, Mar., 1989, *Erdoel Kohle, Erdas, Pertochem.*, Dec. 1988, 41, (12), 491, 496.
- Information Disclosure Statement No. 3, Sections D through G, from U. S. Patent Application Serial No. 081077,243, filed Jun. 14, 1993.
- "Aviation Fuels, 1969," *Mineral Industry Surveys*, Petroleum Products Survey No. 64, McKinney et al., Mar. 1970, title page, table of contents and pp. 5-6.
- "Aviation Fuels, 1964," *Mineral Industry Surveys*, Petroleum Products Survey No. 39, O. C. Blade, May 1965, title page, table of contents, and p. 12.
- "Aviation Fuels, 1983," (Niper 134) National Institute for Petroleum and Energy Research, Shelton et al., Bartlesville, OK, Apr. 1984, cover page, title page and pp. 5-7.
- All Cities SWRI Competitive Fuel Survey-Gasoline, Jul. 1985, p. 3.
- MVMA National Fuel Survey, Summer Season, Oct. 15, 1976.
- "Motor Gasolines, Summer 1971," *Mineral Industry Surveys*, Petroleum Products Survey No. 73, E. M. Shelton, Jan. 1972, cover page, table of contents and pp. 45, 47, 53 and 55-56.
- "Motor Gasolines, Winter 1970-1971," *Mineral Industry Surveys*, Petroleum Products Survey No. 70, Shelton et al., June 1971, cover page, table of contents and p. 44.
- "Motor Gasolines, Summer 1972," *Mineral Industry Surveys*, Petroleum Products Survey No. 78, E. M. Shelton, Jan. 1973, cover page, table of contents and pp. 46-48.
- "Test Gasoline Matrix" a two-page document with handwritten date of Jul. 17, 1990.
- "Effect of Gasoline Property on Exhaust Emissions and Driveability," Toyota Motor Corporation, Dated Oct. 1990, 19 pages.
- ASTM D 323 -89 "Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)".
- ASTM D-86-82 "Standard Method for Distillation of Petroleum Products".
- ASTM D 4814-89 "Standard Specification of Automotive Spark-Ignition Engine Fuel".
- Chevron Salt Lake City 80/87 Aviation Gasoline (Exhibits 9690 and 9690A in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).
- Zaghini, SAE 730836, "Polynuclear Aromatic Hydrocarbons in Vehicle Exhaust Gas" (1973) (Exhibit 6291 in Union Oil Co. of Calif. vs. ARCO et al., C.D. Ca, Case No. CV-95-2379 KMW (JRx)).
- Morris, "The Interaction Approach to Gasoline Blending" National Petroleum Refiners Association, AM-75-30, NPRA 73rd Annual meeting, San Antonio, Texas, Mar. 23-25, 1975 (Exhibit 890 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Nakajima et al., *SAE 780612*, "The Influence of Fuel Characteristics on the Vaporization in S.I. Engine Cylinder During Cranking at Low Temperature," 1978 (Exhibit 6406 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

File History of U.S. Patent 4,812,146, Jessup, "Liquid Fuels of High Octane Values," issued Mar. 4, 1998 (Exhibit 45 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Howell Unleaded Racing Gasoline (1988) (Exhibit 203 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

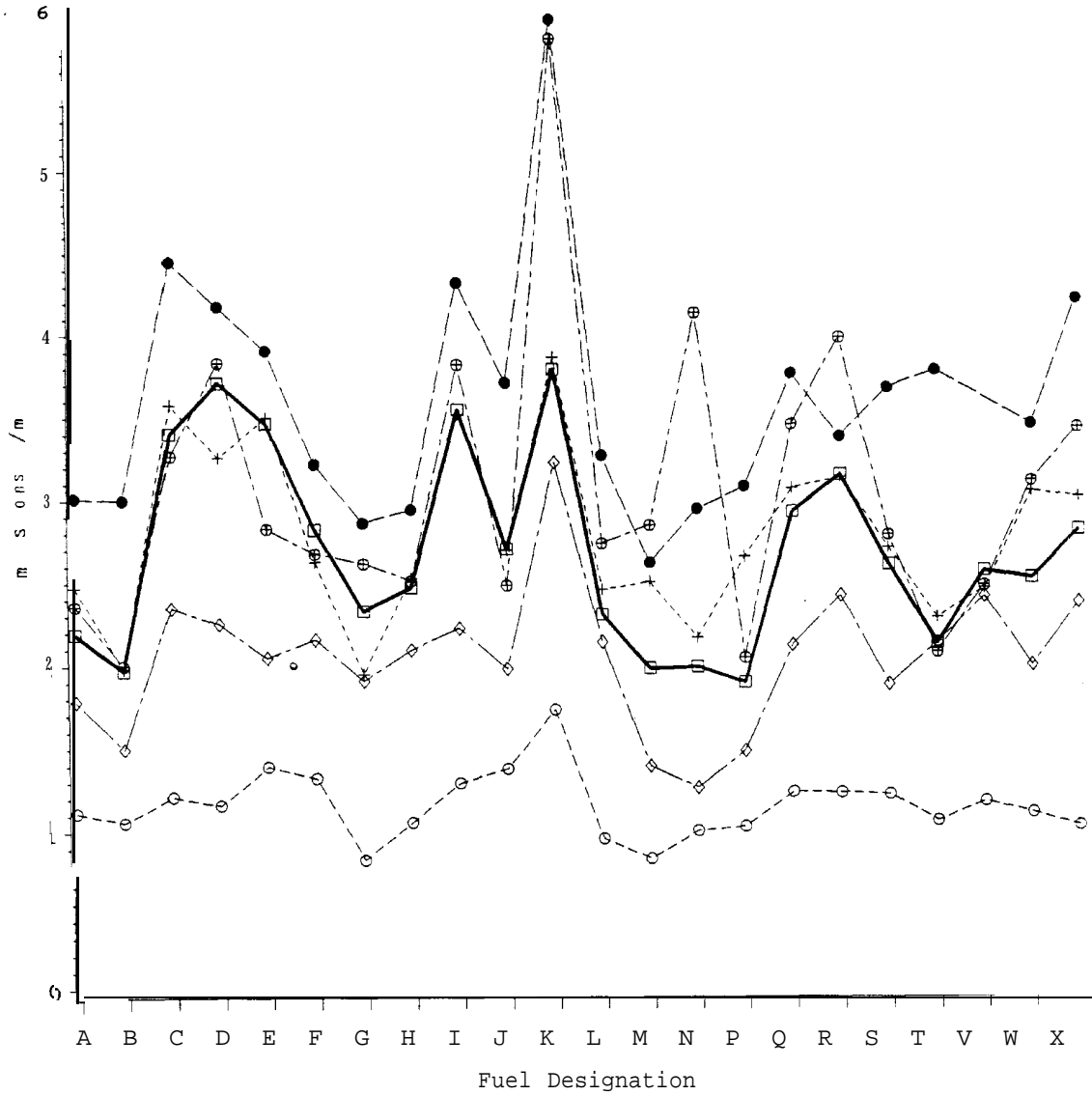
Union Oil Unleaded Racing Gasoline (ULRG) Charlotte (1988) (Exhibits 287 and 897 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Union Oil ULRG Powell-Duffryn (1989) (Exhibit 202 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Union Oil Aviation Gasoline No. 36 (1978) (Exhibit 8230 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

Oberfell et al. "Thermal Alkylation and Neohexane," presented at the Twentieth Annual meeting of the API, Chicago, Illinois, Nov. 9-17, 1939 (Exhibit 5014 in *Union Oil Co. of Calif. vs. ARCO et al.*, C.D. Ca, Case No. CV-95-2379 KMW (JRx)).

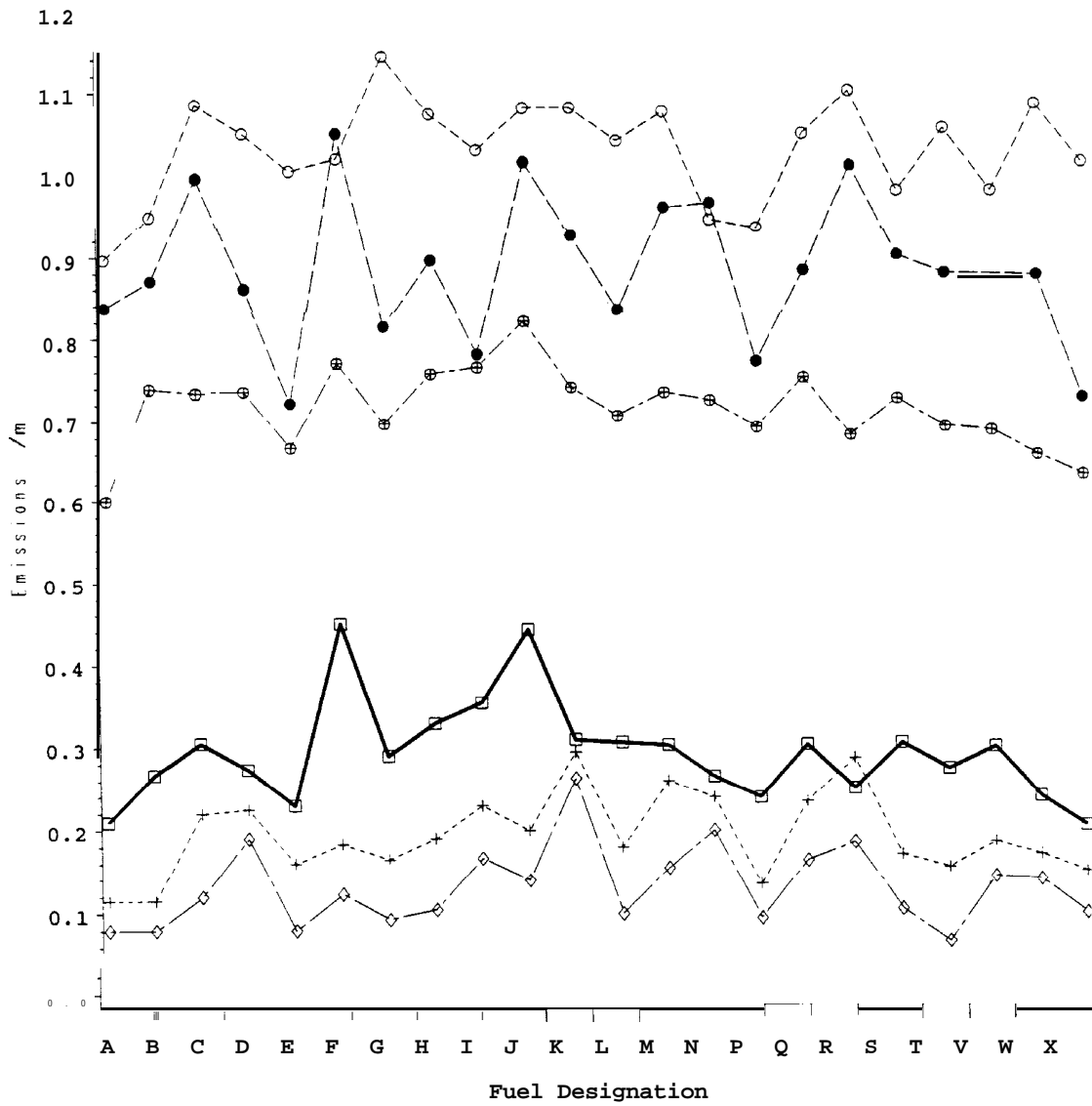
Figure 1
Emissions Test Data - CO



+ + + 1989 Calais □ □ □ 1988 Olds 98
○ ○ ○ 1990 Lincoln ... 1989 Taurus
⊕ ⊕ ⊕ 1990 Shadow ○ ○ ○ 1990 Camry

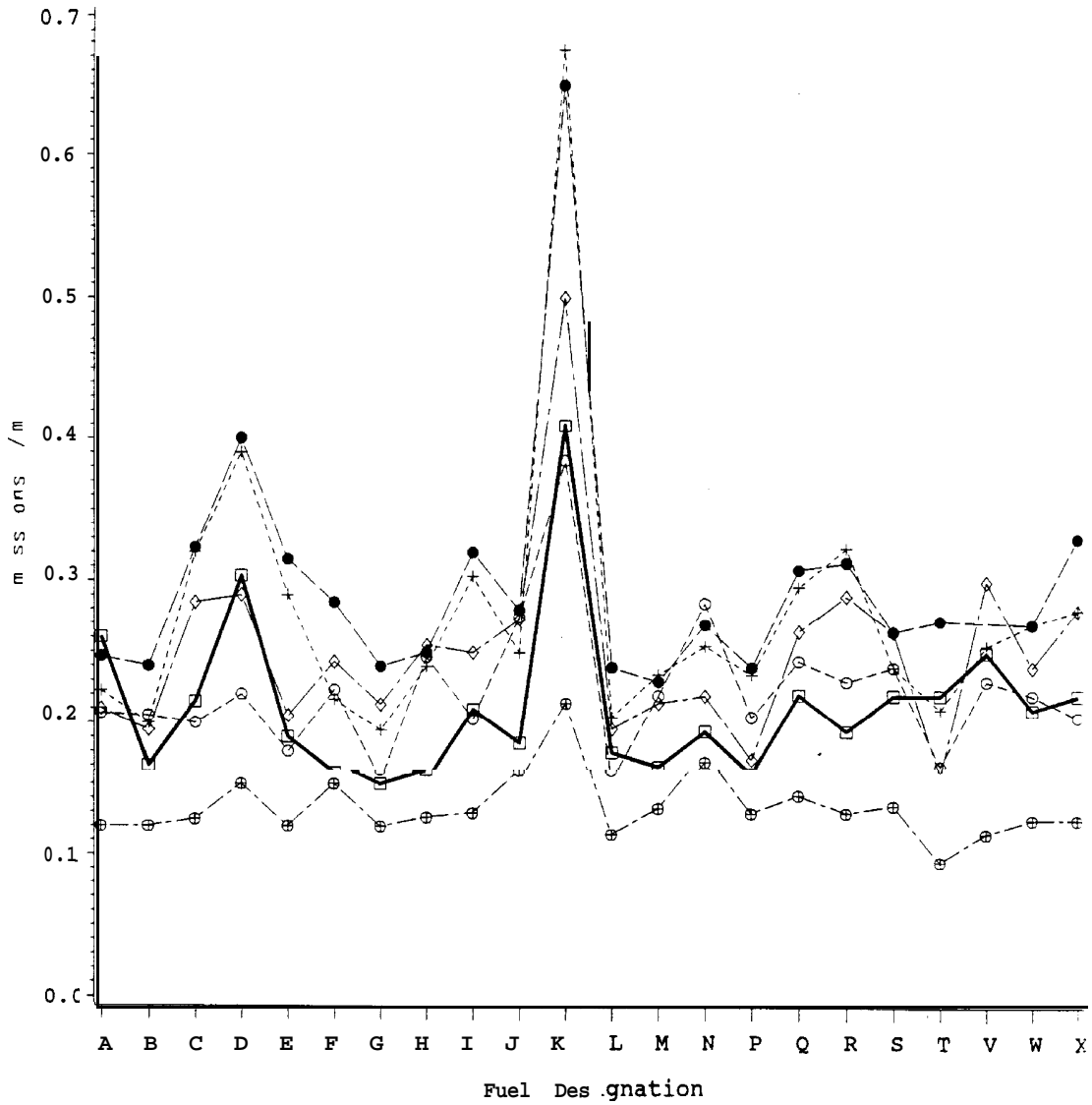
Figure 2

Emissions Test Data • NOX



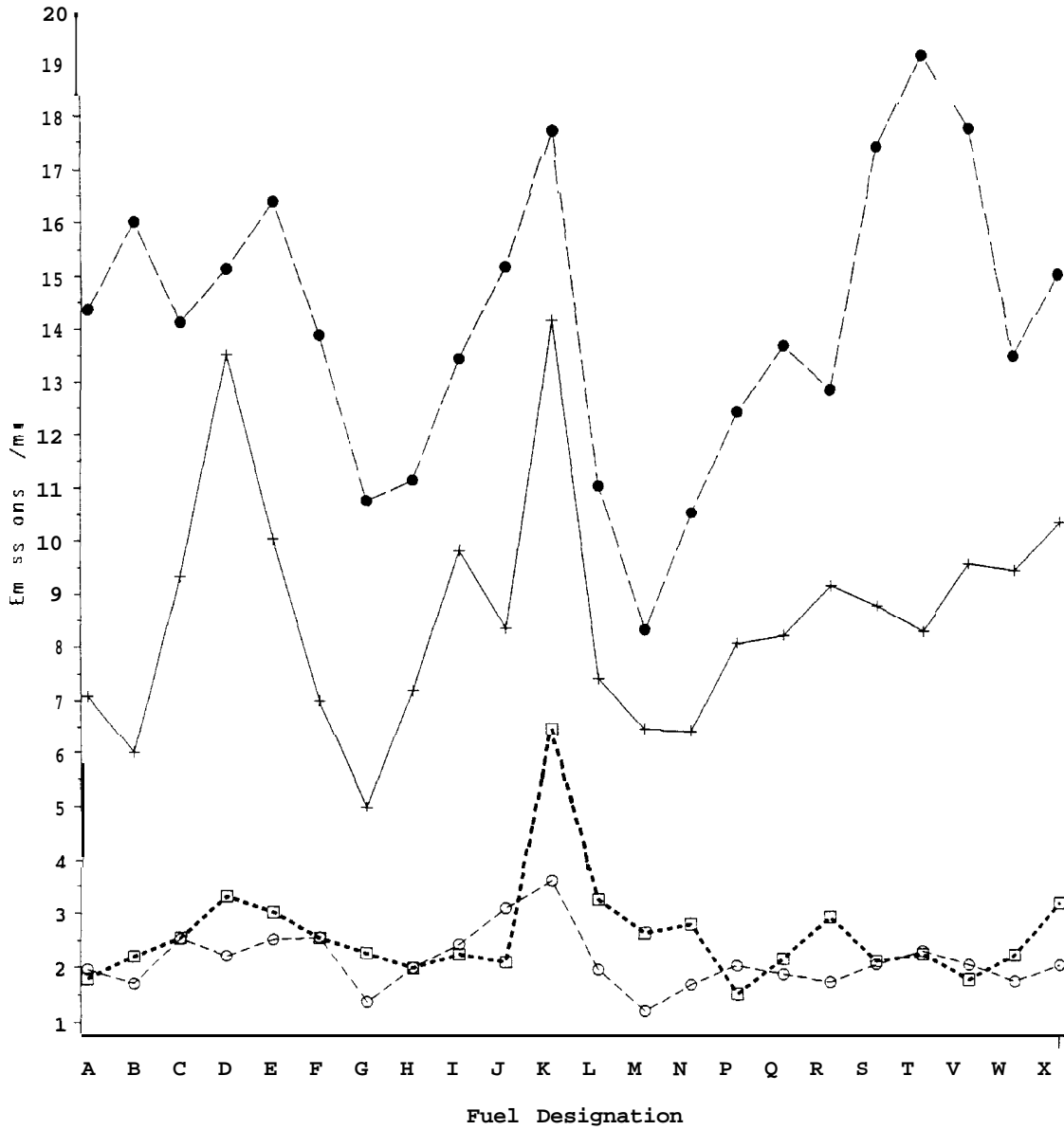
+ + + 1989 Calais □ □ □ 1988 Olds 98
 ○ ○ ○ 1990 Lincoln ... 1989 Taurus
 ⊕ ⊕ ⊕ 1990 Shadow ○ ○ ○ 1990 Camry

Figure 3
Emissions Test Data - HC



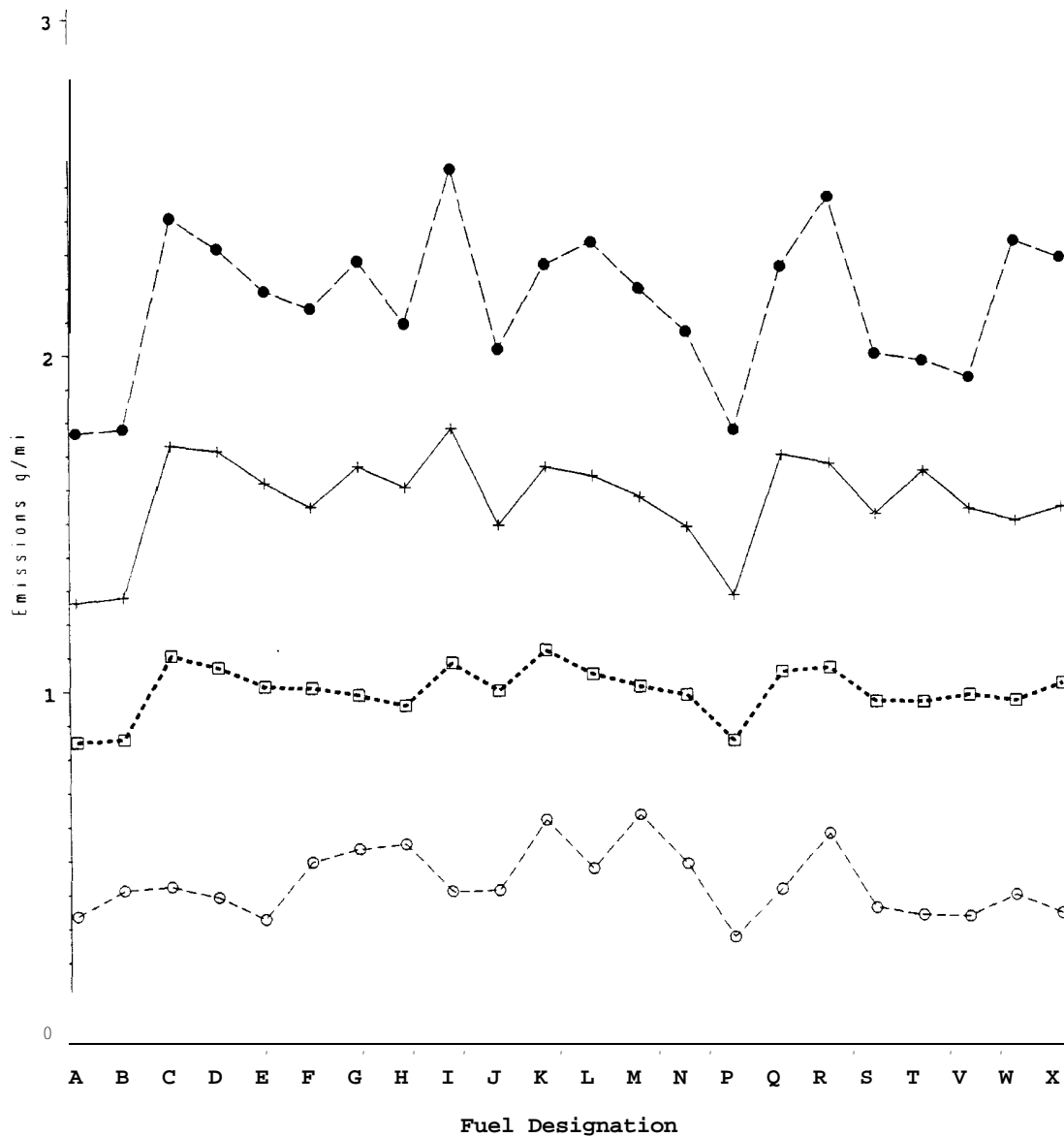
+++ 1989 Calais □□□ 1988 Olds 98
ooo 1990 Lincoln ... 1989 Taurus
⊕⊕⊕ 1990 Shadow ◇◇◇ 1990 Camry

Figure 4
Emissions Test Data - CO



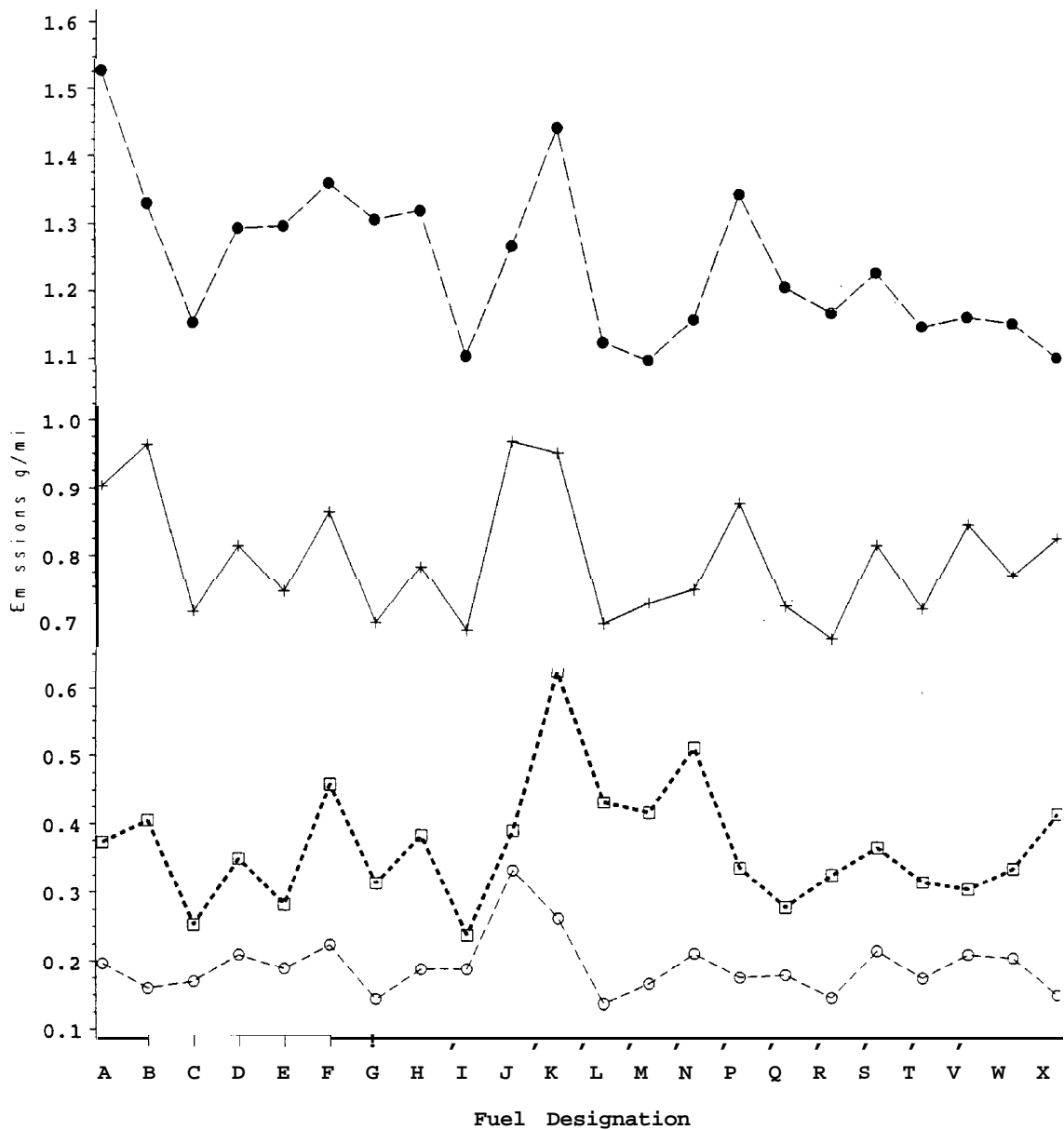
+++ 1995 Tempo □□□ 1994 Caprice
ooo 1988 Accord ... 1995 Suburban

Figure 5
Emissions Test Data - NOx



+++ 1995 Tempo □□□ 1994 Caprice
ooo 1999 Accord .-. 1995 Suburban

Figure 6
Emissions Test Data • HC



+ + + 1985 Tempo □ □ □ 1994 Caprice
 . . . 1999 Accord . . . 1995 Suburban

Figure 7
Individual Car Effects - CO

Car	Fuel Variable										R ²
	Arom	Olef	Para	MTBE	RON	MON	T10	T50	T90	RVP	
1989 Calais			-					+++			0.974
198 Oldsmobile 98			-					+			0.974
1985 Tempo			-					++			0.972
1990 Lincoln								+			0.971
1984 Caprice	-							+			0.926
1988 Accord								+			0.944
1989 Taurus								+			0.980
1990 Shadow			-					+	+		0.966
1985 Suburban			+					++	(-)		0.962
1990 Camry			-					++			0.968

Note: () indicates minor effects

Figure 8
Individual Car Effects - NOx

Car	FUEL VARIABLE											R ²
	Arom	Olef	Para	MTBF	RON	MON	T10	T50	T90	RVP		
1989 Calais		+	(-)				(+)				+++	0.973
1988 Oldsmobile 98		+					(+)				+++	0.965
1985 Tempo		+					(+)				+++ +	0.992
1990 Lincoln		+					+				+++ +++ +++ +	0.995
1984 Caprice		+					+				+++ +	0.994
1988 Accord		+	(-)				(+)				+++ +++ +++ +	0.978
1989 Taurus		+					(+)				+++ +	0.991
1990 Shadow		+					(+)				+++ +++ +	0.995
1985 Suburban		+					+				+++ +	0.990
1990 Camry		+					(+)					0.894

Note: (+) indicates minor effects

Figure 9
Individual Car Effects - HC

Car	Fuel Variable											R ²
	Arom	Olef	Para	MTBE	RON	MON	T10	T50	T90	RVP		
1989 Calais		++			--			+				0.967
1988 Oldsmobile 98					-			+				0.948
1985 Tempo	--							+				0.993
1990 Lincoln	-							+				0.961
1984 Caprice	--							+				0.952
1988 Accord	--							+				0.951
1989 Taurus		+			-			+				0.973
1990 Shadow	-							+				0.965
1985 Suburban	-							+				0.988
1990 Camry		++			-			+				0.977

GASOLINE FUEL

This application is a division of Ser. No. 904,594 filed Aug. 1, 1997, now U.S. Pat. No. 5837,126, which is a division of Ser. No. 464,554 filed Jun. 5, 1995, now U.S. Pat. No. 5,653,866, which is a continuation of Ser. No. 409,074 filed Mar. 22, 1995, now U.S. Pat. No. 5,593,567, which is a continuation of Ser. No. 077,243 filed Jun. 14, 1993, abandoned, which is a division of Ser. No. 628,488 filed Dec. 13, 1990, now U.S. Pat. No. 5,288,393.

The present invention relates to fuels, particularly gasoline fuels, and combustion methods therefor, and methods for preparing gasoline fuels which, upon combustion, minimize the release of CO, NO_x, and/or hydrocarbon emissions to the atmosphere.

One of the major environmental problems confronting the United States and other countries is atmospheric pollution (i.e., "smog") caused by the emission of gaseous pollutants in the exhaust gases from automobiles. This problem is especially acute in major metropolitan areas, such as Los Angeles, California, where the atmospheric conditions and the great number of automobiles account for aggravated air pollution.

It is well known that the three primary gaseous constituents, or pollutants, which contribute to air pollution due to auto exhaust are nitrogen oxides (NO_x), carbon monoxide (CO), and unburned or incompletely burned hydrocarbons (i.e., hydrocarbon components originally present in the gasoline fuel which are not fully converted to carbon monoxide or dioxide and water during combustion in the automobile engine).

SUMMARY OF THE INVENTION

The present invention provides gasoline fuels from which a relatively low amount of gaseous pollutants, and in particular one or more of NO_x, CO, and hydrocarbons, is produced during combustion in an automotive engine. The invention provides methods for producing gasoline fuels having such desirable properties. The invention also provides methods of combusting such fuels in automotive engines while minimizing emission of pollutants released to the atmosphere, which in turn provides a method for reducing air pollution, particularly in congested cities and the like, when large volumes of automotive fuel of the invention are combusted in a great number of automobiles in a relatively small geographical area.

The present invention also provides a petroleum refiner with knowledge of which properties of a gasoline fuel to alter, and in which direction (i.e., increased or decreased), so as to produce a gasoline fuel which will reduce or minimize NO_x, CO, and hydrocarbon emissions upon combustion in an automotive engine.

The present invention, in its broadest aspect, is founded on the discovery that, when gasoline fuels are produced, for example, by blending a plurality of hydrocarbon-containing streams together so as to produce a gasoline product suitable for combustion in an automotive spark-induced internal combustion engine, improvements in emissions of one or more pollutants selected from the group consisting of CO, NO_x, and hydrocarbons upon combustion of the gasoline product in such an engine system can be attained by controlling certain chemical and/or physical properties of said gasoline product. For example, a first hydrocarbon-containing stream boiling in the gasoline range can be blended with a different hydrocarbon stream at rates adjusted so as to effect at least one of the properties of the first gasoline stream as follows:

- (1) decrease the 50% D-86 Distillation Point;
- (2) decrease the olefin content;
- (3) increase the paraffin content;
- (4) decrease the Reid Vapor pressure;
- (5) increase the Research Octane Number;
- (6) decrease the 10% D-86 Distillation Point;
- (7) decrease the 90% D-86 Distillation Point; and
- (8) increase the aromatic content

10 The greater the increase or decrease of the eight properties as set forth above, the greater the resulting benefit in reducing emissions of one or more of CO, NO_x, and hydrocarbons.

For gasoline fuels in which one desires that hydrocarbon emissions and/or CO emissions be minimized or reduced, the principal factor influencing such emissions is the 50% D-86 distillation point, with decreases therein causing decreases in the hydrocarbon emissions. Fuels generally prepared in accordance with this embodiment of the invention have a 50% D-86 distillation point no greater than 215° F. (101.6° C.), with the hydrocarbon and CO emissions progressively decreasing as the 50% D-86 distillation point is reduced below 215° F. (101.6° C.). Preferred fuels have a 50% D-86 Distillation Point of 205° F. (96.1° C.) or less. Best results are attained with fuels having a 50% D-86 distillation point below 195° F. (90.6° C.).

For gasoline fuels in which one desires that emissions of NO_x be minimized or reduced, the principal factor influencing such emissions is Reid Vapor pressure. NO_x emissions decrease as the Reid Vapor Pressure is decreased (e.g., to 8.0 psi (0.54 atm) or less, preferably to 7.5 psi (0.51 atm) or less, and even more preferably below 7.0 psi (0.48 atm)). of secondary importance with respect to NO_x emissions are the 10% D-86 Distillation Point and the olefin content. In general, decreasing olefin content (e.g., below 15 volume percent, preferably to essentially zero volume percent) and/or decreasing the 10% D-86 Distillation Point (e.g., to values below 140° F. (60° C.)) will provide some reduction in NO_x emissions. However, because it is contemplated that decreases in olefin content will be more acceptable to an oil refiner than decreasing the 10% D-86 Distillation Point sufficiently to significantly affect the NO_x emissions, it is believed that, as a practical matter, it will be olefin content which will be the secondary variable providing the most flexibility to an oil refiner in altering the gasoline properties to reduce NO_x emissions. (This is all the more the case inasmuch as, in general, if one wishes to decrease the Reid Vapor Pressure, it is usually necessary to increase the 10% Distillation Point.) Accordingly, best results are attained when both the olefin content is below 15 volume percent (preferably to zero) and the Reid vapor pressure is no greater than 7.5 psi-with it being highly desirable, if possible, to also maintain the 10% D-86 Distillation Point below 140° F. (60° C.).

In view of the foregoing, it can be seen that many modifications of the invention are possible, depending upon which of the three pollutants one desires to reduce and the degree of reduction desired. For example, one can attain significant reductions in all three pollutants-hydrocarbons, CO, and NO_x-by maintaining the 50% D-86 distillation point at or below about 215° F. (101.6° C.) and maintaining the Reid Vapor Pressure no greater than 8.0 psi (0.54 atm). Still better reductions can be obtained by maintaining the olefin content below 10 volume percent, or maintaining the 10% D-86 distillation point below 140° F. (60° C.), with still further reductions being possible when both the olefin content and 10% D-86 Distillation Point are so maintained.

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Yet further reductions are possible by maintaining the 50% D-86 distillation point below 195° F. (90.6° C.), by reducing the olefin content to below 5.0 vol. % (preferably to essentially zero), by decreasing the 10% D-86 Distillation Point to below 120° F. (49° C.), and/or by maintaining the Reid Vapor pressure below 7.0 psi (0.48 atm).

The presently preferred specifications proposed for commercial use for a gasoline produced in accordance with the invention are: (1) Olefin Content of 0%; (2) Reid Vapor Pressure of 7.5 psi (0.51 atm) maximum; and (3) 50% D-86 distillation point greater than 180° F. (82° C.) but no greater than 205° F. (96° C.). However, other fuels falling within the scope of the invention are also possible, for example, fuels meeting the following criteria:

- (1) a 50% D-86 distillation point no greater than 215° F. (101.7° C.) and a Reid Vapor Pressure no greater than 8.0 psi (0.54 atm).
- (2) a 50% D-86 distillation point no greater than 205° F. (96° C.) and an olefin content less than 3 percent by volume;
- (3) a Reid Vapor Pressure no greater than 8.0 psi (0.54 atm) and containing at least 40 volume percent paraffins;
- (4) a Reid Vapor Pressure no greater than 7.5 psi (0.51 atm) and containing essentially no methyl tertiary butyl ether but less than 15 volume percent olefins.

One of the main advantages of the invention is that a less polluting gasoline fuel is provided that can be easily prepared in a petroleum refinery or the like. That is, in a typical refinery in which gasoline is produced, it is necessary or at least desirable in most instances to blend the hydrocarbon stocks so as to produce gasolines of specified Reid Vapor Pressure, olefins content, etc. Thus, the only difference is that now the refinery will blend the stocks in light of the information provided herein such that the NO_x, CO, and hydrocarbon emissions are reduced as much as possible or practicable, given the individual situation (the blend stocks available, refining capacity, etc.) facing the particular refinery.

It will be understood in this disclosure and the claims to follow that the words "reduce" and "reducing" in the context of lowering NO_x, CO, or hydrocarbon emissions are relative terms. Obviously, the simplest way to produce no emissions is to combust no fuel; and equally obviously, almost any combustion of a gasoline fuel will produce some emissions and thus produce greater emissions than if no fuel were combusted. However, on the assumption that the motoring public would find the consequences of combusting no fuel rather unattractive, logic dictates in the context of this invention that "reducing" is in comparison to the results achievable with other fuels. For example, for those embodiments of the invention in which the 50% D-86 Distillation Point is controlled to no more than 200° F. (93° C.), the emissions will be reduced in comparison to the otherwise identical fuel but having a higher 50% D-86 Distillation Point when combusted in the same automotive engine (or in an equivalent number of automotive engines) operating for the same time period in the same way.

BRIEF DESCRIPTION OF THE DRAWING

The invention can be best understood with reference to the drawing, the figures of which provide graphical or tabular data derived from the experiments described hereinafter with respect to Examples 2 and 3.

More particularly, FIG. 1 is a graph of CO emission values for 22 different fuels tested in six different automo-

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biles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 2 is a graph of NO_x emission values for 22 different fuels tested in six different automobiles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 3 is a graph of hydrocarbon emission values for 22 different fuels tested in six different automobiles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 4 is a graph of CO emission values for 22 different fuels tested in four different automobiles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 5 is a graph of NO_x emission values for 22 different fuels tested in four different automobiles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 6 is a graph of hydrocarbon emission values for 22 different fuels tested in four different automobiles. Each data point on the graph is an average of a plurality of runs for each fuel-automobile combination.

FIG. 7 is a table, based on data derived from the experiments in Examples 2 and 3, which identifies the most significant variables which increase emissions of CO when the variable is increased (as identified by one or more + signs) or which decrease emissions of CO when the variable is decreased (as identified by one or more - signs).

FIG. 8 is a table, based on data derived from the experiments in Examples 2 and 3, which identifies the most significant variables which increase emissions of NO_x when the variable is increased (as identified by one or more + signs) or which decrease emissions of NO_x when the variable is decreased (as identified by one or more - signs).

FIG. 9 is a table, based on data derived from the experiments in Examples 2 and 3, which identifies the most significant variables which increase emissions of hydrocarbons when the variable is increased (as identified by one or more + signs) or which decrease emissions of hydrocarbons when the variable is decreased (as identified by one or more - signs).

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to gasoline compositions having chemical and physical properties which reduce and/or minimize the amount of gaseous pollutants emitted during combustion. In particular, the invention aims to reduce and/or minimize the emissions of hydrocarbons, NO_x and/or CO during combustion in an automotive engine.

Gasolines are well known fuels, generally composed of a mixture of hydrocarbons boiling at atmospheric pressure in a very narrow temperature range, e.g., 77° F. (25° C.) to 437° F. (225° C.). Gasolines are typically composed of mixtures of aromatics, olefins, and paraffins, although some gasolines may also contain such added non-hydrocarbons as alcohol (e.g., ethanol) or other oxygenates (e.g., methyl tertiary butyl ether). Gasolines may also contain various additives, such as detergents, anti-icing agents, demulsifiers, corrosion inhibitors, dyes, deposit modifiers, as well as octane enhancers such as tetraethyl lead. However, the preferred fuels contemplated in the invention are unleaded gasolines (herein defined as containing a concentration of lead no greater than 0.05 gram of lead per gallon (0.013 gram of lead per liter)). The preferred fuels will also have a Research Octane Num-

ber (RON) of at least 90. Octane value (R/2+M/2) for regular gasoline is generally at least 87 and for premium at least 92.

At present, most gasolines suitable for combustion in automotive spark-ignition engines conform to the requirements of ASTM D4814-89 specifications, which specifications are herein incorporated by reference in their entirety. Such gasolines fall into five different volatility classes, with some of the specifications therefor set forth in the following Table 1:

TABLE 1

Properties	Class A	Class B	Class C	Class D	Class E
RVP (psi) max	9.0	10.0	11.5	13.5	15.0
(atm) max	0.6	0.7	0.8	0.9	1.0
Dist. 10% (° F.) max	158	149	140	131	122
(° C.) max	70	65	60	55	so
Dist. 50% (° F.) min-max	170-250	170-245	170-240	170-235	170-230
(° C.) min-max	77-121	77-118	77-116	77-113	77-110
Dist. 90% (° F.) max	374	374	365	365	365
(° C.) max	190	190	185	185	185
End Point (° F.) max	437	437	437	437	437
(° C.) max	22s	22s	22s	22s	22s

The most preferred gasolines produced in accordance with the invention are those which meet the requirements of one or more of the five classes specified in Table 1.

In the present invention, the gasoline is formulated, usually by appropriately blending various hydrocarbon streams in a refinery, to reduce or minimize emissions of CO, NO_x, and/or hydrocarbons upon combustion in a spark-induced automotive internal combustion engine. It has been discovered in the present invention, for many automotive engines, that the amount of pollutants emitted upon combustion is closely in accord with the following equations:

$$\text{CO(gm per mile)} = K_1 \times (\text{D-86 Dist. 50\% Point in } ^\circ\text{F.}) + K_2 \times (\text{D-86 Dist. 90\% Point in } ^\circ\text{F.}) + K_3 \times (\text{Vol. \% Paraffins})$$

$$\text{NO}_x(\text{gm per mile}) = K_4 \times (\text{Vol. \% Olefins}) + K_5 \times (\text{Vol. \% Paraffins}) + K_6 \times (\text{D-86 Dist. 10\% Point in } ^\circ\text{F.}) + K_7 \times (\text{RVP in psi})$$

$$\text{HC(gm per mile)} = K_8 \times (\text{Vol. \% Olefins}) + K_9 \times (\text{Research Octane Number}) + K_{10} \times (\text{D-86 Dist. 50\% Point in } ^\circ\text{F.})$$

where each K value in the foregoing equations is a positive number. The K values will be fixed for a particular engine in a particular car but can be readily determined. For example, for a 1988 Oldsmobile Regency 98 equipped with a 3.8 liter V-6 Engine, the K values are such that the equations are as follows:

$$\begin{aligned} \text{CO(gm per mile)} = & 0.00937 \times (\text{D-86 Dist. 50\% Point in } ^\circ\text{F.}) + \\ & 0.00133 \times (\text{D-86 Dist. 90\% Point in } ^\circ\text{F.}) + \\ & 0.00828 \times (\text{Vol. \% Paraffins}) \end{aligned}$$

Equation 4

-continued

$$\begin{aligned} \text{NO}_x(\text{gm per mile)} = & 0.00503 \times (\text{Vol. \% Olefins}) + \\ & 0.00060 \times (\text{Vol. \% Paraffins}) + \\ & 0.00087 \times (\text{D-86 Dist. 10\% Point in } ^\circ\text{F.}) + \\ & 0.0159 \times (\text{RVP in psi}) \end{aligned}$$

Equation 5

$$\begin{aligned} \text{HC(gm per mile)} = & 0.00245 \times (\text{Vol. \% Olefins}) + \\ & 0.00104 \times (\text{Research Octane Number}) + \\ & 0.00109 \times (\text{D-86 Dist. 50\% Point in } ^\circ\text{F.}) \end{aligned}$$

Equation 6

From the foregoing equations, and from the relative sizes of the various K values and the typical values which would pertain for the properties by which the K values are multiplied (e.g., Vol. % Olefins, Research Octane Number, etc.), the following conclusions are obtained for the 1988 Oldsmobile Regency 98 and similar automobiles: For CO emissions, although decreasing the 90% D-86 distillation point has some impact on lowering CO emissions, the paraffin content and the 50% D-86 Distillation point influence such emissions much more substantially. All other things being equal, increasing the paraffin content or reducing the 50% D-86 distillation point will provide the most dramatic effects in reducing CO emissions, with best results being attained when both the paraffin content is substantially increased and the 50% D-86 distillation point is substantially reduced. In like manner, it can be seen that by decreasing the 10% D-86 Distillation Point and/or by increasing the paraffin content, some decrease in the NO_x emissions will be produced. However, far more influential on the NO_x emissions are the olefin content and the Reid Vapor Pressure, both of which cause substantial reductions in NO_x emissions as they are substantially decreased. For hydrocarbon emissions, inspection of the equations indicates, since one is usually constrained to no more than a 5 unit change in Research Octane Number in the range of about 90 to 95, that

it will not normally be practicable to alter the Research Octane Number sufficiently to have a significant impact on the hydrocarbon emissions. Accordingly, although some reduction in hydrocarbon emissions can be attained by increasing the Research Octane Number, the most practical way to significantly lower the hydrocarbon emissions while retaining other beneficial properties of the fuel is by lowering the olefin content and/or by lowering the 50% D-86 Distillation Point.

The foregoing equations also provide those skilled in the art, again as to a 1988 Oldsmobile Regency 98 and similar automobiles, with information as to how to lower the reductions of not just CO, NOX, or hydrocarbons, but also any combination thereof. For example, if one is interested in reducing the emission levels of all three, the equations show, if all other properties are held essentially constant, that reducing the Reid vapor Pressure and the 50% D-86 distillation point will decrease the emissions of CO, NOX, and hydrocarbons. Likewise, decreases in these three pollutants can be attained by decreasing the 50% D-86 Distillation Point and decreasing the olefin content.

The above equations also lead to the following conclusions (again as to the 1988 Oldsmobile Regency and similar automobiles):

All other properties of a gasoline fuel being substantially the same,

1. As the 50% D-86 Distillation Point is progressively decreased, progressively greater reductions in CO and hydrocarbons emissions will result;
2. As the olefin content is progressively decreased, progressively greater reductions in NOX and hydrocarbons emissions will result;
3. As the paraffin content is progressively increased, progressively greater reductions in CO and NOX emissions will result;

4. As the Reid Vapor pressure is progressively decreased, progressively greater reductions in NOX emissions will result;
5. As the Research Octane Number is progressively increased, progressively greater reductions in hydrocarbon emissions will result;
6. As the 10% D-86 Distillation Point is progressively decreased, progressively greater reductions in NOX emissions will result;
7. As the 90% D-86 Distillation Point is progressively decreased, progressively greater reductions in CO emissions will result.

And, of course, combining any of the above seven factors will lead to yet progressively greater reductions.

However, as will become evident in light of the data in the examples to follow, the most important of the foregoing factors are Reid Vapor Pressure (for reducing NOX) and the 50% D-86 Distillation Point (for reducing CO and hydrocarbon emissions). Of secondary importance in reducing NOX are the olefin content and the 10% D-86 Distillation Point, with the former being of greater influence than the latter. The following Examples serve to further illustrate the inventive concept and are not intended to be construed as limitations on the invention, which is defined by the claims.

EXAMPLE 1

A total of 22 different unleaded gasoline fuels was tested in a 1988 Oldsmobile Regency 98 automobile equipped with a 3800 cc V-6 engine. This automobile was selected because it represented a high sales volume product with close to the current state-of-the-art emission technology. The emission system was closed loop control on the air to fuel ratio with a three way catalyst system and adaptive learning capability. The automobile had been previously driven for 38,000 miles to stabilize the Octane Requirement Increase.

The properties of each of the 22 fuels are shown in the following Table 2.

TABLE 2

Blend Designation	GASOLINE PROPERTIES				Research Octane Number	Motor Octane Number	D86 Dist. 10% point (° F.)	D86 Dist. SO% point (° F.)	D86 Dist. 90% point (° F.)	Reid Vapor Pressure psi
	Aromatics Vol. % by FIA	Olefins Vol. % by FIA	Paraffins Vol. % by FIA	MTBE Vol. % by IR						
AR3951-1	7.60	0.2	92.20	0.0	93.6	89.2	131	209	299	9.00
AR3951-2	6.60	0.0	93.40	0.0	90.3	86.8	111	203	383	10.10
AR3951-3	43.30	9.5	47.20	0.0	96.1	84.5	126	235	312	8.90
AR3951-4	47.50	8.3	44.20	0.0	95.8	84.4	150	251	355	5.60
AR3951-5	38.15	0.2	61.65	0.0	91.3	82.7	166	221	284	6.37
AR3951-6	11.90	15.9	55.00	17.2	91.5	82.2	128	174	368	8.50
AR3951-7	36.80	0.6	48.30	14.3	95.0	86.1	120	224	405	9.70
AR3951-8	12.30	12.7	60.40	14.6	94.4	85.1	120	185	341	9.20
AR3951-9	44.10	11.3	44.60	0.0	96.6	84.5	128	229	305	8.80
AR3951-10	4.50	19.6	75.90	0.0	94.4	84.8	127	198	310	9.70
AR3951-11	51.60	11.6	36.80	0.0	95.9	84.0	149	308	382	6.50
AR3951-12	28.80	0.6	55.70	14.9	92.9	85.7	128	210	271	9.55
AR3951-13	14.70	17.9	51.50	15.9	91.6	82.2	127	169	392	7.90
AR3951-14	11.60	12.9	75.50	0.0	90.7	82.8	107	193	416	9.20
AR3951-15	9.50	0.0	90.50	0.0	88.6	85.1	158	207	329	6.25
ULRG	58.30	0.4	30.40	10.9	107.0	95.7	160	218	229	5.35
G3297-PJ	40.90	11.1	48.00	0.0	96.4	85.2	120	214	339	8.20
A/O 1111	19.50	4.1	76.40	0.0	90.6	84.4	123	196	282	8.80
A/O 2222	48.30	21.0	15.40	15.3	99.0	86.1	128	221	356	8.80
A/O AVE	30.70	9.5	59.80	0.0	92.2	82.7	112	218	318	8.70
ARCO EC-1	20.70	10.8	61.40	7.1	92.8	84.0	128	198	348	8.20
SU2000E	40	9	45.3	5.7	97.9	86.7	139	224	321	8.0

The fuels were tested in random order with no back to back runs of the same fuel. At first, only the 15 test fuels (designated AR3951-1 through AR3951-15) were run, in random order, and all more than once. However, every fifth run was conducted with fuel G3297-PJ as a control to evaluate systematic error. Each fuel was tested in accordance with the Federal Test Procedure except that (1) instead of allowing the engine between tests to cool down in still air for 10 to 12 hours at 680 to 86" F. (20.0 to 30.0" C.), the engine was subjected for 4.75 hours to a 70" F. (21.1" C.) wind of 50 miles per hour (80.5 km/hr) and (2) instead of a Clayton dynamometer, a General Electric dynamometer was used. It will be noted that the 15 test fuels were purposely blended to provide widely different values for the ten properties shown in Table 2. The emissions data derived from combusting the 15 different test fuels were then analyzed by computer program using the SAS system commercially available from SAS Institute Inc. In this program, the results of the runs with the 15 different fuels were regressed against each of the 10 variables shown in Table 2, as well as against

all possible combinations thereof, searching for an equation for each of the three pollutants of interest (NO_x, CO, and hydrocarbons) defined by the minimum number of variables that gives the best surface fit based on the R squared value. As a result, the Equations 4, 5, and 6 hereinbefore presented were derived as the equations which best define the amount of pollutants (in grams per mile) emitted as a function of the properties of the fuel combusted in the 1988 Regency vehicle.

After developing the foregoing equation, the other fuels shown in Table 2 were tested, most in multiple runs, and again with the G3297-PJ fuel being used in every fifth run. These fuels were tested for the purpose of checking the accuracy of the foregoing equations in forecasting emissions for new fuel, i.e., they were used as "check fuels."

The emissions data for all runs-the test, control, and check fuels-as well as the calculated emissions according to the foregoing developed equations, are tabulated in Table 3, with it being specifically noted that the order shown in Table 3 is not the exact order in which the fuels were tested.

TABLE 3

Fuel Exp. Designation	CO g/mile	NO _x g/mile	HC g/mile	Calculated CO g/mile	Calculated NO _x g/mile	Calculated HC g/mile
AR3951-1	1.106	0.196	0.100	1.593	0.203	0.131
AR3951-2	0.948	0.186	0.094	1.638	0.201	0.127
AR3951-3	1.590	0.264	0.145	2.226	0.271	0.179
AR3951-4	2.228	0.252	0.193	2.458	0.235	0.194
AR3951-5	2.034	N.D.	0.157	1.938	0.218	0.146
AR3951-6	1.637	0.280	0.143	1.664	0.293	0.133
AR3951-7	2.335	0.232	0.166	2.238	0.233	0.147
AR3951-8	1.374	0.257	0.118	1.687	0.278	0.135
AR3951-9	2.068	0.286	0.165	2.182	0.281	0.177
10 AR3951-10	1.357	0.307	0.134	1.611	0.318	0.162
11 AR3951-11	3.752	0.273	0.268	3.089	0.269	0.264
12 AR3951-12	1.738	0.278	0.154	1.867	0.233	0.134
13 AR3951-13	2.275	0.311	0.159	1.678	0.295	0.133
14 AR3951-14	1.959	0.271	0.147	1.737	0.259	0.148
15 AR3951-15	1.654	0.190	0.114	1.628	0.183	0.133
16 ULRG	1.901	0.200	0.142	2.096	0.208	0.127
17 AR3951-14	1.708	0.255	0.156	1.737	0.259	0.148
18 G3297-PJ	2.267	0.273	0.187	2.059	0.262	0.160
19 G3297-PJ	1.784	0.254	0.167	2.059	0.262	0.160
20 G3297-PJ	1.975	0.288	0.160	2.059	0.262	0.160
21 G3297-PJ	2.265	0.263	0.180	2.059	0.262	0.160
22 AR3951-1	1.269	0.200	0.137	1.593	0.203	0.131
23 AR3951-1	1.535	0.200	0.135	1.593	0.203	0.131

Fuel Exp. Designation	FTP CO Emissions	FTP NO _x Emissions	FTP HC Emissions	Calculated CO Emissions	Calculated NO _x Emissions	Calculated HC Emissions
24 AR3951-2	1.253	0.163	0.133	1.638	0.201	0.127
25 AR3951-3	1.692	0.244	0.148	2.226	0.271	0.179
26 AR3951-4	2.835	0.274	0.235	2.458	0.235	0.194
27 AR3951-5	1.764	0.250	0.159	1.938	0.218	0.146
28 AR3951-6	1.338	0.268	0.115	1.664	0.293	0.133
29 AR3951-7	2.059	0.223	0.146	2.238	0.233	0.147
30 AR3951-8	1.633	0.271	0.140	1.687	0.278	0.135
31 AR3951-9	1.952	0.281	0.157	2.182	0.281	0.177
32 AR3951-11	3.443	0.237	0.272	3.089	0.269	0.264
33 AR3951-12	1.959	0.266	0.146	1.867	0.233	0.134
34 AR3951-13	2.127	0.320	0.156	1.678	0.295	0.133
35 AR3951-14	2.552	0.284	0.182	1.737	0.259	0.148
36 G3297-PJ	2.240	0.263	0.204	2.059	0.262	0.160
37 G3297-PJ	2.059	0.240	0.168	2.059	0.262	0.160
38 G3297-PJ	2.322	0.278	0.172	2.059	0.262	0.160
39 G3297-PJ	1.890	0.286	0.169	2.059	0.262	0.160
40 G3297-PJ	2.339	0.252	0.192	2.059	0.262	0.160
41 A/O 1111	1.641	0.296	0.173	1.579	0.222	0.129
42 A/O 2222	1.999	0.251	0.172	2.417	0.345	0.189
43 A/O AVE	2.162	0.298	0.210	1.798	0.248	0.145
44 A/O AVE	2.476	0.274	0.167	1.798	0.248	0.145

TABLE 3-continued

45	ARCO EC-1	1.651	0.271	0.139	1.810	0.257	0.146
46	ARCO EC-1	1.517	0.255	0.139	1.810	0.257	0.146
47	SUZ000E	1.738	0.203	0.166	2.104	0.256	0.164
48	AR3951-15	1.511	0.244	0.152	1.553	0.172	0.125
49	G3297-PJ	1.862	0.284	0.161	2.059	0.262	0.160
50	AR3951-5	2.012	0.261	0.201	1.938	0.218	0.146
51	A/O 1111	1.545	0.293	0.224	1.579	0.222	0.129
52	A/O 2222	1.963	0.246	0.157	2.417	0.34s	0.189
53	ULRG	1.769	0.217	0.139	2.096	0.208	0.127

The multiple test emissions data for each of the check fuels and the control fuel were then averaged, set against the calculated values, the deviation from the calculated value then determined, and compared against the standard deviation, which in turn was calculated from only the data pertaining to the control fuel G3297-PJ. These data are set forth in the following Table 4:

TABLE 4

Emis. Fuel	Actual g/mi	Calculated g/mi	Deviation	Standard Deviation
c o ULRG	1.835	2.096	0.261	0.20s
c o G3297-PJ	2.127	2.059	0.067	0.20s
c o Arco EC1	1.584	1.810	0.226	0.20s
c o A/O 1111	1.593	1.579	0.014	0.20s
c o A/O 2222	1.981	2.417	0.436	0.20s
c o SUZ000E	1.738	2.104	0.366	0.20s
c o A/OAVE	2.319	1.798	0.521	0.20s
NOx ULRG	0.209	0.207	0.002	0.0162
NOx G3297-PJ	0.266	0.261	0.00s	0.0162
NOx Arco EC1	0.263	0.256	0.007	0.0162
NOx A/O 1111	0.295	0.222	0.073	0.0162
NOx A/O 2222	0.249	0.34s	0.096	0.0162
NOx SUZ000E	0.203	0.256	0.053	0.0162
NOx A/O AVE	0.286	0.248	0.038	0.0162
H C ULRG	0.141	0.127	0.014	0.0142
H C G3297-PJ	0.178	0.160	0.017	0.0142

TABLE 4-continued

Emis. Fuel	Actual g/mi	Calculated g/mi	Deviation	Standard Deviation
H C Arco EC1	0.139	0.146	0.007	0.0142
H C A/O 1111	0.198	0.129	0.069	0.0142
H C A/O 2222	0.165	0.189	0.024	0.0142
H C SUZ000E	0.166	0.164	0.002	0.0142
H C A/O AVE	0.189	0.145	0.044	0.0142

15

20

2s

30

35

It will be seen that, in most cases, the deviations shown in Table 4 are well within three times the standard deviation. In turn, this means that the equations accurately define the scientific phenomena at work within normal realms of variabilities.

EXAMPLE 2

In this example, 22 gasoline fuels, including 15 test fuels A through N and P, one control fuel, Q, and six check fuels, R, S, T, V, W and X were run in six different automobiles. The properties of the 22 gasolines used are shown in the following Table 5.

TABLE 5

Blend Designation	GASOLINE PROPERTIES											Reid Vapor Pressure psi
	Aromatics Vol. % by FIA	Olefins Vol. % by FIA	Paraffins Vol. % by FIA	MTBE Vol. % by IR	Research Octane Number	Motor Octane Number	D86 Dist. 10% point (° F.)	D86 Dist. 50% point (° F.)	D86 Dist. 90% point (° F.)			
A	9.6	0.0	90.4	0.0	94.0	89.5	128	206	291	9.23		
B	5.3	0.0	94.7	0.0	91.1	87.4	106	178	290	11.45		
C	48.8	10.3	41.0	0.0	97.0	84.7	122	22s	300	9.14		
D	46.6	11.4	42.1	0.0	96.2	84.0	147	236	334	6.63		
E	39.4	0.4	60.1	0.0	97.3	83.2	164	219	271	6.46		
F	9.8	16.8	73.3	15.9	92.0	83.0	121	161	231	9.3s		
G	32.8	0.6	66.6	13.7	96.6	87.5	107	194	296	11.54		
H	12.7	15.0	72.3	14.0	94.3	84.8	119	180	302	9.88		
I	46.4	12.6	41.0	0.0	97.3	84.9	126	220	294	8.73		
J	4.8	6.2	89.1	0.0	93.9	84.9	119	188	290	9.65		
K	45.6	13.6	40.8	0.0	95.9	83.9	13s	274	370	7.60		
L	31.0	0.2	68.8	14.4	93.3	85.6	12s	206	262	9.43		
M	15.9	15.3	68.8	15.8	92.1	82.9	114	157	368	9.77		
N	12.8	11.6	75.6	0.0	90.7	83.2	107	185	403	10.51		
P	10.6	0.0	89.4	0.0	89.7	85.8	144	204	318	7.07		
Q	31.8	9.9	58.3	0.0	92.1	82.7	129	220	331	8.31		
R	52.0	21.9	26.1	14.6	98.8	85.5	130	224	358	8.37		
S	21.1	3.9	75.0	0.0	91.0	84.3	129	199	284	8.44		
T	30.2	0.0	69.8	0.0	88.5	81.2	127	182	293	8.00		
V	23.3	6.0	70.7	0.0	92.0	83.5	132	196	319	7.96		
W	25.6	11.8	62.5	10.1	97.7	86.7	134	21s	33s	8.12		
X	38.5	0.0	61.5	0.0	94.8	85.0	123	211	326	7.63		

The automobiles (and accompanying engines) utilized were:

1. 1988 Oldsmobile 98 Regency-3.8 liter V-6
2. 1989 Ford Taurus-3.0 liter V-6
3. 1990 Toyota Camry-2.0 liter 4 cylinders
4. 1989 GM Cutlass Calais-3.8 liter V-6
5. 1990 Ford Lincoln-5.0 liter V-8
6. 1990 Dodge Shadow-2.5 liter 4 cylinders

The fuels were tested in the foregoing automobiles in the same manner as described in Example 1 except that the control fuel was used in every sixth run and the Federal Test Procedure (FTP) was followed exactly. Each fuel was tested at least twice, many three times, and some four times, in each of the vehicles.

The CO, NO_x, and hydrocarbon emission data obtained by the Federal Test Procedure for each fuel in a given automobile were averaged, and then plotted respectively in the graphs in FIGS. 1, 2, and 3. (Thus, each data point in FIGS. 1 through 3 is an average of the values obtained for each automobile with the specified fuel.) Given the great number of fuels and automobiles tested, each of the three graphs shows a remarkable similarity in the overall shape of the curves in the graphs. It is clearly evident from these figures that the general effect of a given fuel is the same for different vehicles, with only the magnitude of the effect varying.

EXAMPLE 3

In this example, Example 2 was repeated except on the following automobiles (and accompanying engines):

1. 1985 Ford Tempo-2.3 liter 4 cylinders
2. 1984 GM Caprice-5.0 liter V-8
3. 1988 Honda Accord-2.0 liter 4 cylinders
4. 1985 GM Suburban-5.7 liter V-8

The fuels were tested in the foregoing automobiles in the same manner as described in Example 2. The emission data obtained were averaged and plotted on FIGS. 4 through 6, and once again, the results show a remarkable consistency in the effects of a given fuel.

In all, for Examples 2 and 3, a total of over 500 FTP runs was made so as to provide a large enough data base to ensure the validity of the results. It should be noted that Examples 2 and 3, and the figures of the drawing pertaining to each, focused on automobiles and engines which were dissimilar in many respects. However, the automobiles in Example 2 all had adaptive learning computers with fuel-to-air feedback control loops whereas those in Example 3 did not. The figures thus show that groups of cars with these similar engineering features behave similarly to changes in the fuel, which in turn shows the universality of one of the inventive concepts. The automobiles of Examples 2 and 3 were chosen because of their high commercial sales. The automobiles of Example 2 were all relatively recent models while those of Example 3 were generally older. All but one of the Example 3 automobiles had carburetor systems whereas all of those in Example 2 had fuel injection systems.

The data derived in Examples 2 and 3 were analyzed by the same computer program as described for Example 1, searching, as in Example 1, for an equation for each automobile which would provide a value for NO_x, CO, and hydrocarbon emissions as a function of the minimum number of fuel properties. Not every equation so derived conformed to the generalized equation set forth hereinbefore; some, for example, showed a minor increase in hydrocarbon emissions with increases in aromatics content. Nevertheless, many of the equations did fit the generalized equation set

forth hereinbefore, and more importantly, the data overall validated the fact that the most important factors as shown in the generalized Equations 1 to 3 proved almost universally most significant for each automobile.

More specifically, where much of the previous discussion was limited to 1988 Oldsmobile Regency 98 and similar automobiles, the data in tables 7 to 9—which were obtained from the data from which FIGS. 1 to 6 were derived—indicate that some variables universally or essentially universally affect emissions from automobile engines, others are limited to one or only a few vehicles, and yet others affect a particular pollutant in about 50% of the vehicles.

More specifically still, in the tables of FIGS. 7 to 9 there are indicated for each automobile tested in Examples 2 and 3 those factors which proved to be significant in increasing the specified emission when the variable is increased (as indicated by one or more + signs) and significant in decreasing the specified emission when the variable is increased (as indicated by one or more - signs). Those variables which dramatically affect emissions (i.e., principal factors) are indicated by more than one + or - signs, with increasing numbers of + or - signs indicating increased significance for that variable. Those variables which are of least importance among the significant variables are indicated by a (+) or (-) sign. (Also shown in FIGS. 7 to 9 are the values obtained by summing the square of all the data predicted by the particular equation for each automobile for a particular pollutant and dividing by the sum of the square of all the data actually obtained for the automobile. It will be recognized that, the closer such value is to 1.0, the better the equation defines the effect under consideration. In the case of FIGS. 7 to 9, 29 of the 30 values are above 0.9 and only one is below—and that scarcely below at 0.894. Accordingly, it was determined that the equations for each of the automobiles was statistically accurate, and that therefore the data derived therefrom—as shown in FIGS. 7 to 9—would meaningfully point to those variables which would have a statistically significant effect upon the emission characteristics from a given automobile in FIGS. 7 to 9.)

When the data of Examples 2 and 3 are analyzed as shown in FIGS. 7 to 9, the following facts stand out as most significant:

1. Decreases in the 50% D-86 Distillation Point caused decreases in CO and hydrocarbon emissions for all of the automobiles.
2. Decreases in the Olefin Content caused reductions in NO_x emissions from all the vehicles.
3. Decreases in the 10% D-86 Distillation Point caused reductions in NO_x emissions from all the vehicles.
4. Decreases in Reid Vapor Pressure caused reductions in NO_x emissions from all the vehicles but one.

Accordingly, from the data in FIGS. 7 to 9, it can be seen that for automobiles in general that decreasing any of the variables 1 to 4 above will have a positive effect, especially for any large population of automobiles. In turn, it can be appreciated that the preferred fuels of the invention will be prepared (e.g., by appropriate blending in a refinery) so as to decrease each of the foregoing variables, and in particular, the 50% D-86 Distillation Point, the Reid Vapor Pressure, and the Olefin content, all three of which are more significantly (and easily) decreaseable in refinery practice than the 10% D-86 distillation Point.

Presently, the most commercially attractive fuel producible in accordance with the invention has the following properties: (1) Olefin Content of 0%; (2) Reid Vapor Pressure of 7.5 psi (0.51 atm) maximum; and (3) 50% D-86 distillation point greater than 180° F. (82° C.) but no greater than 205° F. (96° C.).

Where it is desired to take advantage of the emission reductions attainable by varying the 50% D-86 distillation point, this value usually is no greater than 215° F. (101.6° C.), e.g., no greater than 210° F. (98.9° C.) but preferably is no greater than 205° F. (96.1° C.), e.g., less than 203° F. (95° C.), or less than 200° F. (93.3° C.), or less than 198° F. (92.2° C.), more preferably less than 195° F. (90.6° C.), e.g., less than 193° F. (89.4° C.), or less than 190° F. (87.8° C.), or less than 187° F. (86.1° C.), and most preferably less than 185° F. (85.0° C.), e.g., less than 183° F. (83.9° C.). In general, the 50% D-86 Distillation Point is above 170° F. (77° C.) and most often above 180° F. (82.2° C.).

Where it is desired to take advantage of the emission reductions attainable by varying the olefin content, this value is generally maintained less than 15 volume percent, with decreasing values providing progressively improved results. Thus, it is contemplated that each unit reduction, e.g., to values below 14, below 13, below 12, below 11, below 10, below 9, below 8, below 7, below 6, below 5, below 4, below 3, below 2, below 1 providing progressively better results, with values of 0.5 or less and essentially zero providing the best results possible.

Where it is desired to take advantage of reductions attainable by reducing the Reid Vapor Pressure, the gasoline will generally have a Reid Vapor Pressure specification of 8.0 psi (0.54 atm) max., most often less than 8.0 psi (0.54 atm), preferably no greater than 7.5 psi (0.51 atm), even more preferably no greater than 7.0 psi (0.48 atm), and most preferably of all, no greater than 6.5 psi (0.44 atm).

Where the emissions reductions attainable by reducing the 10% D-86 Distillation Point is desired, this value is most often maintained no greater than 140° F. (71° C.), preferably no more than 135° F. (57.2° C.), even more preferably no more than 130° F. (54° C.), and most preferably of all, no more than 122° F. (48.9° C.).

It can also be seen from the data in FIG. 7 that the paraffin content has an effect on 50% of the automobiles with respect to reducing CO, i.e., progressively increasing the paraffin content progressively decreases the CO emitted. Accordingly, where it is desired to take advantage of these facts, the paraffin content would be increased to above 40 volume percent, usually above 50 volume percent, most often to above 65 volume percent, preferably above 68 volume percent, more preferably above 70 volume percent, e.g., above 72 volume percent, even more preferably above 75 volume percent, e.g., above 77 volume percent, and most preferably, above 80 volume percent, e.g., above 82 volume percent, and most preferably of all, above 85 volume percent, e.g., above 87 or 90 volume percent.

Likewise, 60% of the automobiles shown in FIG. 9 evidenced reductions in hydrocarbon emissions when the aromatics content was increased. Where it is desired to take advantage of this fact, the aromatics content would be increased to at least 35 volume percent, preferably at least 40 volume percent.

In view of the information presented above, a petroleum refiner may take advantage of the invention by blending hydrocarbon streams boiling in the gasoline range of 77° F. (25° C.) to about 437° F. (225° C.) so as to affect at least one (and preferably more than one) of the properties of one of the streams as follows:

- (1) decrease the 50% D-86 Distillation Point;
- (2) decrease the olefin content;
- (3) increase the paraffin content;
- (4) decrease the Reid Vapor pressure;
- (5) increase the Research Octane Number;

- (6) decrease the 10% D-86 Distillation Point;
- (7) decrease the 90% D-86 Distillation Point; and
- (8) increase the aromatics content.

In such case, the petroleum refiner is, in essence, using the information provided by the present invention so as to convert a given gasoline stream into another with better properties with respect to CO, NO_x, and/or hydrocarbon emissions.

It will also follow that one can increase or decrease any combination of the eight properties listed above, i.e., at least two, at least three, at least four, etc., of the properties can be increased or decreased in the direction indicated above, as well as all eight. In addition, the greater any individual property is changed in the direction indicated, the better the result, with at least 10% changes being normally used, and preferably at least 20%. In addition, one can change the property by difference instead of by percentage, for example, affecting the properties as follows:

- (a) decreasing the 50% D-86 distillation point by at least 20° F. (11.1° C.) or by at least 40° F. (22.1° C.);
- (b) decreasing the Reid Vapor Pressure by at least 1 psi (0.07 atm.) or by at least 2 psi (0.14 atm.);
- (c) decreasing the olefin content by at least 3 volume percent or by at least 5 volume percent;
- (d) increasing the paraffin content by at least 10 volume percent by at least 20 volume percent.
- (e) decreasing the 10% D-86 distillation point by at least 10° F. (5.5° C.) or by at least 20° F. (11.1° C.); and
- (f) increasing the aromatics content by at least 10 volume percent. Moreover, as would stand to reason, one could also elect to employ any combination of (a) to (f) above to produce the desired lower emission gasoline product.

While the invention may be used to advantage even on a small volume basis, e.g., a single automobile operating with a fuel composition of the invention for a week or for at least 200 consecutive miles, it is clear that the benefits offered by the invention are best taken advantage of when a large number of automobiles operating with spark induced internal combustion engines requiring a gasoline fuel are powered with the fuel of the invention. In fact, the benefits of the invention increase directly with the number of automobiles which employ the fuel. Therefore, in one embodiment of the invention, on a given day, and preferably on a daily basis over a period of at least one month, at least 1,000 and more preferably at least 10,000 automobiles are provided with a fuel composition of the invention-and even more preferably it is desired that the 1000+ or 10,000+ automobiles be provided with such fuel in a highly congested area, e.g., within the limits of a city or county encompassing a population of 500,000 or more people. Most advantageously, the amount of fuel dispensed into automobile fuel tanks within the city or county should be sufficient to effect a noticeable decrease in the amount of one or more of NO_x, CO, and hydrocarbons in the air. At the present time, it is believed that, if as little as 10% of the gasoline fuel supplied to automobiles within a given city or county were a composition of the invention, a decrease in the pollution caused by one or more of these components would be obtained (assuming no significant increase in the automobile traffic within said city or county). Higher percentages, e.g., at least 25%, will yield still better results. If at least 50% of the fuel sold within a given city or county on a daily basis were a composition of the invention, it is believed, based on the data in the Examples hereinabove, that reductions in auto emissions of CO, NO_x, and/or hydrocarbons at least as high as 20% as compared to the typical gasoline fuel could be

observed (depending, of course, on how each of the variables is adjusted in the appropriate direction and the magnitude of such changes). Yet better results can be expected if at least 75%, even more preferably at least 90%, of the gasoline fuel were supplied on a given day from gasoline service stations within a given geographical area, e.g., a governmental district such as a city or county. Alternatively, if the same percentages pertained to a specific unit area, e.g., any 5,000 square mile (12,948 square kilometer) or 10,000 square mile (25,895 square kilometer) or any 50,000 square mile (129,476 square kilometer) area, one would expect to see reductions in one or more of CO, NOx, and hydrocarbons.

In any event, because the benefits of the invention are best realized when the gasoline fuel of the invention is supplied and combusted on a large quantity basis (i.e., large volume consumption), it is contemplated that there are many ways by which this can be accomplished, among which the following are merely illustrative:

1. Operating a fleet of automotive vehicles, numbering at least 10, preferably at least 25, with a fuel composition of the invention.
2. Operating a single automobile for an extended period of time, e.g., at least six months, or for at least 2,000 consecutive miles (3,218 kilometers), with a fuel composition of the invention.
3. Consuming at least 500 gallons (1,893 liters) of a fuel composition of the invention in one vehicle.
4. Consuming at least 2,000 gallons (7,570 liters) of a fuel composition of the invention in either one automobile or a fleet of automobiles.

Yet greater consumption can be attained by, for example:

1. Supplying, via gasoline service stations and the like, at least 1,000 vehicles, preferably at least 10,000 vehicles, per day with a fuel composition of the invention.
2. Supplying, via gasoline service stations and the like, at least 10,000,000 gallons (37,850,000 liters) per week of a fuel composition of the invention to automotive vehicles.

In order to supply and consume a gasoline composition of the invention on a large volume basis, it follows that the gasoline composition must be produced at a petroleum refinery or the like in large volumes. Typically, a refinery has a capacity to process at least 20,000 barrels per day (132,500 liters per hour), preferably at least 30,000 barrels per day (198,750 liters per hour), of crude oil and to produce at least 30,000 gallons (113,550 liters), preferably at least 50,000 gallons (189,250 liters), and most preferably at least 100,000 gallons (378,500 liters) of gasoline per day. While the invention would best be taken advantage of if all the gasoline fuel produced in a refinery were a composition of the invention, good results can be obtained if a significant fraction thereof—e.g., at least 10%, were a fuel composition of the invention. In commercial practice, it is contemplated that usual procedures will result in at least 25%, often at least 50%, and sometimes at least 75% of the daily refinery output being a fuel composition of the invention. Such output would then be delivered to gasoline service stations for introduction into automobiles, with, again, the greatest significant advantage being if all the gasoline service stations so supplied—or some significant portion thereof, e.g., at least 25%, more preferably at least 50%, and most preferably at least 75%—are located in a congested area of high population density, e.g., a city or county as described above.

Accordingly, in view of the foregoing, it will be seen that there are many ways of employing the inventive concept on

a large volume basis. Obviously, the best results will be obtained when the fuel composition of the invention is so blended in a refinery or the like as to reduce the emissions of hydrocarbons, CO, and NOx to the lowest possible levels, then combusting such fuel in automobiles on a large volume basis over extended periods of time, e.g., at least one month, preferably at least six months, and with the most advantage to be realized in the most densely populated areas, e.g., counties or cities of populations exceeding 1,000,000, or more than 2,500,000, or more than 5,000,000, or, in areas like Los Angeles county, more than 10,000,000 persons. To provide for the needs of such high population density areas, it may be necessary to supply the fuel composition of the invention from more than one refinery, and to deliver it to a large fraction of the gasoline service stations in such area, e.g., at least 25%, preferably at least 50%, most preferably at least 75%, so that a large number of automobiles can be supplied with the inventive fuel on a daily basis, e.g., at least 100,000, preferably at least 500,000 automobiles.

In view of the foregoing, it can be seen that the invention offers many advantages, not the least of which are the obvious health benefits associated with reduced air pollutants emitted to the atmosphere from automobiles, trucks, and other gasoline powered motor vehicles. Additionally, the invention can be put into immediate practice; current refining equipment can be employed to produce the low polluting fuels of the invention. Moreover, the invention offers the petroleum refiner a great deal of flexibility, for the invention is highly adaptable to a wide variety of hydrocarbon refinery streams. More specifically, since the description hereinbefore shows the effect of different variables, the refiner is not constrained to producing one particular fuel, but has several options, depending on what hydrocarbon streams are at hand and what properties of the fuel can be most easily altered.

By offering such flexibility with no needed hardware changes in a refinery, the invention is relatively easy to implement—and all the more so in light of the fact that the invention can be taken advantage of without need for additives specific for reducing polluting emissions. As an example, many current fuels contain methyl tertiary butyl ether as an additive for reducing CO emissions. The present invention, however, requires no methyl tertiary butyl ether to be present. Thus, while the invention in its broadest embodiment encompasses fuels with additives that may aid in reducing such emissions, the advantages of the invention can be obtained without the necessity, for example, of a refinery having to deliberately change its practices to provide for the continuous blending of an emission-reducing additive into the fuel.

The invention, of course, as described hereinbefore, offers significant reductions in NOx, CO, and hydrocarbon emissions. Present indications are that, on a side-by-side basis, preferred fuels of the present invention offer at least a 10%, usually at least a 20%, sometimes at least 40%, reduction in emissions when tested in identical vehicles (e.g., the 1988 Oldsmobile Regency 98 described above) with identical engines and identical catalytic converter systems as compared to results obtained with a typical fuel, for example, the fuel identified in Table 2 as A/O AVE and that in Table 5 as Fuel Q. (These fuels are, in essence, identical, having been made in identical fashion but at different times; the slight differences in results shown in the two tables being within normal tolerance variations.)

It should also be recognized that the invention offers an advantage for automobile manufacturers. As government regulations progressively become more stringent in the amount of pollutants that can be emitted from motor

vehicles, the present invention, by providing for a fuel inherently having properties which reduce or minimize such emissions, allows an automobile manufacturer to meet such regulations with fewer-if any-hardware design changes being needed.

It will be understood that reference hereinabove to the "D-86 Distillation Point" refers to the distillation point obtained by the procedure identified as ASTM D 86-82, which can be found in the 1990 Annual Book of ASTM Standards, Section 5, Petroleum Products, Lubricants, and Fossil Fuels, herein incorporated by reference in its entirety.

The FTP (Federal Test Procedure) specified hereinabove refers to Code of Federal Regulations, volume 40, "Protection of the Environment," Subpart B, "Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures, herein incorporated by reference in its entirety.

"Reid Vapor Pressure" is a pressure determined by a conventional analytical method for determining the vapor pressure of petroleum products. In essence, a liquid petroleum sample is introduced into a chamber, then immersed in a bath at 100° F. (37.8° C.) until a constant pressure is observed. Thus, the Reid Vapor Pressure is the difference, or the partial pressure, produced by the sample at 100° F. (37.8° C.). The complete test procedure is reported as ASTM test method D 323-89 in the 1990 Annual Book of ASTM Standards, Section 5, Petroleum Products, Lubricants, and Fossil Fuels, herein incorporated by reference in its entirety.

While the invention has been described in conjunction with preferred embodiments thereof, various modifications and substitutions can be made thereto without departing from the spirit and scope of the present invention. The invention has also been described with reference to examples, which are presented for illustration only, and thus no limitation should be imposed other than those indicated by the following claims:

We claim:

1. A process comprising blending at least two hydrocarbon streams boiling in the range of 77° F. to about 437° F. to produce an unleaded gasoline suitable for combustion in an automotive engine, said blending being controlled in accordance with at least one mathematical equation predicting for the produced gasoline one or more pollutants selected from the group consisting of CO, NO_x, and unburned hydrocarbons emitted in the exhaust of an automobile with a catalytic converter as a function of at least two of the following properties of the produced gasoline:

- (1) the Reid Vapor Pressure;
- (2) the 10% D-86 distillation point;
- (3) the 50% D-86 distillation point;
- (4) the 90% D-86 distillation point;
- (5) the aromatics content;
- (6) the olefin content;
- (7) the paraffin content; and
- (8) the Research Octane Number,

with the produced unleaded gasoline having:

- (A) a Reid Vapor Pressure less than 7.5 psi;
- (B) a 10% D-86 distillation point no greater than 158° F.;
- (C) a 50% D-86 distillation point no greater than 215° F.;
- (D) a 90% D-86 distillation point no greater than 315° F.;
- (E) an olefin content less than 15 volume percent;
- (F) a paraffin content greater than 65 volume percent;
- (G) a Research Octane Number greater than 90; and
- (H) an octane value of at least 87.

2. A process as defined in claim 1 wherein said blending is in accordance with at least one mathematical equation predicting NO_x as a pollutant emitted.

3. A process as defined in claim 1 wherein said blending is in accordance with at least one mathematical equation predicting CO as a pollutant emitted.

4. A process as defined in claim 1 wherein said blending is in accordance with at least one mathematical equation predicting unburned hydrocarbons as a pollutant emitted.

5. A process as defined in claim 1 wherein said blending is in accordance with at least two mathematical equations, one predicting CO as a pollutant emitted and another predicting NO_x as a pollutant emitted.

6. A process as defined in claim 1 wherein said blending is in accordance with at least two mathematical equations, one predicting unburned hydrocarbons as a pollutant emitted and another predicting NO_x as a pollutant emitted.

7. A process as defined in claim 1 wherein said blending is in accordance with at least two mathematical equations, one predicting CO as a pollutant emitted and another predicting unburned hydrocarbons as a pollutant emitted.

8. A process as defined in claim 1 wherein said blending is in accordance with at least three mathematical equations, one predicting CO as a pollutant emitted, another predicting NO_x as a pollutant emitted, and another predicting unburned hydrocarbons as a pollutant emitted.

9. A process as defined in claim 1 wherein said blending is in accordance with at least one mathematical equation predicting the pollutant emitted as a function of (i) at least one property selected from the group consisting of the Reid Vapor Pressure, the 10% D-86 distillation point, the 50% D-86 distillation point, the 90% D-86 distillation point, and the Research Octane Number and (ii) at least one property selected from the group consisting of the aromatics content, the olefin content, and the paraffin content.

10. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the 10% D-86 distillation point.

11. A process as defined in claim 1 or 9 wherein said mathematical equation predicts NO_x emitted as a function of properties including the 10% D-86 distillation point.

12. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the 50% D-86 distillation point.

13. A process as defined in claim 1 or 9 wherein said mathematical equation predicts CO emitted as a function of properties including the 50% D-86 distillation point.

14. A process as defined in claim 1 or 9 wherein said mathematical equation predicts unburned hydrocarbons emitted as a function of properties including the 50% D-86 distillation point.

15. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the 90% D-86 distillation point.

16. A process as defined in claim 1 or 9 wherein said mathematical equation predicts CO emitted as a function of properties including the 90% D-86 distillation point.

17. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the Reid Vapor pressure.

18. A process as defined in claim 1 or 9 wherein said mathematical equation predicts NO_x emitted as a function of properties including the Reid Vapor pressure.

19. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the paraffin content.

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20. A process as defined in claim 1 or 9 wherein said mathematical equation predicts NOX emitted as a function of properties including the paraffin content.

21. A process as defined in claim 1 or 9 wherein said mathematical equation predicts CO emitted as a function of properties including the paraffin content.

22. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the olefin content.

23. A process as defined in claim 1 or 9 wherein said mathematical equation predicts unburned hydrocarbons emitted as a function of properties including the olefin content.

24. A process as defined in claim 1 or 9 wherein said mathematical equation predicts NOX emitted as a function of properties including the olefin content.

25. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the Research Octane Number.

26. A process as defined in claim 1 or 9 wherein said mathematical equation predicts unburned hydrocarbons emitted as a function of properties including the Research Octane Number.

27. A process as defined in claim 1 or 9 wherein said mathematical equation predicts a pollutant emitted as a function of properties including the aromatics content.

28. A process as defined in claim 1 or 9 wherein said mathematical equation predicts unburned hydrocarbons emitted as a function of properties including the aromatics content.

29. A process as defined in claim 2 or 9 wherein said mathematical equation predicts NOX as a function of properties including paraffins and olefins.

30. A process as defined in claim 9 wherein said mathematical equation predicts NOX as a function of properties including Reid Vapor Pressure and the 10% D-86 distillation point.

31. A process as defined in claim 30 wherein said mathematical equation predicts NOX as a function of properties including paraffin content and olefin content.

32. A process as defined in claim 9 wherein said mathematical equation predicts unburned hydrocarbons as a function of properties including the 50% D-86 distillation point and olefin content.

33. A process as defined in claim 32 wherein said mathematical equation predicts unburned hydrocarbons as a function of properties including the Research Octane Number.

34. A process as defined in claim 3 or 9 wherein said mathematical equation predicts CO as a function of properties including the 50% D-86 distillation point and the 90% D-86 distillation point.

35. A process as defined in claim 9 wherein said mathematical equation predicts CO as a function of properties including the 50% D-86 distillation point and the paraffin content.

36. A process as defined in claim 9 wherein said mathematical equation predicts CO as a function of properties including the 90% D-86 distillation point and the paraffin content.

37. A process as defined in claim 36 wherein said mathematical equation predicts CO as a function of properties including the 50% D-86 distillation point.

38. A process as defined in claim 1 wherein said blending is in accordance with at least three independent mathematical equations, one predicting the NOX emitted, another the

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CO emitted, and the third the unburned hydrocarbons emitted, with all three as functions of (i) at least one property selected from the group consisting of the Reid Vapor Pressure, the 10% D-86 distillation point, the 50% D-86 distillation point, the 90% D-86 distillation point, and the Research Octane Number and (ii) at least one property selected from the group consisting of the aromatics content, the olefin content, and the paraffin content.

39. A process as defined in claim 1 wherein said blending is in accordance with at least two mathematical equations, one predicting one said pollutant emitted, and the other independently predicting another, but both as functions of (i) at least one property selected from the group consisting of the Reid Vapor Pressure, the 10% D-86 distillation point, the 50% D-86 distillation point, the 90% D-86 distillation point, and the Research Octane Number and (ii) at least one property selected from the group consisting of the aromatics content, the olefin content, and the paraffin content.

40. A process as defined in claim 39 wherein one of said mathematical equations predicts CO as a pollutant emitted and a second predicts NOX as a pollutant emitted.

41. A process as defined in claim 39 wherein one of said mathematical equations predicts unburned hydrocarbons as a pollutant emitted and a second predicts NOX as a pollutant emitted.

42. A process as defined in claim 39 wherein one of said mathematical equations predicts unburned hydrocarbons as a pollutant emitted and a second predicts CO as a pollutant emitted.

43. A process as defined in claim 1 wherein said blending is controlled by at least two said mathematical equations, one predicting one said pollutant emitted, and the other predicting another, but both as a function of at least two of said properties.

44. A process as defined in claim 38, 39, or 43 wherein at least one of said mathematical equations predicts a pollutant emitted as a function of properties including Reid Vapor Pressure and at least one other of said mathematical equations predicts another pollutant emitted as a function of properties including the 50% D-86 distillation point.

45. A process as defined in claim 38, 39, or 43 wherein at least one of said mathematical equations predicts NOX emitted as a function of properties including Reid Vapor Pressure and at least one other of said mathematical equations predicts unburned hydrocarbons emitted as a function of properties including the 50% D-86 distillation point.

46. A process as defined in claim 38, 39, or 43 wherein at least one of said mathematical equations predicts NOX emitted as a function of properties including a property selected from the group consisting of Reid Vapor Pressure, olefin content, paraffin content, and the 10% D-86 distillation point and at least one other of said mathematical equations predicts unburned hydrocarbons emitted as a function of properties including a property selected from the group consisting of the 50% D-86 distillation point, the Research Octane Number, and the olefin content.

47. A process as defined in claim 38, 39, or 43 wherein at least one of said mathematical equations predicts NOX emitted as a function of properties including at least two properties selected from the group consisting of Reid Vapor Pressure, olefin content, paraffin content, and the 10% D-86 distillation point and at least one other of said mathematical equations predicts unburned hydrocarbons emitted as a function of properties including two properties selected from the group consisting of the 50% D-86 distillation point, the Research Octane Number, and the olefin content.

48. The process as defined in claim 47 wherein said mathematical equation predicting NOX emitted is a function

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of properties including Reid Vapor Pressure and said mathematical equation predicting unburned hydrocarbons emitted is a function of properties including the 50% D-86 distillation point.

49. A process as defined in claim 43 wherein at least one of said mathematical equations predicts NO_x emitted as a function of properties including Reid Vapor Pressure, olefin content, paraffin content, and the 10% D-86 distillation point and at least one other of said mathematical equations predicts unburned hydrocarbons emitted as a function of properties including the 50% D-86 distillation point, the Research Octane Number, and the olefin content.

50. A process as defined in claim 49 wherein a further of said mathematical equations predicts CO emitted as a function of properties including at least one property selected from the group consisting of paraffin content, the 50% D-86 distillation point, and the 90% D-86 distillation point.

51. A process as defined in claim 49 wherein a further of said mathematical equations predicts CO emitted as a function of properties including at least two properties selected from the group consisting of paraffin content, the 50% D-86 distillation point, and the 90% D-86 distillation point.

52. A process as defined in claim 49 wherein a further of said mathematical equations predicts CO emitted as a func-

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tion of properties including paraffin content, the 50% D-86 distillation point, and the 90% D-86 distillation point.

53. A process as defined in claim 1, 2, 3, 4, 8, 9, 38, or 39 wherein said blending produces at least 30,000 gallons of said produced unleaded gasoline.

54. A process as defined in claim 1, 4, 6, 7, 9, 32, 35, 37, 38, 39, 41, 43, or 51 wherein said produced unleaded gasoline has a 50% D-4 distillation point no greater than 210° F.

55. A process as defined in claim 1, 6, 9, 32, 37, 38, 39, 41, 43, or 52 wherein said produced unleaded gasoline has a Reid Vapor Pressure less than 7.0 psi.

56. A process as defined in claim 55 wherein said produced unleaded gasoline has a 50% D-4 distillation point no greater than 210° F.

57. A process as defined in claim 56 wherein said blending produces at least 50,000 gallons of said produced unleaded gasoline.

58. A process as defined in claim 57 wherein said produced unleaded gasoline has a 8% D-4 distillation point no greater than 300° F. and an olefin content less than 10 volume percent.

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