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EVALUATION OF HYDROCARBON DILUENTS FOR THE PUREX PROCESS

by

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ABSTRACT

Forty-nine hydrocarbon products were evaluated in the laboratory in a search for a highly stable diluent for the organic extractant used in a radiochemical separations plant. The formation of zirconium ligands during chemical and radiolytic degradation increased with boiling point for isoparaffinic products but was approximately constant for n-paraffins. Of those materials that met the local flash point specification, the n-paraffins were superior.

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EVALUATION OF HYDROCARBON DILUENTS FOR THE PUREX PROCESS

INTRODUCTION

The Purex process is a solvent extraction process employed at the Savannah River Plant to separate and recover plutonium and uranium from fission products that form during irradiation of uranium in a nuclear reactor. Tri-n-butyl phosphate (TBP) is used as the organic extractant in the Purex process. The TBP is used as a solution in a hydrocarbon product of which "Ultrasene"*, a purified kerosene, is typical. Unknown components in "Ultrasene" degrade chemically and radiolytically to form ligands that complex zirconium and other fission products^(1,2,3). These ligands are not removed from the solvent by either caustic or acidic washes⁽¹⁾ but remain in the solvent and cause operating difficulties. Di-n-butyl phosphate (DBP), the principal zirconium ligand produced by the degradation of TBP, can be removed from the solvent by a caustic wash⁽¹⁾.

A search was conducted for a diluent that would form fewer zirconium ligands. The primary objective of this study was to find a better diluent by evaluating the resistance of commercially available hydrocarbon products to chemical and radiolytic degradation. The number of zirconium ligands formed was a measure of stability. Relationships between stability and composition of the diluent were also studied.

Previous work in the Savannah River Laboratory served as a guide in the selection and evaluation of these diluents. Pollock demonstrated that olefin-free n-dodecane, obtained from Humphrey-Wilkinson, was a superior diluent for the Purex process on the basis of its resistance to chemical attack.⁽¹⁾ West found that the zirconium retention characteristics of the n-paraffins in "Ultrasene", separated from "Ultrasene" by urea treatment, were comparable to those of n-dodecane, and were much superior to those of "Ultrasene" itself.⁽⁴⁾ The characteristics reported by Dennis for the zirconium retention of certain pure iso- and cycloparaffins indicated that the stabilities of these compounds were comparable to those of n-dodecane.⁽⁵⁾ On the basis of this information, a diluent composed of normal paraffins and free of olefins and aromatics would be preferable although certain iso- or cycloparaffins might also make comparable diluents.

This report describes the evaluation of several commercially available hydrocarbon products that were considered as potential diluents. After this work was complete a British report⁽⁶⁾ was issued that described similar studies, but on different diluents.

"Adakane 12" was chosen for plant-scale evaluation in the most severe Purex service at Savannah River. The laboratory evaluation of this n-paraffin mixture is described in a separate report⁽⁷⁾.

*The supplier of each diluent is listed in Table I.

Although "Ultrasene" had served adequately as a Purex diluent in prior normal service at Savannah River, an incentive existed to search for a diluent that might diminish solvent recycle problems to a minimum for a TBP process. Other diluents comparable in stability to "Ultrasene" are also used at other sites, with satisfactory results. Thus, the "stabilities" given in this report cannot be used as absolute criteria of acceptability for any given service; specific needs are complex functions of radiation exposure, chemical exposure, time of contact, unit costs, and the like.

SUMMARY

The chemical and radiolytic stabilities of 30% TBP solvents made from nine of the forty-nine hydrocarbon products tested were sufficiently close to those of solvents of olefin-free n-dodecane to warrant consideration of these products as high-performance diluents. Of these nine hydrocarbon products with high stabilities only n-dodecane and "Adakane 12" had flash points equal to or above the 72°C minimum that is specified for the process at the Savannah River Plant (SRP). The other seven hydrocarbon products of high stability were mixtures of C₁₁-C₁₅ isoparaffins. Formation of zirconium ligands in isoparaffinic materials increased with boiling point, and a fraction with a boiling point high enough to have a satisfactory flash point offered little more stability than the "Ultrasene" diluent presently in use at SRP. Correlations were observed between stability and boiling point as well as between stability and compound class.

DISCUSSION

EXPERIMENTAL METHODS

The criterion for stability in this study was the resistance of the diluent to degradation to form zirconium ligands. Each of the candidate diluents was tested for chemical and radiolytic stability as a 30 vol % TBP solvent. The TBP was added to approximate more closely the plant environment for exposure to radiation and acids.

Aliquots of the solvents were degraded in contact with 4M HNO₃ - 0.1M HNO₂ either chemically for 7 days at 70°C or radiolytically to 10⁷ rep by exposure to a beta-gamma source. The degraded samples were then washed successively with distilled water, 1M NaOH, distilled water, 1M HNO₃, and distilled water. The washed samples were tested for zirconium retention by means of the "Z Test".⁽⁸⁾ Detailed descriptions of the degradation and washing procedures were given in an earlier report⁽⁴⁾.

Solvents prepared from olefin-free n-dodecane and "Ultrasene" were employed as controls in all of the stability tests. The stability ratios (shown in Table I) are the ratios of the "Z" numbers obtained for solvents made with each diluent to the "Z" numbers obtained for solvents made with n-dodecane. On this basis the best diluents are those with lowest stability ratios.

Gas-liquid chromatography (GLC) was utilized to characterize each of the diluents. A description of the experimental techniques and chromatograms of all the candidate diluents are in Appendix A. The chromatograms are calibrated for boiling points of the components.⁽⁴⁾

Selected samples were analyzed by infrared and ultraviolet spectrophotometry, low ionizing voltage mass spectrometry⁽⁹⁾, and Fluorescent Indicator Adsorption (FIA). The infrared and ultraviolet spectrograms, which provide further indication of sample purity, are described in Appendix B and Appendix C, respectively. Flash points were determined by Tag closed cup⁽¹⁰⁾. Fluorescent Indicator Adsorption analyses were done according to ASTM D-1319-60T⁽¹¹⁾.

COMPARATIVE STABILITIES

The stabilities and physical properties of hydrocarbon products obtained from commercial sources are compared to those properties of n-dodecane and "Ultrasene" in Table I. The stability ratios provide a measure of the resistance of the diluent to degradation to form zirconium ligands (the higher the ratio, the lower the stability). Specifications required the flash point of the diluent to be a minimum of 72°C and the specific gravity to be a maximum of 0.79. Although candidate diluents are listed in order of decreasing resistance to chemical degradation, care must be taken when comparing diluents whose stability ratios differ by a small amount. In order to make such a comparison easier, a summary of the precision of stability ratios is given in Appendix D. From the data in this table and the "Student's" t value⁽¹⁴⁾ corresponding to the number of determinations, the confidence limits at any desired probability level can be calculated. However, for the purpose of this study a detailed statistical analysis was not considered necessary since the stability tests were designed to select candidates for further consideration, and, therefore, minute differences in stability were not considered to be significant.

Only those candidate diluents with chemical stability ratios less than 15 and radiolytic stability ratios less than 1.1 were given further consideration. Of the diluents meeting these requirements, only "Adakane 12", a mixture of n-paraffins derived from 1-dodecanol, and n-dodecane had measured flash points at or above the required 72°C minimum. Ashland R-13 had a nominal flash point that met specifications, but insufficient sample was available to determine a flash point. However, a flash point of 67°C was obtained for Ashland R-22, a sample that had a nominal flash point identical to R-13. This topic will be discussed in more detail under Relationship Between Stability and Volatility.

RELATIONSHIP BETWEEN STABILITY AND COMPOUND CLASS

Of the compound classes tested, the n-paraffins were the most stable to chemical degradation. The excellent stability of the n-paraffins is shown in Table I and in Figure 1. "Kendall" SN-552a, a hydrocarbon

TABLE I

Comparative Stability and Physical Properties of Hydrocarbon Products

Diluent	Supplier	Source	Stability Ratio ^(a)		Flash Point ^(b) , °C		Boiling Point Range, °C		Sp Gr ^(e) Nominal ^(c)
			Chem.	Rad.	Nominal ^(c)	Measured	Nominal ^(c)	Measured ^(d)	
Olefin-free n-Dodecane (Control)	Humphrey-Wilkinson, Inc. North Haven, Conn.	Derived from 1-dodecanol	1	1.0	78	78	214	174-214	0.75
"Adakane 12"	Archer-Daniels-Midland Co. Minneapolis, Minn.	Derived from 1-dodecanol	1	0.6	96 (COC)	80	-	175-253	0.75
Amsco 125-82	American Mineral Spirits Co. Murray Hill, N. J.	Hydrogenated polymerized olefins	4	0.6	51	51	177-199	150-220	0.76
Ashland R-12	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	4	0.8	71	1.s.	188-198	155-230	0.77
Ashland R-13	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	6	1.0	72	1.s.	198-202	170-235	0.76
Ashland R-23	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	10	0.6	74	30	188-246	25-245	0.77
Ashland R-21	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	11	0.4	72	63 (PM)	188-199	180-215	0.77
Sonneborn Acid- Treated Hydrocarbon Fraction No. 285	Sonneborn Chemical & Refining Corp. New York, N. Y.	H ₂ SO ₄ -treated Stoddard solvent fraction	12	0.8	49	49	169-201	150-205	0.76
Sinclair Odorless Solvent (Light)	Sinclair Refining Co. New York, N. Y.	Isoparaffins from petroleum fraction	14	0.3	52	52	174-204	155-210	0.76
"Kendall" SN-552b	Kendall Refining Co. Bradford, Pa.	Petroleum alkylate (H ₂ SO ₄ washed)	15	0.8	72	76	-	175-250	0.77
Ashland R-14	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	15	1.2	74	1.s.	202-207	175-245	0.77
Ashland R-22	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	20	0.6	72	67	193-204	188-230	0.77
Ashland R-40 through R-44(f)	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	20	0.8	74	50 (PM)	188-246	50-245	0.77
Ashland R-23A	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	20	1.1	74	25	188-246	25-245	0.77
Ashland R-24	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	25	0.6	74	25	188-246	25-245	0.77
Ashland R-25	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	25	0.9	74	25	188-246	25-245	0.77
Ashland R-1 through R-11(f)	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	25	1.0	74	1.s.	188-246	155-250	0.77

A benzene 250	California Research Corp. San Francisco, Calif.	Aklylation product of benzene with polypropylene	25	4.0	125	-	210-250	210-255	0.81
Sonneborn Acid-Treated Hydrocarbon Fraction No. 338	Sonneborn Chemical & Refining Corp. New York, N. Y.	H ₂ SO ₄ -treated Stoddard solvent fraction	30	2.0	82	-	195-252	150-260	0.78
Ashland R-15	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	30	2.0	75	-	207-216	190-250	0.78
Ashland R-20	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	50	0.5	74	25	188-246	25-245	0.77
Amsco O-450 Naphtha	American Mineral Spirits Co. Murray Hill, N. J.	Petroleum distillate	50	1.6	83 (PM)	-	217-238	210-255	0.77
"Kendall" SN-552a	Kendall Refining Co. Bradford, Pa.	n-Paraffins from petroleum by urea treatment	50	1.6	88 (PM)	-	-	195-253	0.77
Phillips Iso-paraffinic Fraction	Phillips Petroleum Co. Bartlesville, Okla.	Petroleum alkylate	50	1.2	85	-	218-238	210-255	0.77
Ashland R-16	Ashland Oil & Refining Co. Ashland, Ky.	Isoparaffin	50	3.0	77	-	216-246	190-275	0.78
"Penn-Drake" 2251 Oil	Pennsylvania Refining Co. Butler, Pa.	Petroleum distillate	80	1.5	80 (COC)	-	196-249	150-254	-
Raffinate Wash Oil	Continental Oil Co. Houston, Tex.	Dearomatized (SO ₂ treated) kerosene	100	4.0	-	-	195-252	150-270	-
Sinclair Odorless Solvent (Heavy)	Sinclair Refining Co. New York, N. Y.	Isoparaffins from petroleum fraction	130	1.7	66	-	190-237	155-245	0.77
"Ultrasene"	Atlantic Refining Co. Philadelphia, Pa.	Refined kerosene	150	3	77	77	199-254	150-254	0.78
Kremol 40 White Mineral Oil	Continental Oil Co. Houston, Tex.	White mineral oil	200	0.5	132 (COC)	-	189-492 (10 mm Hg)	195-320	-
Amsco DeoBase S	American Mineral Spirits Co. Murray Hill, N. J.	Petroleum distillate	200	5.0	79	-	204-268	160-270	0.79
Shell Purex Diluent	Shell Chemical Co. (g) New York, N. Y.		200	8.0	-	-	-	150-254	
JP-5 Aviation Fuel	Texaco Inc. New York, N. Y.	Petroleum distillate	250	3.0	-	-	-	110-265	-
Amsco Odorless Base Oil 450 W-1	American Mineral Spirits Co. Murray Hill, N. J.	Petroleum distillate	250	6.0	64	-	191-238	160-270	0.77
Pennteck	Pennsylvania Refining Co. Butler, Pa.	White oil from petroleum	400	5.0	-	-	-	270-305	0.80

(a) "Z" number of 30% TBP-70% diluent
(a) "Z" number of 30% TBP-70% n-dodecane following chemical or radiolytic degradation.

(b) Determined by Tag closed-cup method⁽¹⁰⁾ unless noted: PM - Pensky-Martens closed cup⁽¹²⁾; COC - Cleveland open cup⁽¹³⁾.
1.s. indicates insufficient sample

(c) Data furnished by supplier

(d) From gas-liquid chromatograms

(e) Specific gravity at 25°C/25°C

(f) These samples were essentially identical.

(g) Sample obtained from Hanford Atomic Products Operation

FIG. 1 ZIRCONIUM LIGAND FORMATION AS A FUNCTION OF VOLATILITY

product produced on a laboratory scale by urea treatment of a kerosene fraction, was composed predominantly of n-paraffins but had a chemical stability ratio of 50. Previous work⁽⁴⁾ showed that such a diluent should be approximately as stable as n-dodecane. The chromatograms of the "Kendall" SN-552a diluent (see Appendix A) showed that this sample contained about 10 wt % nonlinear components. Subsequent treatment in this laboratory of "Kendall" SN-552a with urea reduced the concentration of nonlinear components to less than 2 wt % and improved the chemical stability to the level of olefin-free n-dodecane and "Adakane 12".

The stability of the isoparaffins was found to be a function of their volatility and will be discussed in the section on Relationship Between Stability and Volatility.

The only sample that was predominantly aromatic, Alkylbenzene 250, was moderately stable to chemical degradation but unstable to radiolytic degradation. This result verified previous work by the authors^(4,5).

Although no samples composed predominantly of olefins were tested, Amsco 125-82 contained approximately 1.5 vol % olefins, probably highly branched olefins. From the previous work of Dennis⁽⁵⁾ it was expected that the stability would be decreased by the presence of olefins. In that work, however, degradations were conducted in the absence of TBP. Therefore, the work was repeated with 30% TBP - 70% diluent. The curves shown in Figure 2 depict the effect of an olefin, propylene tetramer, on the stability of n-dodecane. Mixtures of 1-dodecene in n-dodecane followed the same general curves. Similar results are expected for other olefins although the magnitude of the ligand formation will probably vary with the degree of branching and the boiling point of the olefin in a manner similar to that reported for paraffins in the following section.

FIG. 2 EFFECT OF OLEFIN CONTENT ON STABILITY OF n-DODECANE-TBP MIXTURE

RELATIONSHIP BETWEEN STABILITY AND VOLATILITY

A relationship between stability and volatility was observed for the isoparaffins supplied by the Ashland Oil and Refining Co. Samples R-12 through R-16, reported by the suppliers to be distillation cuts from the same base material as samples R-1 through R-11, showed an inverse relationship between stability and boiling point as seen in Table II.

TABLE II

Stability and Volatility of Isoparaffins

	Stability Ratio		Boiling Point Range, °C	
	Chemically Degraded	Radiolytically Degraded	Nominal	Observed ^(a)
Ashland R-12	4	0.8	188-188	155-230
R-13	6	1.0	198-202	170-235
R-14	15	1.2	202-207	175-285
R-15	30	2.0	207-216	195-250
R-16	50	3.0	216-246	190-275
R-1 - R-11	25	1.0	188-246	155-250

(a) From gas-liquid chromatograms

The dependence of stability upon volatility for isoparaffins and for n-paraffins is shown in Figure 1. While the stabilities of the n-paraffins were only slightly affected by their volatilities, the stabilities of the isoparaffins decreased approximately linearly (stability ratio increased) with increase in boiling point over the range 200 to 250°C. For isoparaffins with boiling points below 200°C there was no significant change in the stability ratio. The n-paraffinic samples for this study

were obtained from the National Bureau of Standards and contained less than 0.2 mol % impurities. The isoparaffinic samples were fractions with boiling ranges narrower than 6°C; they were obtained from a fractional distillation of 1500 ml of Ashland sample R-20. The fractionation of this sample was performed by the Petroleum Analytical Research Corporation, Houston, Texas, by means of a 1-inch-diameter column with 75 theoretical plates at a reflux ratio of 20:1.

Since the flash point of an isoparaffin is directly related to its volatility⁽¹⁵⁾, the flash point specification at SRP establishes a limiting stability level. According to Butler's rule⁽¹⁵⁾, the temperature at which a hydrocarbon will flash is given by the equation

$$T_F = 0.683 T_B - 119$$

where T_F = flash point at 1 atmosphere, °F

T_B = boiling point at 1 atmosphere, °F

The upper abscissa of Figure 1 was graduated in flash point (°C) by applying the above equation to the boiling points given on the lower abscissa. These data show that a chemical stability ratio of 20 or above is expected for any isoparaffin of the type tested that meets the 72°C flash point specification at SRP. If a flash point of 65°C or lower were acceptable, an isoparaffinic diluent could be made that was approximately equivalent to the resistance of n-paraffins to degradation to zirconium ligands. For isoparaffinic diluents with flash points above 65°C, the higher flash points are achieved only by accepting a loss in stability.

The chromatograms of all of the hydrocarbon products evaluated in this study are included in Appendix A. The chromatographic column that was employed separated the components by the differences in their vapor pressures and had no other pronounced selective properties. Therefore, the chromatograms were presented as differential distillation curves with the approximate boiling points of the components in the sample indicated on the abscissa. The area under all of the peaks in each chromatogram is proportional to the weight of material sampled, and the area encompassed between any two temperatures represents the weight of the sampled material that boils between those two temperatures. These chromatograms, plus the selected infrared and ultraviolet spectrograms, provide a permanent record of the composition and purity of the materials that were investigated in the course of this work.

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APPENDIX A

GAS CHROMATOGRAMS OF THE HYDROCARBON DILUENTS

The chromatograms represent the fractionation of 5-microliter samples of each of the diluents with a Perkin-Elmer Model 188 Triple Stage Fractometer. The chromatograph was equipped with a 4-meter column that was packed with silicone grease on "Celite"*. The instrument was operated at 200°C with an inlet pressure of 22 psi. A thermal conductivity cell was used as a detector. The chromatograms were calibrated for the boiling point of the hydrocarbons so that the time scale on the conventional chromatograms became a temperature scale that represented the boiling point at one atmosphere.

With some samples it was necessary to attenuate the signal from the detector in order to prevent the recorder pen from driving off scale. In these cases the attenuation is indicated on the chromatogram, e.g. X8, which means the real peak height is eight times that shown on the chromatogram.

The supplier of each diluent is listed in Table I.

*A product of the Johns-Manville Corp., New York, N. Y.

FIG. A-1 GAS CHROMATOGRAMS OF DILUENTS FROM RADIOCHEMICAL SEPARATIONS PLANTS

FIG. A-2 GAS CHROMATOGRAMS OF n-PARAFFIN MIXTURES

FIG. A-3 GAS CHROMATOGRAMS OF DISTILLATION FRACTIONS OF AN ISOPARAFFIN MIXTURE
(from Ashland Oil & Refining Co.)

FIG. A-4 GAS CHROMATOGRAMS OF ISOPARAFFIN MIXTURES
(from Ashland Oil & Refining Co.)

FIG. A - 5 GAS CHROMATOGRAMS OF HIGH BOILING HYDROCARBONS

FIG. A-6 GAS CHROMATOGRAMS OF OTHER CANDIDATE DILUENTS

APPENDIX B

INFRARED SPECTROGRAMS OF SELECTED DILUENTS

Infrared spectra were measured either on those candidate diluents that exhibited a more favorable degree of stability or on those that are used in radiochemical separations processes at other sites. The spectra were recorded from 2 to 15 μ on a Perkin-Elmer Model 221 Spectrophotometer equipped with a sodium chloride prism. A sodium chloride plate was placed in the reference beam to compensate for reflectance losses. The cell thickness is shown on each spectrogram.

When considered in conjunction with the manufacturer's literature and the chromatograms of Appendix A, these infrared data provide useful information on the gross composition and purity of the hydrocarbon mixtures evaluated. For example, the percentage of normal paraffins present may be deduced from the relative intensity of the band that appears at 13.9 μ for molecules with more than four methylene ($-\text{CH}_2-$) groups in series.

The supplier of each diluent is listed in Table I.

FIG. B - 1 IR SPECTROGRAMS OF DILUENTS FROM RADIOCHEMICAL SEPARATIONS PLANTS

FIG. B-2 IR SPECTROGRAMS OF n-PARAFFIN MIXTURES

FIG. B-3 IR SPECTROGRAMS OF ISOPARAFFIN MIXTURES
(from Ashland Oil & Refining Co.)

FIG. B-4 IR SPECTROGRAMS OF OTHER CANDIDATE DILUENTS

APPENDIX C

ULTRAVIOLET SPECTROGRAMS OF SELECTED DILUENTS

As with the infrared spectra, ultraviolet spectra were measured on candidate diluents of interest because of high stability or known use in radiochemical plants at other AEC sites. The samples were measured from 4000 to 2000 Å in 1-cm cells (unless otherwise indicated) against isooctane with a Cary Recording Quartz Spectrophotometer Model 11 at a scanning rate of 300 Å/inch.

These ultraviolet spectra were used to ensure the absence of aromatic or conjugated olefinic compounds, which are known to be deleterious to chemical or radiolytic stability. They also served to ensure the absence of organic compounds such as acetone, that are commonly used to clean and dry laboratory glassware and sample containers.

The supplier of each diluent is listed in Table I.

FIG C-1 UV SPECTROGRAMS OF DILUENTS FROM RADIOCHEMICAL SEPARATIONS PLANTS

FIG. C-2 UV SPECTROGRAMS OF *n*-PARAFFIN MIXTURES

FIG. C-3 UV SPECTROGRAMS OF ISOPARAFFIN MIXTURES
(from Ashland Oil & Refining Co.)

FIG. C-4 UV SPECTROGRAMS OF OTHER CANDIDATE DILUENTS

APPENDIX D

STATISTICAL ANALYSIS OF STABILITY RATIOS

Description	Stability Ratio after Chemical Degradation ^(a)			Stability Ratio after Radiolytic Degradation		
	$\bar{x}$	$s/\sqrt{n}$	n	$\bar{x}$	$s/\sqrt{n}$	n
Olefin-free n-Dodecane (Control)	1			1		
"Adakane 12"	1	0.2	9	0.6	-	1
Amsco 125-82	4	1	3	0.56	0.10	5
Ashland R-12	4	1	2	0.76	0.075	2
Ashland R-13	6	1	2	1.0	0.1	2
Ashland R-23	10	2	4	0.61	0.18	4
Ashland R-21	11	2	6	0.42	0.04	6
Sonneborn Acid-Treated Hydrocarbon Fraction No. 285	12	1	2	0.8	0.4	2
Sinclair Odorless Solvent (Light)	14	4	2	0.31	0.01	2
"Kendall" SN-552b	15	2	2	0.8	-	1
Ashland R-14	15	1	2	1.2	0.1	2
Ashland R-22	20	5	3	0.56	0.12	4
Ashland R-40 through R-44	20	5	20	0.80	0.01	20
Ashland R-23A	20	4	2	1.1	0.6	2
Ashland R-24	25	4	4	0.6	0.1	4
Ashland R-25	25	6	2	0.9	0.2	4
Ashland R-1 through R-11	25	2	20	0.90	0.01	20
Alkylbenzene 250	25	2	2	3.7	0.1	2
Sonneborn Acid-Treated Hydrocarbon Fraction No. 338	30	5	2	2	-	1
Ashland R-15	30	8	2	1.8	0.1	2
Ashland R-20	50	13	6	0.54	0.09	6
Amsco O-450 Naphtha	50	4	4	1.6	0.3	2
"Kendall" SN-552a	50	7	2	1.6	-	1
Phillips Isoparaaffinic Fraction	50	7	2	1.2	-	1
Ashland R-16	50	10	2	2.7	0.1	2
"Penn-Drake" 2251 Oil	80	20	2	1.5	0.2	2
Raffinate Wash Oil	100	50	2	4	2	2
Sinclair Odorless Solvent (Heavy)	130	60	2	1.7	0.1	2
"Ultrasene"	150	30	10	2.8	0.3	10
Kremol 40 White Mineral Oil	200	-	1	0.5	-	1
Amsco DeoBase S	200	70	2	4.6	0.5	2
Shell Purex Diluent	200	70	2	8	4	2
JP-5 Aviation Fuel	250	40	2	3	-	1
Amsco Odorless Base Oil 450 W-1	250	15	2	5.6	0.1	2
Pennteck	400	140	2	4.8	0.2	2

(a) $\bar{x}$ is the average stability ratio.
 s is the standard deviation.
 n is the number of determinations.