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SAFETY ASPECTS OF SOLVENT NITRATION IN HTGR FUEL REPROCESSING

by
R. G. WILBOURN

Prepared under
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ABSTRACT

Reprocessing of HTGR fuels requires evaporative concentration of uranium and thorium nitrate solutions. The results of a bench-scale test program conducted to assess the safety aspects of planned concentrator operations are reported herein.

SUMMARY

Tributyl phosphate (TBP) solvent extraction will be used for the separation of uranium and thorium from fission products in spent HTGR fuel reprocessing. The Acid-Thorex process will be used for the combined Th/U-233 fertile and U-233 fissile dissolver solutions and a modified Purex process will be used for the U-235 fissile solutions.

Both the modified Purex and Acid-Thorex solvent extraction flowsheets specify heavy metal concentration steps using evaporators. The concentration steps are required to reduce acidity levels and solution volumes prior to further processing or product storage. In previous work with the Purex process, vigorous reactions were encountered during the uranium concentration operations, resulting in equipment loss and presenting a hazard to personnel.

This report covers the bench-scale experimentation performed at General Atomic Company to assess the potential for the occurrence of a rapid, exothermic reaction in planned heavy metal concentrator operations. The bench-scale work was done to serve as a guide for expected behavior of the thorium nitrate/solvent system in pilot and engineering scale concentrators under normal flowsheet operation, as well as extreme conditions potentially arising from inadvertent concentrator maloperation.

Based on data obtained from bench-scale experiments, the following conclusions were drawn:

1. The hydrocarbon diluent employed has an important role in solvent nitration.
2. The normal paraffin hydrocarbon diluent, i.e., NPH, currently being used in pilot plant HTGR fuel reprocessing studies is more

resistant to nitration than diluents used in early plant applications of the Purex process. "Red-oil" (an organic phase mixture of heavy metal nitrate and organic decomposition products) was not formed in tests using TBP/NPH as the solvent system during concentration of thorium and uranyl nitrate solutions under literature conditions reported to produce "red-oil" with a previously employed diluent.

3. No vigorous, uncontrolled reactions were observed for the TBP/NPH thorium nitrate system or the TBP/NPH uranyl nitrate system at temperatures to 150°C under experimental conditions described herein.
4. With suitable concentrator design (to control foaming and to vent flammable gases), an inadvertent temperature excursion to 150°C does not constitute an undue safety hazard, if a nitration-resistant diluent is used.

1. INTRODUCTION

Two processes, i.e., Purex (Ref. 1) and Acid-Thorex (Ref. 2), are used in nuclear fuel reprocessing applications. The Purex process was developed for the separation and recovery of fissionable isotopes in uranium-plutonium reprocessing campaigns. The Acid-Thorex process was developed for the reprocessing of thorium-uranium based nuclear fuels.

Tributyl phosphate is the extractant employed in both the Purex and Acid-Thorex solvent extraction processes for heavy metal-fission product separation. The extractant is generally used in a kerosene diluent to reduce the density and viscosity of the extractant and to enhance aqueous/organic phase separation. The TBP/diluent system is commonly referred to as the process solvent. Many kerosene-type diluents have been used over the years, and Tables A, B, and C in the Appendix contain the physical and chemical properties of some of these diluents. Inertness of the diluent toward chemical reactions with process materials and radiation, as well as cost, are major considerations in the selection of the diluent.

The most obvious effect of diluent degradation due to nitration in solvent extraction process applications is a marked reduction in observed heavy metal - fission product decontamination factors (DFs). The deleterious DFs observed in processes with degraded solvents are due partly to the formation of ligands which complex with fission products, e.g., zirconium, and are soluble in the solvent phase. Experiments conducted at Savannah River (Ref. 3) have shown n-dodecane to be the most nitration-resistant diluent among a group of normal and isoparaffin hydrocarbons tested. The nitration stability of n-dodecane was found to be 20 to 30 times greater than the purified kerosene diluent "Ultrasene" used in early solvent extraction work (see Table A in the Appendix). Degraded solvents also show poor phase separation and decreased mass transfer coefficients for

uranium and thorium. Consequently, nitration-resistant diluents have been identified and used in more recent solvent extraction operations (Ref. 4).

The present work has shown diluent nitration resistance to be an important consideration in the safe operation of heavy metal concentrators. Figures 1 and 2 contain simplified flowsheets for the modified Purex and Acid-Thorex processes. Heavy metal concentration is a requirement common to both flowsheets.

In earlier Purex process work (Refs. 5, 6), vigorous, exothermic reactions were encountered during concentration of uranyl nitrate product. Previously reported concentrator incidents have four features in common: (a) solvent was present in the concentrate; (b) concentration had proceeded to the point of incipient calcination of the uranyl nitrate (temperatures above 135°C); (c) the explosion, or rapid reaction, involved the evolution of nitrogen oxides; and (d) "red-oil" was found on subsequent examination of concentrator contents (Ref. 7).

As a result of the rapid, exothermic reactions encountered in the concentration of uranyl nitrate in the Purex process, maximum concentrator operating temperatures were routinely restricted to 135°C. In addition, laboratory studies were undertaken at both Savannah River (Ref. 5) and Hanford (Ref. 8) to determine the conditions necessary for "red-oil" formation and rapid reactions between Purex process solvent and uranyl nitrate solutions containing nitric acid. The formation of "red-oil" is a precursor of vigorous, exothermic reactions in concentrator operations (Ref. 9). Experiments were also performed at Hanford (Ref. 10) with the plutonyl nitrate/solvent system with similar results; however, no experiments were performed with the thorium nitrate system.

In the tests conducted at Hanford (Ref. 8), "red-oil" formation was observed on refluxing of 1.1 M nitric acid containing 0.1 M uranyl nitrate with 30 volume percent TBP/diluent for 72 hours. The diluent used in the

Fig. 1. Modified Purex process - simplified flowsheet

Fig. 2. Acid-Thorex process - simplified flowsheet, Th/U-233 fertile stream

Hanford solvent extraction operations and subsequent laboratory work was Shell Deodorized Spray Base (see Table A in the Appendix).^{*} No literature reports of "red-oil" formation could be found in which the solvent system was composed of TBP/NPH.

A bench-scale experimental study was undertaken at General Atomic Company in an effort to establish conditions for "red-oil" formation or vigorous, exothermic reactions with the currently used diluent, i.e., South Hampton Company NPH,^{**} and Chevron Deodorized Spray Base Solvent 450.^{***} The physical properties of these diluents are given in Tables A and B in the Appendix. The tests consisted of heating various mixtures of uranyl and thorium nitrate solutions with solvent and monitoring reaction rates as a function of time. All tests were performed at atmospheric pressure. Tests were not performed with Shell Deodorized Spray Base diluent used in previous work (Ref. 8) because the material is currently unavailable.

*A product of Shell Oil Company.

**A product of South Hampton Company, Silsbee, Texas.

***A product of Standard Oil Company of California.

2. EXPERIMENTAL AND RESULTS

2.1. OPEN CUP EXPERIMENTS

Several nitration experiments were performed in 25 x 50 mm open glass cups. A sand bath and a phosphoric acid bath were used to heat the cups and contents on a hot plate under controlled conditions. Time and temperature data were taken during heat-up and any visual evidence of a rapid reaction was noted. A slow evolution of NO_2 was observed in all open cup experiments on heating to $>125^\circ\text{C}$.

Data collected for diluent only (no TBP content) in contact with 1 M uranium or thorium nitrate in Thorex dissolver solution (9 M HNO_3 , 0.1 M Al^{+3} , 0.05 M F^-) appear in Table 1. The greater susceptibility of Chevron Deodorized Spray Base Solvent 450 to nitration, as opposed to NPH, is readily apparent in the results shown in Table 1.

Data are summarized in Table 2 for experiments in which thorium nitrate-nitric acid-30% TBP/diluent mixtures prepared at ambient temperatures were quickly immersed in open cups into a phosphoric acid bath at 138°C (these experiments were designed to simulate the sudden introduction of organic material into a concentrator under inadvertent maloperation). Results presented in Table 2 indicate that temperatures well in excess of 150°C were required for rapid reaction with heavy metal-TBP/NPH systems.

Additional experiments were conducted by insertion of open cups containing 30% TBP/diluent organic phases following equilibration with 1 M thorium/uranium Thorex solutions into a preheated aluminum block (7.6 cm x 5.1 cm x 5.1 cm) machined to receive the cups (see Fig. 3). This method was used to test samples of Conoco $\text{C}_{12}\text{C}_{14}^*$ and Texaco P-4^{**} normal paraffin

*A product of Continental Oil Company.

**A product of Texaco.

TABLE 1
DILUENT NITRATION STUDY - DATA SUMMARY

Time (min)	Temperature (°C)	Observation
0	25	
12	59	
17	75	
22	86	
24	91	Yellow discoloration - Spray Base samples
27	99	NO ₂ evolution - Spray Base samples
37	108	
40	112	Incipient foaming - Spray Base samples
45	115	
47	117	Excessive foaming - Spray Base samples
61	125	No reaction observed - NPH samples

Sample Composition:

2 ml of 1 M U or 1 M Th in Thorex

1 ml of test diluent (Chevron 450 Spray Base or NPH)

TABLE 2
TBP/DILUENT NITRATION STUDY - DATA SUMMARY A

Time (min)	Temperature (°C)	Observation
0	138	
3	125	Foaming and NO ₂ Tubes 3 and 5
6	119	
18	116	
24	118	
29	120	
34	122	
41	127	Excessive foaming Tubes 3 and 5
52	133	
59	137	
68	145	
73	150	Organic layer turbid Tube 4
80	153	Incipient foaming Tube 4
92	180	
94	185	
104	197	

Initial Temperature: 138°C.

Sample Composition:

Tube 1 2 ml 1 M Th-Thorex solution only

Tube 2 2 ml 1 M Th-Thorex solution + 1.0 ml 30% TBP/NPH

Tube 3 2 ml 1 M Th-Thorex solution + 1.0 ml 30% TBP/S. Base

Tube 4 2 ml 1 M Th-Thorex solution + 1.0 ml 30% TBP/NPH

Tube 5 2 ml 1 M Th-Thorex solution + 1.0 ml 30% TBP/S. Base

Fig. 3. Aluminum block-glass cup heating apparatus

hydrocarbons (commercially available materials furnished through the courtesy of Allied General Nuclear Services from inventory -- see Table C in the Appendix), as well as the previously mentioned diluents. Data obtained for these tests appear in Table 3.

No rapid, exothermic reactions were observed during these tests. Slow evolution of NO_2 , however, was observed in all tests performed, and incipient NO_2 evolution occurred at a lower temperature with Chevron Deodorized Spray Base Solvent 450 than with NPH.

A photograph of some of the organic layers resulting from these tests appears as Fig. A-1 in the Appendix. The varying degree of solvent degradation as a function of diluent is evident in Fig. A-1.

2.2. REFLUX EXPERIMENTS

Initial experimentation at General Atomic Company revealed the NPH diluent to be more resistant to nitration than a previously used naphthenic-type solvent (Shell Deodorized Spray Base). To verify this finding, reflux experiments were performed under literature conditions reported to produce "red-oil" (Ref. 8). These experiments consisted of refluxing 200 ml of 1.1 M nitric acid containing 0.1 M uranyl nitrate or thorium nitrate (b.p. = 101°C) with 25 ml of 30% TBP/diluent for 72 hours. "Red-oil" formation was observed only in organic phases containing the naphthenic-type diluent and was formed in both thorium and uranyl nitrate heavy metal systems. Additional reflux experiments demonstrated "red oil" was not formed in systems containing NPH diluent under conditions more extreme than described above (aqueous concentrations to 1 M heavy metal and 6.5 M nitric acid, boiling at 113°C).

As further evidence of the nitration susceptibility of the naphthenic-type diluent, an infrared spectrogram is given in Fig. 4. A "red-oil" sample derived from Chevron Deodorized Spray Base Solvent 450, as described above, was prepared for the spectral analysis by water washing to remove

TABLE 3
TBP/DILUENT NITRATION STUDY - DATA SUMMARY B

System ^(a)	Aluminum Block Temperature (°C)	Temperature Incipient NO ₂ Evolution (°C)	Final Temperature (°C)	Time Elapsed Insertion-Final Temperature (min)
30% TBP/Chev. S. Base/Th	175	77	171	6.5
30% TBP/Chev. S. Base/U	175	109	170	8.5
30% TBP/So. Hamp. NPH/Th	175	109	159	6.5
30% TBP/So. Hamp. NPH/U	175	129	158	6.5
30% TBP/Conoco NPH/Th	175	121	150	7.0
30% TBP/Texaco NPH/Th	175	122	159	7.0

(a) Prior to test, organic phase was equilibrated with 1 M Th/U-Thorex solution.

CONCENTRATION _____	FILM _____	SCAN MODE	ACCY. ☐	SURVEY ☒	SPECTRUM NO. 42652
THICKNESS _____			HI ENERGY ☐	CAL ☐	SAMPLE 1=30% TBP IN SPRAY BASE
PHASE _____			RESOLUTION ☐		2=72 HOUR NITRATION PRODUCT
REMARKS _____		OPERATOR CLC	DATE 1/29/75		ORIGIN _____

Fig. 4. Infrared spectrogram

thorium nitrate and nitric acid. The original 30% TBP/Spray Base infrared scan is included in Fig. 4 for reference. The additional regions of infrared absorption for the "red-oil" sample generally correspond to nitro substitution in organic compounds.

2.3. SIMULATED CONCENTRATOR EXPERIMENTS

Chemical analyses of a typical pilot plant intercycle concentrator product solution (ITC) gave a composition of 1.43 M Th^{+4} and 3.50 M H^{+} . The boiling point of the typical ITC solution was determined to be 112°C . An aqueous solution of the above composition was prepared from reagent grade thorium-nitrate tetrahydrate and nitric acid and was used for all experiments described in this section. Two organic solutions were prepared for static flooding and continuous addition tests; these were composed of 30% TBP by volume dissolved in South Hampton Company NPH and Chevron Deodorized Spray Base Solvent 450, respectively.

2.3.1. Simulated Thorium Intercycle Concentrator Operation - Organic Static Flooding Tests

A drawing of the apparatus used for organic static flooding tests appears as Fig. 5.

In these tests, an amount of TBP/diluent solution to yield a TBP/thorium nitrate weight ratio of 0.15^{*} was added to a simulated ITC solution, which had its boiling point adjusted by evaporation to a predetermined temperature prior to operation under reflux. Thorium intercycle concentrator bottom solutions with boiling points greater than $\sim 118^{\circ}\text{C}$ would result only during maloperation of a thorium intercycle concentrator. Following addition of the organic solution, the system was allowed to reflux for several hours to monitor (a) the occurrence of a vigorous reaction, and (b) the formation of "red-oil" (evidence of solvent nitration).

*This ratio was selected because work at Hanford (Ref. 8) indicated a minimum critical ratio of 0.15 for vigorous reactions with the TBP/uranyl nitrate system.

Fig. 5. Experimental apparatus for static organic flooding tests

Experimental data obtained and observations recorded during static flooding tests are presented in Tables 4 and 5.

No vigorous reactions were observed in tests with either the South Hampton Company NPH or Chevron Deodorized Spray Base Solvent 450 system. Slow evolution of NO_2 was observed in all tests performed. The presence of "red-oil" was noted in all tests in which Chevron Deodorized Spray Base Solvent 450 was used as a diluent. A slight red organic phase coloration was noted for the NPH diluent system only after twelve hours of refluxing at 150°C . A photograph of typical reaction products from these tests is given in Fig. A-2 in the Appendix.

2.3.2. Simulated Thorium Intercycle Concentrator Operation - Continuous Organic Addition Tests

A drawing and a photograph of the apparatus used for continuous organic flooding tests appear as Figs. 6 and 7, respectively.

The aqueous solution described above was heated to 135°C to simulate thorium intercycle product overconcentration which could occur during mal-operation of a thorium intercycle concentrator. On attainment of 135°C , 30% by volume TBP/diluent was added to the boiler pot at a rate of 0.42 ml/min with a metering pump (FMI RPIG 50). The total volume of 30% TBP/diluent added was 25.2 ml, which is equivalent to a TBP/thorium nitrate weight ratio of 0.23.*

In continuous organic addition experiments, no vigorous reactions occurred at 135°C . Examination of boiler pot contents following continuous operations revealed "red-oil" formation only in tests employing Chevron Deodorized Spray Base Solvent 450.

*This ratio is considerably in excess of the 0.15 critical ratio for vigorous reactions found in earlier work (Ref. 8).

TABLE 4
SYSTEM TBP/CHEVRON SPRAY BASE - STATIC FLOODING TESTS - DATA SUMMARY

Test No.	Boiling Point Aqueous Solution (°C)	Total Initial Vol. Aqueous Solution ^(a) (ml)	Time Period for Organic Addition (min)	Total Vol. 30% TBP/S. Base Added (ml)	Total Reflux Time (hr)	Observation ^(b)
1	118	67.5	10	10	12	A
2	125	67.5	15	10	16	B
3	135	101.3	20	15	8.5	C
4	150	101.3	20	15	4.25	D

(a) Initial aqueous composition = 1.38 M Th⁺⁴, 3.37 M H⁺.

(b) All organic layers had red colorations. The color intensity increased directly as a function of temperature. The NO₂ evolution rate appeared to decrease with increasing temperature and may be due to decreasing free acidity at higher temperatures.

A Considerable NO₂ evolution. No foaming.

B Considerable NO₂ evolution. No foaming.

C NO₂ evolution. Some evidence of foaming.

D NO₂ evolution. Some evidence of foaming. Boiling point (constant) of aqueous layer dropped to 135°C by end of reflux period (due possibly to lower boiling point of the denitrated salt).

TABLE 5
SYSTEM TBP/NPH - STATIC FLOODING TESTS - DATA SUMMARY

Test No.	Boiling Point Aqueous Solution (°C)	Total Initial Vol. Aqueous Solution(a) (ml)	Time Period for Organic Addition (min)	Total Vol. 30% TBP/NPH Added (ml)	Total Reflux Time (hr)	Observation (b)
1	112	67.5	5	10	19.5	A
2	117	67.5	5	10	16.0	B
3	124	67.5	5	10	18.75	C
4	130	101.2	10	15	14.75	D
5	135	101.2	15	15	13.5	E
6	150	101.2	5	15	12.0	F

(a) Initial aqueous composition = 1.38 M Th^{+4} , 3.37 M H^{+} .

(b) Only the organic layer from Test 6 had a slight red coloration. The NO_2 evolution rate appeared to decrease with increasing temperature and may be due to decreasing free acidity at higher temperatures.

A Slow NO_2 evolution throughout reflux period. No foaming.

B NO_2 evolution more rapid than Test 1. Gelatinous ppt observed on return to ambient temperature. It is speculated that ppt is a reaction product of thorium and TBP hydrolysis products. No foaming.

C NO_2 evolution. No foaming.

D NO_2 evolution. No foaming.

E NO_2 evolution. Boiling point (constant) of aqueous layer dropped to 122°C by end of reflux period.

F Slow NO_2 evolution. Boiling point (constant) of aqueous layer dropped to 135°C by end of reflux period.

Fig. 6. Experimental apparatus for continuous organic addition tests

Fig. 7. Experimental apparatus for continuous organic flooding tests

3. CONCLUSIONS

Bench-scale experimentation conducted at General Atomic Company has given no evidence to support the existence of an undue safety hazard in the planned operation of the heavy metal concentrators in the Acid-Thorex flowsheet. Also, no vigorous, exothermic reactions were encountered in tests designed to simulate concentrator maloperations (temperatures to 150°C) with South Hampton and Conoco NPH or Chevron Deodorized Spray Base Solvent 450. Test results indicate operation of a heavy metal nitrate concentrator with shell temperatures to 150°C (with attendant increase in effective ΔT , which controls the heat transfer to the solution and thus the evaporation rate) is permissible provided adequate safety factors are incorporated in the design of the concentrator. These safety factors would include the following:

1. Use of a nitration-resistant diluent, e.g., South Hampton, Conoco, or Texaco NPH.
2. A maximum allowable steam chest temperature of 150°C.
3. Incorporation of design safeguards to prevent (a) concentrator deentrainment tower plugging and resultant pressure buildup and (b) organic flooding of the concentrator with a resultant TBP/thorium nitrate weight ratio in excess of 0.15 at 150°C (0.23 at 135°C).

In addition to improving heavy metal - fission product DFs, use of the nitration diluent, NPH, has significantly reduced the hazard potential of heavy metal concentrator operations.

4. RECOMMENDED FUTURE STUDY

Additional tests should be conducted at atmospheric pressure to determine whether a minimum critical weight ratio for vigorous reactions exists for the thorium nitrate-TBP/NPH system as a function of temperature. The present work has shown the minimum critical thorium nitrate/TBP weight ratio to be >0.23 at 135°C and >0.15 at 150°C . Also, a study of the nitration behavior of uranium/thorium - solvent systems during heating under pressure greater than atmospheric is suggested.

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APPENDIX

<u>Sample</u>	<u>System Composition</u>	<u>Final Temperature °C</u>
A	TBP/ Conoco - Thorium Nitrate	150
B	TBP/South Hampton - Thorium Nitrate	159
C	TBP/Chevron S. Base - Thorium Nitrate	171
D	TBP/Chevron S. Base - Thorium Nitrate	128
E	TBP/South Hampton - Uranyl Nitrate	158
F	TBP/Chevron S. Base - Uranyl Nitrate	143
G	TBP/Chevron S. Base - Thorium Nitrate	160

Fig. A-1. Representative degraded solvent test products

<u>Sample</u>	<u>System Composition</u>	<u>Final Temperature °C</u>
A	TBP/NPH - Thorium Nitrate	150
B	TBP/S. Base - Thorium Nitrate	150

Fig. A-2. Typical reaction products from organic static flooding tests

TABLE A
PROPERTIES OF DILUENTS^(a)

Diluent	Density at 25°C (g/ml)	Index of Refraction, 25 n _D	Viscosity at 25°C, Millipoises	Boiling Range and Mid-Point (°C)	Flash Point Tag Closed Cup (°C)	Aromatic Content Vol. %	Naphthene Content Vol. %	Iodine Number	Specific Heat at 25°C) Cal./(0.) (°C)	References
Soltrol-170(c)	0.7728	1.4315	--	208-239 (225)	89	Nil	Nil	<1.1(c)	--	10
Soltrol-170(d)	0.7764	1.4289	22.9	214-235 (225)	84	--	--	<1(c)	--	10
Shell Deodorized Spray Base	0.8038	1.4435	19.0	193-260 (232)	66	<1.0	20 to 30	0.42	--	
Shell E-2342	0.801	--	16.8	--	74	0.1	ca. 80	--	--	10
Deobase	0.7804	1.4344	17.3	198-269 (225)	72	<1.0	--	0.02	--	10
Amsco 125-90W	0.7570	1.4226	14.1	186-199 (190)	56	<1.0	--	0.49	--	10
Amsco 123-15N	0.7879	--	11.4	187-204 (191)	62	11	--	--	0.48	10
Ultrasene	0.776	--	15.7	200-250	73 (91)(b)	--	--	--	--	10
Gulf BT "Varsol"	0.7606	1.4271	8.9	165-198 (177)	44	9.1	--	1.07	0.45	10
Dodecane (C ₁₂ H ₂₆)	0.746	1.419	14.0	216	74	--	--	--	--	10
Chevron 450	0.809	1.442	--	191-260 (215)	63	2	63	--	--	Standard Oil Co.

(a) The properties of commercial diluents are subject to slight variations from batch to batch. The data tabulated represent typical values for the indicated diluents.

(b) After washing with water. The Cleveland closed cup flash point is 84°C.

(c) Properties as cited by manufacturer [see Note (a)].

(d) Properties as determined on one sample at H.A.P.O. [see Note (a)].

Source: See Reference No. 11.

TABLE B
NORMAL PARAFFIN HYDROCARBON - SPECIFICATIONS

N-paraffin hydrocarbon	Min. 98 vol. %
C ₁₀ to C ₁₄ components	Min. 99 vol. %
Aromatics as 1, 2, 3, 4-tetrahydronaphthalene	Max. 0.2 wt. %
Iodine number (olefins as wt. % 1-tetradecene)	Max. 0.1 wt. %
Alcohol	Max. 0.05 wt. %
Sp. Gr. @ 20/20°C	Max. 0.76
Viscosity @ 25°C	Max. 1.8 Centipoise
Flash point	70°C

TABLE C
NORMAL PARAFFIN HYDROCARBON PROPERTIES

	Conoco C ₁₂ C ₁₄		Texaco P-4	
	Spex	AGNS Analysis	Spex	AGNS Analysis
C ₁₀ and lighter	--	<0.2 wt. %	--	<0.1
C ₁₁ and lighter	2.0 % Max.	0.8 wt. %	--	0.5
C ₁₂	10 ± 5%	8.5 wt. %	8-15%	8.5
C ₁₃	50 Min.	58.1 wt. %	45-50%	48.5
C ₁₄	30-45%	32.4 wt. %	30-45%	40.9
C ₁₅ and higher	2.0 Max	<0.2 wt. %	--	1.5
C ₁₆	--	--	--	0.2
C ₁₇ or greater	--	--	--	<0.1
Total N- Paraffin	97.5 Min.	--	98% Min.	--
Aromatics	0.6 Max.	0.27%	0.5% Max.	0.42%
Bromine index	200 Max.	<20 (mg/100g)	100 Max.	<20 (mg/100g)
Sulfur, ppm	10 Max.	--	5 ppm Max.	--

Specific Gravity ----- 16%C ----- 0.763.

Flash, pt. ----- (Pensky-Martens) -- 96°C.

Source of table: Ref. 12.