



Properties of Real and “Virtual” Blends of FT IPK and JP-8

Reference:

Muzzell, P.; Stavinocha, L.; Freerks, R.; McKay, B.; Terry, A.; Sattler, E.
“Properties of Fischer-Tropsch (FT) Blends for Use in Military Equipment”,
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Presentation Content

- Single Fuel on the Battlefield Policy
- OSD Assured Fuels Initiative (formerly OSD Clean Fuels Initiative)
 - Joint Battlespace Use Fuel of the Future (JBUFF)
- Near-term use of Fischer-Tropsch (FT) fuel
- Properties of JP-8 and FT IPK
- Properties of blends of FT IPK and JP-8
- Conclusions / Recommended Follow-on Study



Single Fuel on the Battlefield Policy

- JP-8 / JP-5 / Jet A-1(+CI/LI) is the single fuel for all tactical equipment (land, air, marine fleets)
 - Utilized in training and combat operation; CONUS and OCONUS
 - “Ready at a moment’s notice!”
 - Improved reliability and readiness
 - Reduced maintenance
- Currently, fuel is produced from crude oil (petroleum)
- Over 70% of fuel consumed by DoD is JP-8 / JP-5 / Jet A-1



OSD Assured Fuels Initiative

- Vision: DoD intends to catalyze commercial industry to produce clean fuels for the military from secure domestic resources using environmentally sensitive processes as a bridge to the future.
- Initiative aims to reduce/offset:
 - Growing dependence of the U.S. on foreign oil
 - Vulnerability of the mega-refineries supply
 - Divergence in the sulfur content of jet fuel and diesel fuel
 - Potential limits on operations due to emission regulations
 - Rising cost of fuel



Properties of FT IPK

- FT IPK can be refined to meet the JP-8 specification Table I values with exception of density
 - FT IPK included in this study is S-8 made by Syntroleum Corp.
- Properties of S-8
 - Density of 0.751-0.754 kg/L [ASTM D 4052]
 - Data for S-8 used in this study as reported by Syntroleum Corp.
 - JP-8 specification range of 0.775 – 0.840 kg/L
 - Negligible aromatics and sulfur content
 - JP-8 specification mandates maximum contents only
 - Cetane index of 67-70 [ASTM D 976*]
 - Data for S-8 used in this study as calculated by Army TARDEC
 - Cetane number >55 [ASTM D 613*]
 - S-8 data reported by Southwest Research Institute

* Test methods are not validated for Fischer-Tropsch fuels.



Technical Challenge

- Ensure that FT fuel can be used interchangeably with petroleum JP-8/JP-5/Jet A-1 fuel in use today
- FT Iso-Paraffinic Kerosene (IPK) contains no/low aromatic content
 - Some fuel-wetted elastomers sensitive to aromatic compounds (most notably nitrile) found in fuel distribution systems (e.g., o-rings)
 - Sensitive elastomers are known to swell when exposed to aromatic content in petroleum-derived fuels such as JP-8/JP-5/Jet A-1
 - When exposed to FT IPK, these sensitive elastomers may then shrink, creating risk of fuel leakage
 - Risk of fuel leakage is greatest for aged elastomer components that have taken on some compression set



Near-term use of FT Fuel

- Mitigate risk of introducing FT fuels to military fleet by blending FT fuels with petroleum derived fuels
- DEF STAN 91-91 approves the use of a blend of FT kerosene, produced by Sasol, with Jet A-1 for use at Johannesburg International Airport with two limitations:
 1. Final blend must have a minimum 8 vol. % aromatic concentration supplied by JP-8
 2. Final blend must contain less than 50% FT kerosene and have density >0.775 kg/L
- In near-term, FT fuel supply availability realistically only supports wide-use implementation of FT/petroleum fuel blends
 - Furthermore, most realistic scenario supports use of FT/petroleum fuel blends nearest manufacturing sites of FT IPK



Properties of JP-8

- Petroleum Quality Information System (PQIS)
 - Very useful database maintained by Defense Energy Support Center (DESC)
 - Contains critical chemical/physical properties for all bulk fuels procured
- PQIS data can be used to define a “property box” for JP-8 procured by region in CONUS (U.S.) and/or in OCONUS (worldwide)
- For the purposes of this study, 2004 CONUS data was used to develop the property ‘box’ for CONUS JP-8 fuel



Analysis of PQIS JP-8 Data

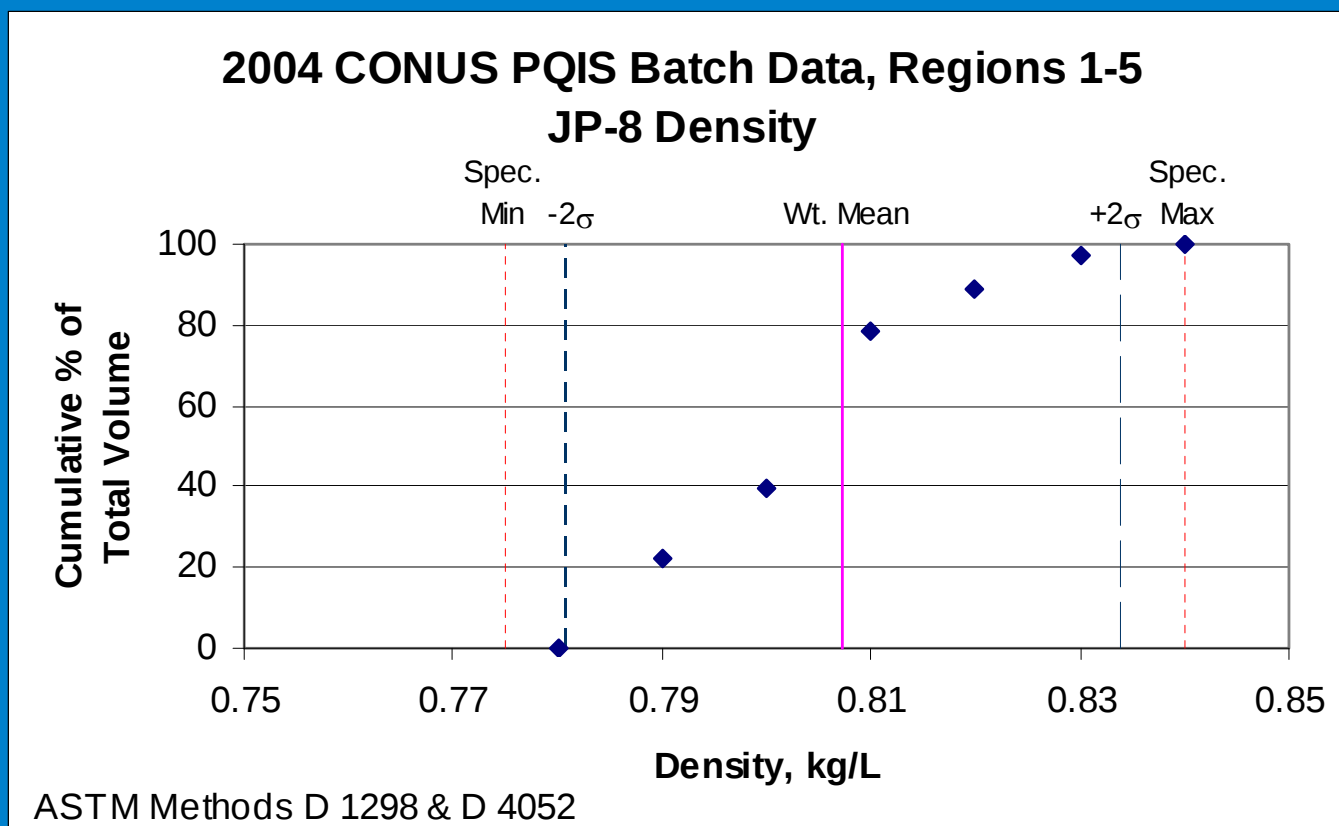
- Analysis included 16,000+ JP-8 data points from 2061 batches associated with 2,004,941,934 gallons of JP-8 fuel (2004 only, CONUS Regions 1-5 only)
- Mean, weighted mean, +/- 2 sigma standard deviations, were calculated for several properties according to:
 - Fraction of regional and total CONUS volumes
 - Cumulative fraction of regional and total CONUS volumes
- Data included in analysis*
 - Density
 - Aromatic Content
 - Sulfur Content
 - Viscosity at -20 °C
 - Freeze Point
 - Final Boiling Point
 - Net Heat of Combustion
 - Cetane Index

*only a portion of the results from data analysis are presented in the SAE Paper



JP-8 Density

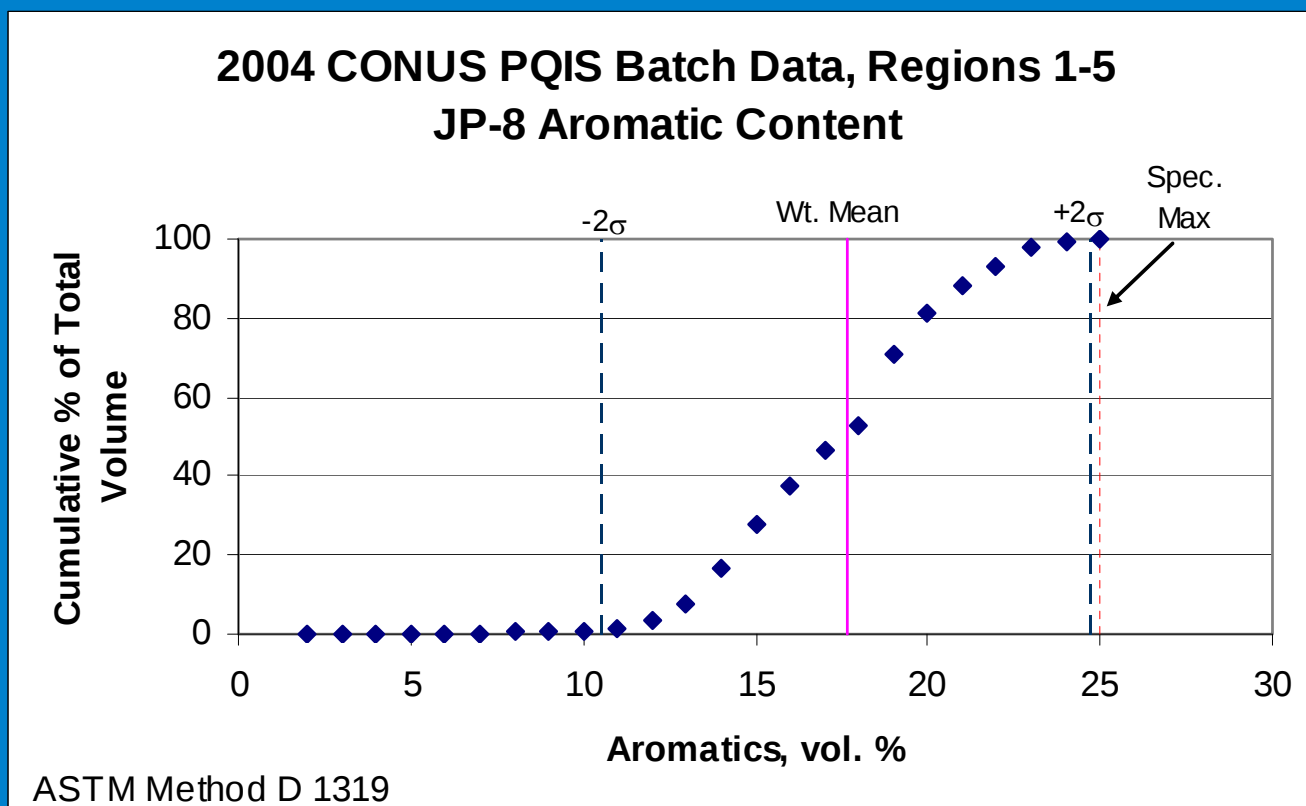
- JP-8 density ranged from 0.791 to 0.839 kg/L
- Weighted mean density is 0.807 kg/L





JP-8 Aromatic Content

- JP-8 Aromatic content ranged from 1.8 to 25.0 vol. %
- Weighted mean aromatic content is 17.7 vol. %

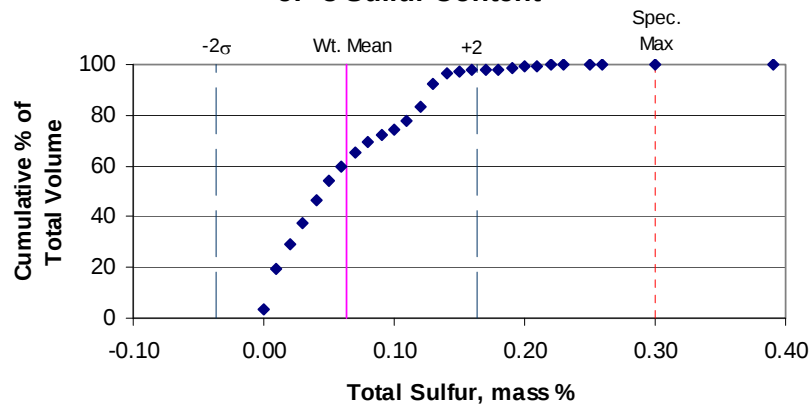




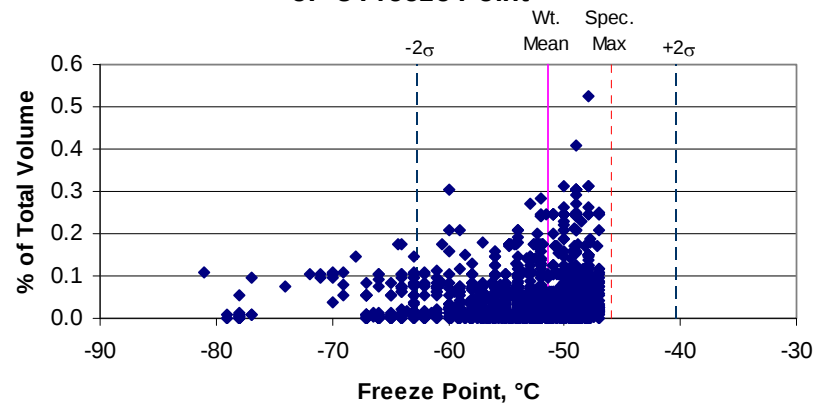
JP-8 Fuel Properties

- Weighted mean sulfur content is 0.06 mass %
- Weighted mean freeze point is -51.5 °C
- Weighted mean viscosity at -20 °C is 4.7 mm²/s
- Weighted mean cetane index is 43.9

2004 CONUS PQIS Batch Data, Regions 1-5
JP-8 Sulfur Content



2004 CONUS PQIS Batch Data, Regions 1-5
JP-8 Freeze Point





Organizing JP-8 Data to Create “Virtual” Blends

- JP-8 2004 PQIS was organized according to two properties:
 - Density; range of 0.791 to 0.839 kg/L
 - Aromatic content; range of 1.8 to 25.0 vol. %
- Density and Aromatic values were rounded-off to create “Levels”
 - Density Levels = 0.79, 0.80.... 0.83, 0.84 kg/L
 - Aromatic Levels = 2.0, 3.0.... 24.0, 25.0 vol. %
- At each Density Level, the weighted mean aromatic content was calculated, also the average sulfur content and average cetane index
- At each Aromatic Level, the weighted mean density was calculated, also the average sulfur content and average cetane index
- At each Level, the percentage of total volume of JP-8 procured was calculated to quantify overall exposure of military fleet to fuel with the property values at that Level
- “Virtual” blends were developed and associated properties predicted based on mathematical calculations



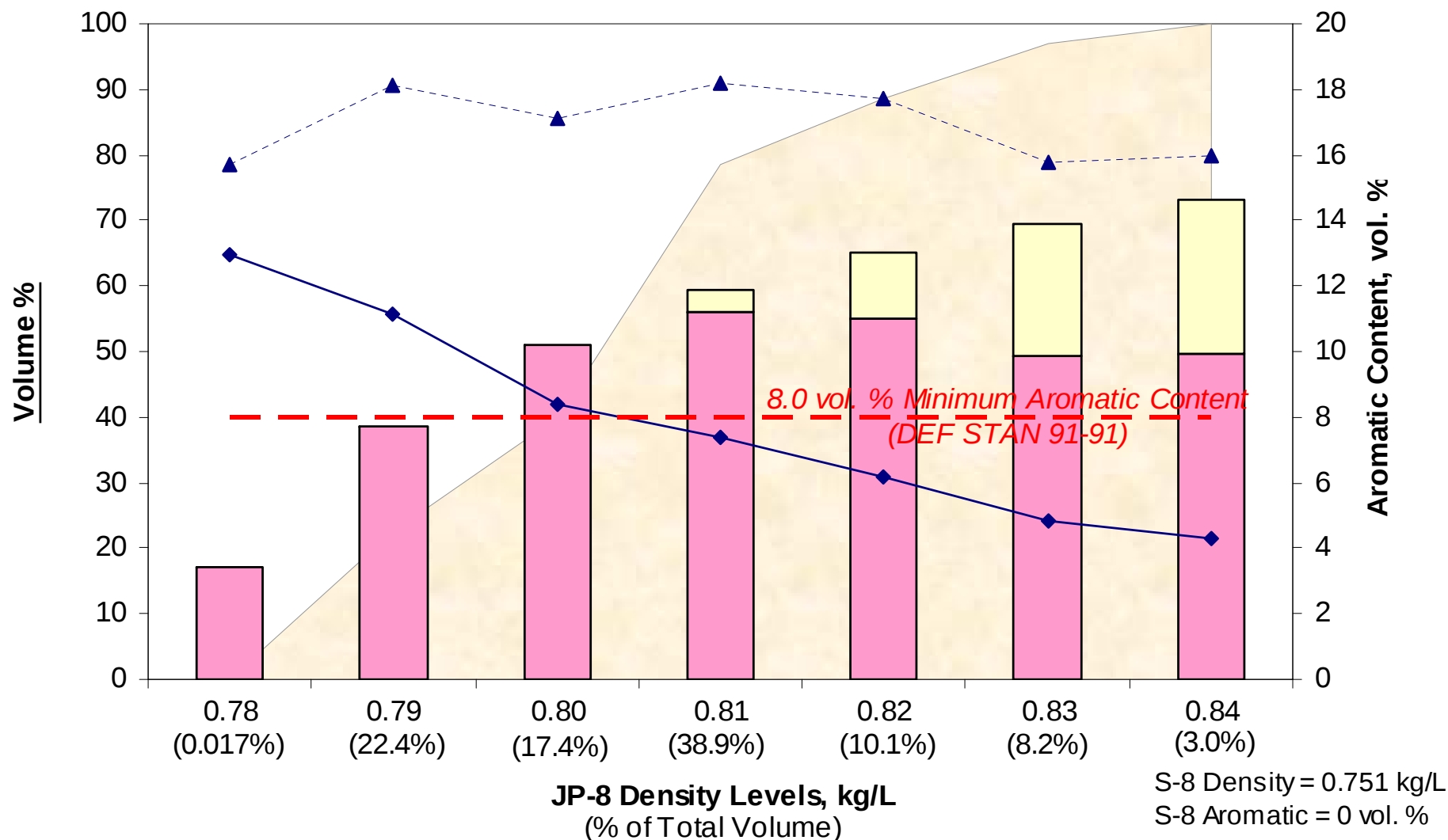
Creating “Virtual” Blends Based on Meeting Minimum Density

- Assume an S-8 density of 0.751 kg/L
- At each Density Level, calculated the maximum concentration of S-8 that can be blended in total volume (at that Density Level) to reach the minimum density allowable per JP-8 specification (0.775 kg/L)
- For example, at the JP-8 Density Level = 0.80 kg/L the calculation determines that 51 vol. % of S-8 can be blended to the JP-8 to reach min. density of 0.775 kg/L

$$51 \text{ vol. \%} = \left(1 - \frac{(0.775 - 0.751) \frac{\text{kg}}{\text{L}}}{(0.80 - 0.751) \frac{\text{kg}}{\text{L}}} \right) * 100$$

- S-8/JP-8 blend contains 51 vol. % of S-8 and 49 vol. % of JP-8

- Cumulative Volume of JP-8 Density Levels (Volume %)
- Additional S-8 Conc. Possible in S-8/JP-8 Blend to Meet Just 0.775 kg/L Density (Volume %)
- Max. S-8 Conc. Possible in S-8/JP-8 Blend to Meet 0.775 kg/L Density & 8.0 vol. % Aromatic Content (Volume %)
- Aromatic Content of S-8/JP-8 Blend with a 0.775 kg/L Density at JP-8 Density Level (Aromatic Content, vol. %)
- JP-8 Wt. Mean Aromatic Content at JP-8 Density Level (Aromatic Content, vol. %)
- Min. Aromatic Content DEF STAN 91-91 (Aromatic Content, vol. %)





Key Takeaways from JP-8 Density Level Slide

- For JP-8 2004 PQIS data ranging from 0.78 – 0.84 kg/L Density Levels it is possible to blend in FT IPK with density of 0.751 kg/L:
 - In concentrations ranging from 17.2% to as high as 73.0% by volume and still meet the JP-8 specification lower density of 0.775 kg/L
 - In concentrations ranging from 17.2% to as high as 56.0% by volume and meet both the JP-8 specification lower density of 0.775 kg/L and a minimum aromatic content of 8.0% vol.
- For JP-8 2004 PQIS data, on a weighted basis across all JP-8 Density Levels, it is possible to blend in FT IPK with density of 0.751 kg/L:
 - At a concentration of 55.1% by volume and still meet the JP-8 specification lower density of 0.775 kg/L
 - At a concentration of 50.4% by volume and still meet both the JP-8 specification lower density of 0.775 kg/L and a minimum aromatic content of 8.0% vol.



Calculating Properties of “Virtual” Blends Based on Meeting Minimum Density

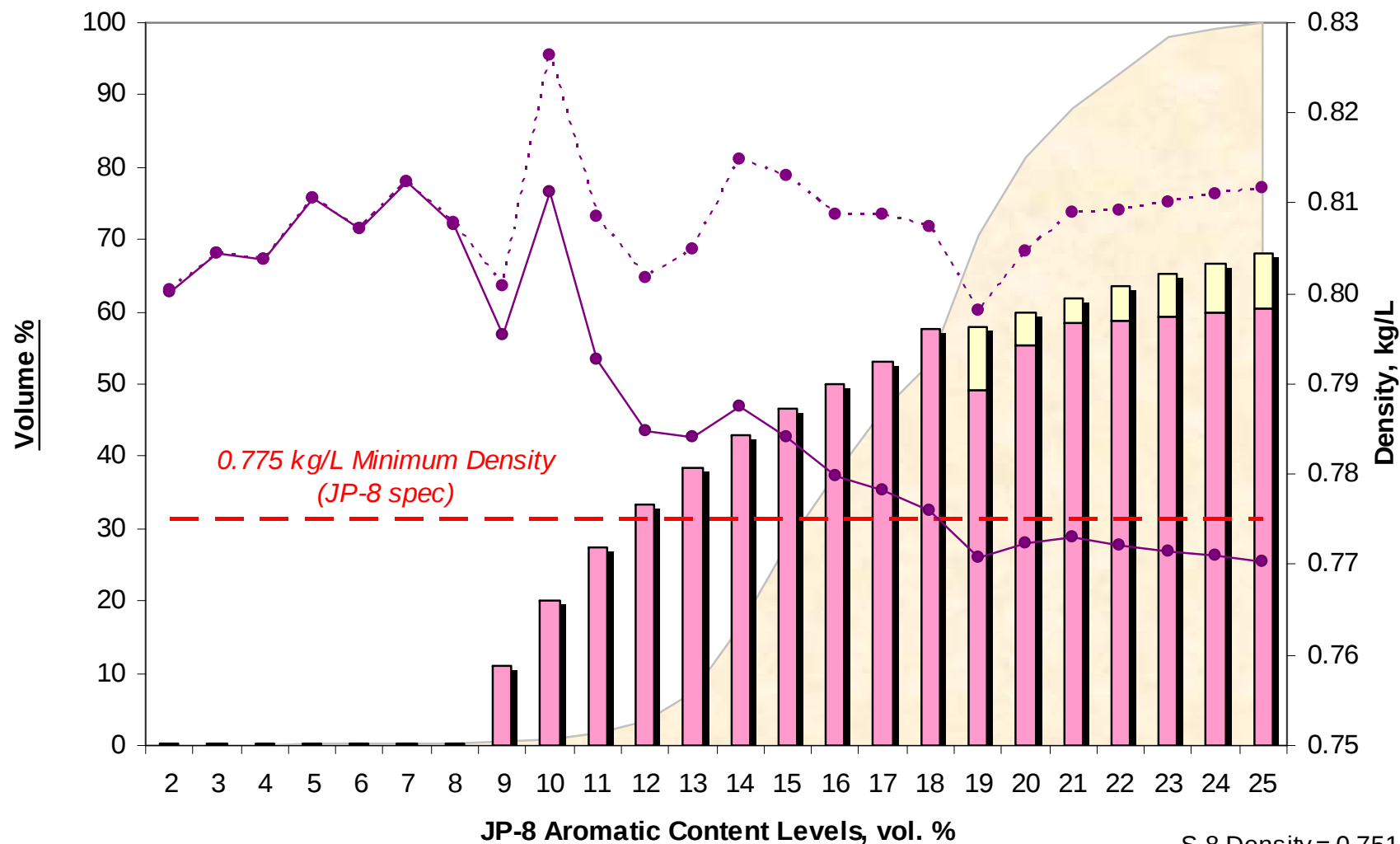
- At JP-8 Density Level = 0.80 kg/L, a maximum S-8 concentration of 51 vol. % is possible while still meeting JP-8 minimum specification density of 0.775 kg/L
- Blending in 51 vol. % of S-8 changes other fuel properties in addition to density:
 - Aromatic content is diluted from 17.1 to 8.4 vol. %
 - 17.1 vol. % aromatic content is the weighted mean aromatic content at the JP-8 Density Level = 0.80 kg/L
 - Sulfur content decreases from 0.036 to 0.018 mass %
 - Cetane index improves from 44.9 to 56.2



Creating “Virtual” Blends Based on Meeting Minimum Aromatic Content

- If the calculation is done based on reaching the minimum aromatic content at each Density Level, the maximum blend percentage of S-8 possible is different
- For example, the weighted mean aromatic content at the JP-8 Density Level = 0.80 kg/L is 17.1 vol. %
- Assuming the desired final blend aromatic content is 8.0 vol. % (to meet the minimum allowed per DEF STAN 91-91) then:
 - 53.2 vol. % S-8 can be blended into the fuel blend
 - Again, other properties of the blend change accordingly with the amount of S-8 blended

- Cumulative Volume of JP-8 Aromatic Content Levels (Volume %)
- Additional S-8 Conc. Possible in S-8/JP-8 Blend to Meet Just 8.0 vol. % Aromatic Content (Volume %)
- Max. S-8 Conc. Possible in S-8/JP-8 Blend to Meet 8.0 vol. % Aromatic Content & 0.775 kg/L Density (Volume %)
- JP-8 Wt. Mean Density at JP-8 Aromatic Content Level (Density, kg/L)
- Density of S-8/JP-8 Blend with a 8.0 vol. % Aromatic Content at JP-8 Aromatic Content Level (Density, kg/L)
- Min. Density Limit JP-8 Spec (Density, kg/L)



S-8 Density = 0.751 kg/L
S-8 Aromatic = 0 vol. %



Key Takeaways from JP-8 Aromatic Level Slide

- For JP-8 2004 PQIS data ranging from 2 – 25% vol. Aromatic Levels it is possible to blend in FT IPK with density of 0.751 kg/L:
 - In concentrations ranging from 0% to as high as 68.0% by volume and still meet a minimum aromatic content of 8.0% vol.
 - In concentrations ranging from 0% to as high as 60.5% by volume and meet both a minimum aromatic content of 8.0% vol. and the JP-8 specification lower density of 0.775 kg/L and For JP-8 2004
- For JP-8 2004 PQIS data, on a weighted basis across all JP-8 Aromatic Levels, it is possible to blend in FT IPK with density of 0.751 kg/L:
 - At a concentration of 53.4% by volume and still meet a minimum aromatic content of 8.0% vol.
 - At a concentration of 50.5% by volume and still meet both a minimum aromatic content of 8.0% vol. and the JP-8 specification lower density of 0.775 kg/L



Properties of Real Blends

- Real S-8/JP-8 fuel blends were prepared and property tests were performed
- Five unidentified JP-8 fuels and one unidentified S-8 fuel (control sample) were blended with two S-8 fuels at 25 and 50 vol. % of S-8 each
- The five JP-8 fuels had densities ranging from 0.794 to 0.810 kg/L
 - About 78% of the JP-8 fuels in the PQIS database fall into this density range
- Their aromatic content ranged from 14.0 to 19.7 vol. %.
 - About 74% of the JP-8 in the PQIS database fall into this aromatic content range



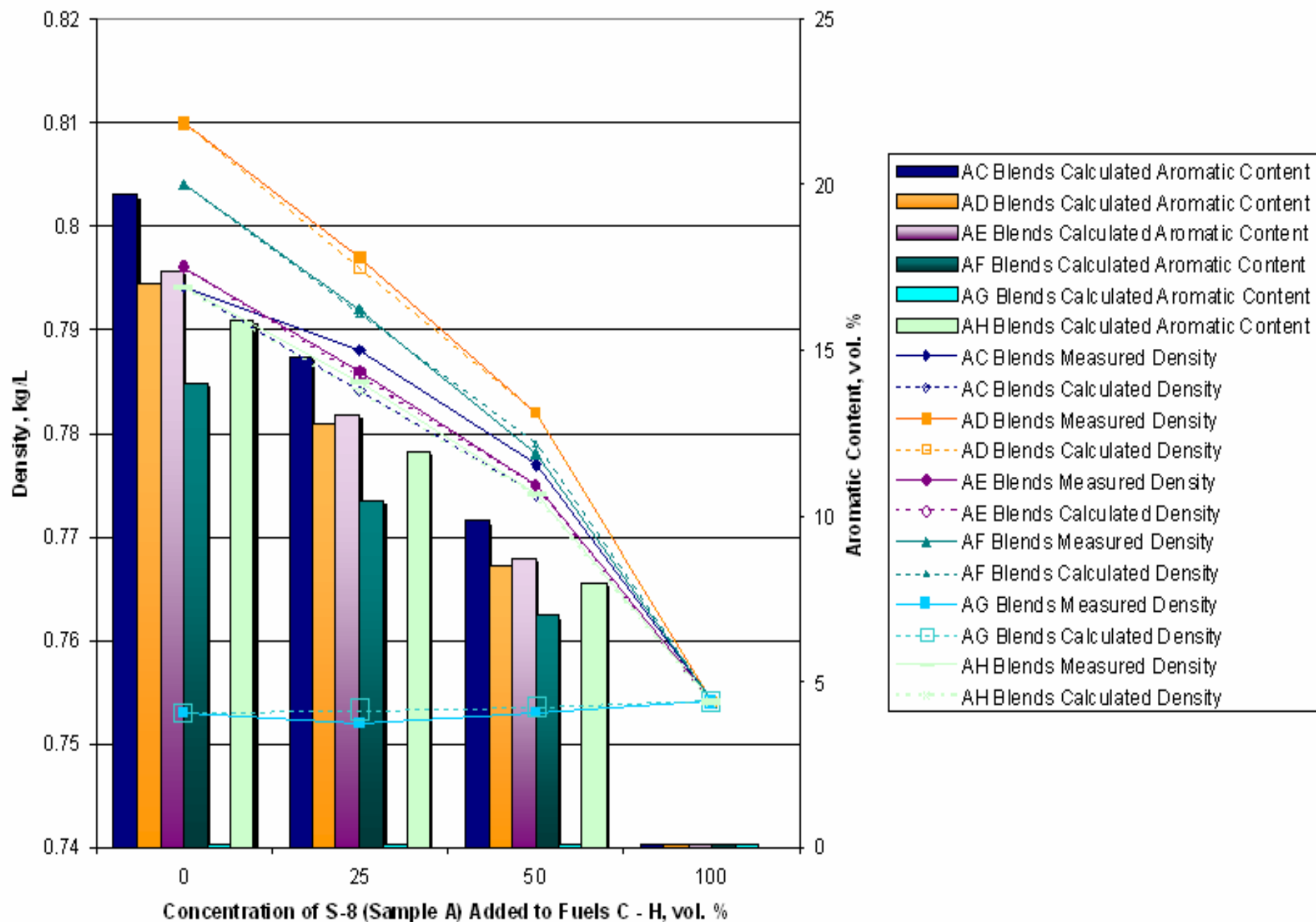
Properties of S-8 and JP-8

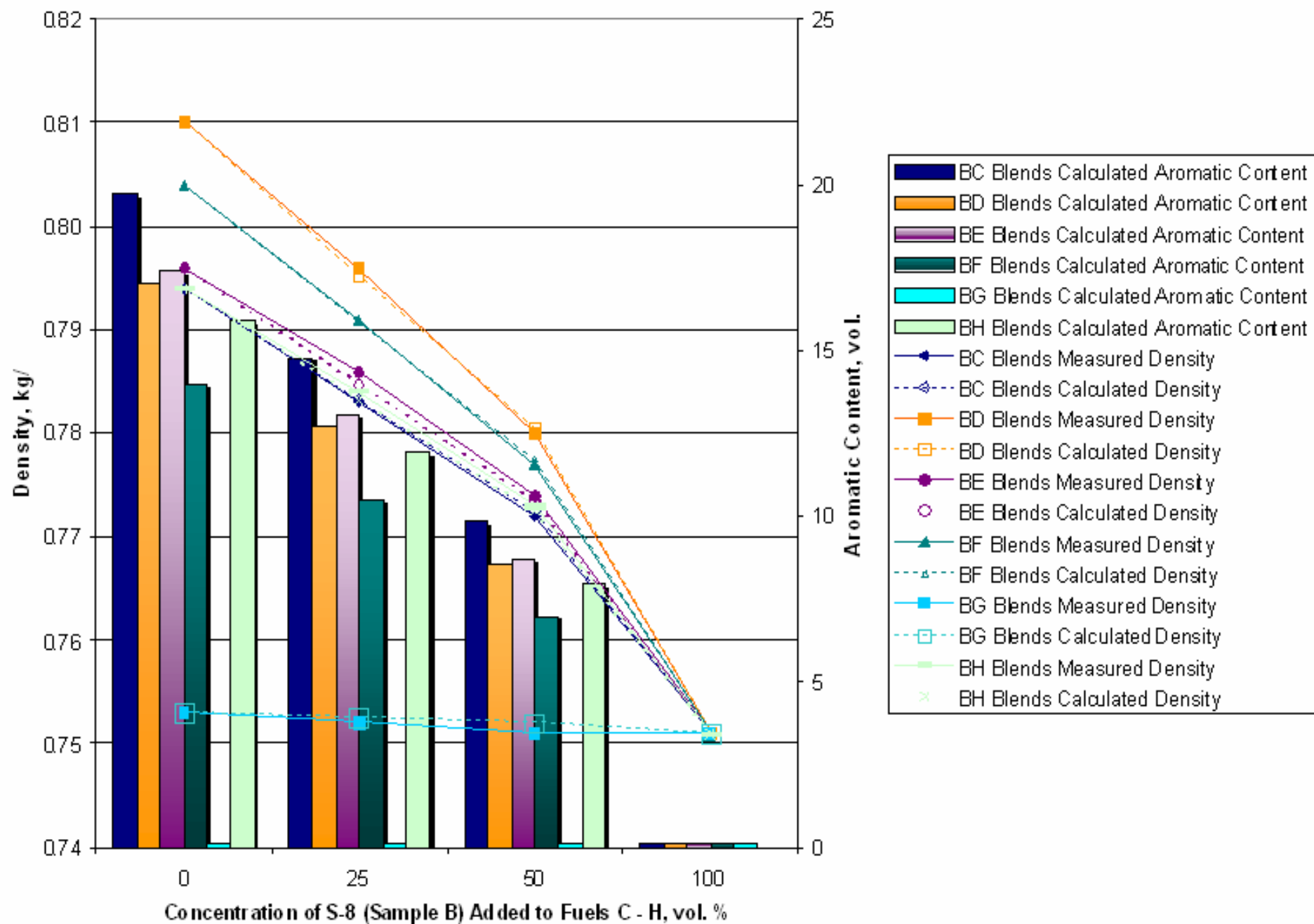
		S-8		JP-8					
Fuel Type		S-8	S-8	JP-8	JP-8	JP-8	JP-8	S-8	JP-8
Designation		A	B	C	D	E	F	G	H
Property, Units	Method								
Flash Pt., °C	D 93	54	48	48	51	48	53	---	---
Density, kg/L	D 4052	0.754	0.751	0.794	0.810	0.796	0.804	0.753	0.794
Aromatics, vol. %	D 1319	<1	<1	19.7	17.0	17.4	14.0	0.0	15.9
Sulfur, mass %	D 2622	<0.002	<0.002	0.08	0.14	0.08	0.12	0.00	0.07
Net Heat of Combustion				18604	18541	18594	---	18965	18625
Freeze Pt., °C	D 5972	-52	-57	-49	-57	-50	-44	-57	-50
Viscosity at 40°C	D 445	1.4	1.3	1.3	1.4	1.4	1.4	1.5	1.5
SimDist., °C	D 2887								
IBP		131	116	109	105	102	109	116	104
5%		143	139	149	147	143	151	139	142
50%		216	204	202	209	201	217	204	198
95%		282	280	259	261	266	272	279	265
FBP		332	316	282	303	289	301	310	288
Cetane Index	D 976	70	67	47	43	46	48	66	46



Properties of Real S-8/JP-8 Blends

- 20 of the 24 samples were S-8/JP-8 blends and four were S-8/S-8 blends
- When 25 vol. % of S-8 was added to the JP-8 samples:
 - None of the samples fell below the minimum density requirement
 - None fell below the minimum allowable aromatic content
- When 50 vol. % of S-8 was added to the JP-8 samples:
 - Five of the 20 fuels fell below the minimum density requirement (actually measured density; six fell below when density was mathematically predicted)
 - Two of the 20 fell below the minimum aromatic content requirement







Measured vs. Predicted Properties of Blends

- Predicted (calculated) properties, as expected, closely matched measured properties
 - Sulfur content was predicted for the real blends. Similar to aromatic content, the concentration of sulfur decreases as the concentration of S-8 (zero sulfur) is increased
 - Measured and predicted densities show a trend of lower blend density as the concentration of S-8 increased
 - Average standard deviation between densities measured by ASTM D 4052 and those mathematically predicted was 5.89×10^{-4} kg/L
 - Standard deviation suggests mathematical prediction of densities is representative of real fuel blend densities



Conclusions

- This study examined and presented the “property box” of JP-8 fuel (CONUS) using the Defense Energy Support Center “Petroleum Quality Information System” (PQIS) database for JP-8 fuel procured during 2004
- Employed key criteria for creating blends of FT IPK and JP-8:
 - That meet the minimum acceptable density of 0.775 kg/L in the current JP-8 specification, and
 - That meet the minimum acceptable aromatic content of 8.0 vol. % as published in DEF STAN 91-91 Issue 5
 - To develop and present data for “virtual” blends of FT IPK and JP-8 (CONUS Defense Regions 1-5) and illustrating that significant volumes of FT IPK could be used in blends with JP-8 while still meeting the key blending criteria
 - On a macro-scale across all JP-8 volume (2004 PQIS data), it is possible to add 50.5% FT IPK (by volume) and still meet both 0.775 kg/L and minimum aromatic content of 8% vol.
 - Amounts of FT IPK possible in individual blend batches will vary widely based on actual properties of the specific JP-8 used for that batch
- Showed that mathematically predicted (calculated) properties closely matched measured properties for real blends of FT IPK and JP-8



Recommended Follow-on Study

- Develop most likely scenarios for implementing near-term use of blends based on proximity of DoD bases to potential manufacturing sites of FT IPK
 - Obtain and analyze JP-8 samples from DoD bases identified in the most likely scenarios
- Obtain as possible and analyze JP-8 samples “of interest” based on analysis of 2004 PQIS data; e.g., there were batches of JP-8 with very low aromatic content (Region 3)
- Make blends of the JP-8 samples obtained with FT IPK and analyze to populate database of blend properties
- Analysis of JP-8 fuels and blends to include
 - Standard specification tests per ASTM D 1655
 - Kinematic Viscosity at 40°C, Cetane Index (of interest for diesel engines)
 - Kinematic Viscosity at low temperatures (other than just -20°C) to better understand low temperature characteristics and determine temperature at which viscosity = 12 cSt

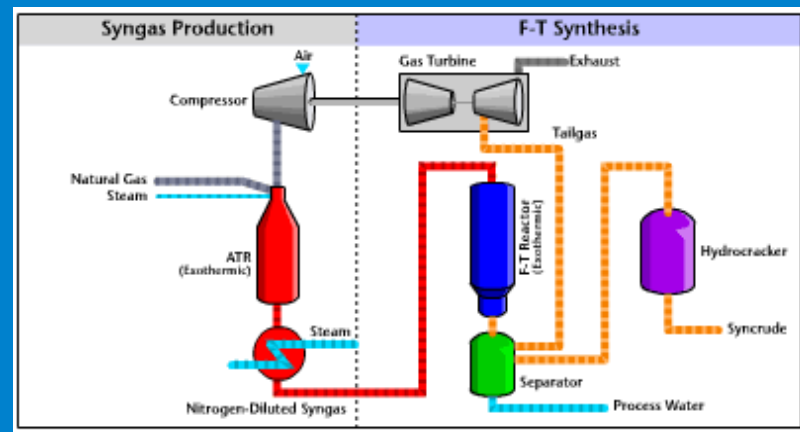


Questions?



Fischer-Tropsch (FT) Fuel

- FT fuels can be produced domestically from a variety of non-petroleum feed stocks including:
 - Natural gas
 - Coal
 - Petroleum coke
 - Biomass and various wastes
- FT process:
 - Production of synthesis gas (syngas)
 - Process syngas to high-boiling hydrocarbons.
 - Hydrocarbons are then hydrocracked, hydroisomerized, and/or hydroprocessed to produce the desired liquid fuels



Graphic representation of Syntroleum Corp. process, used with Syntroleum permission

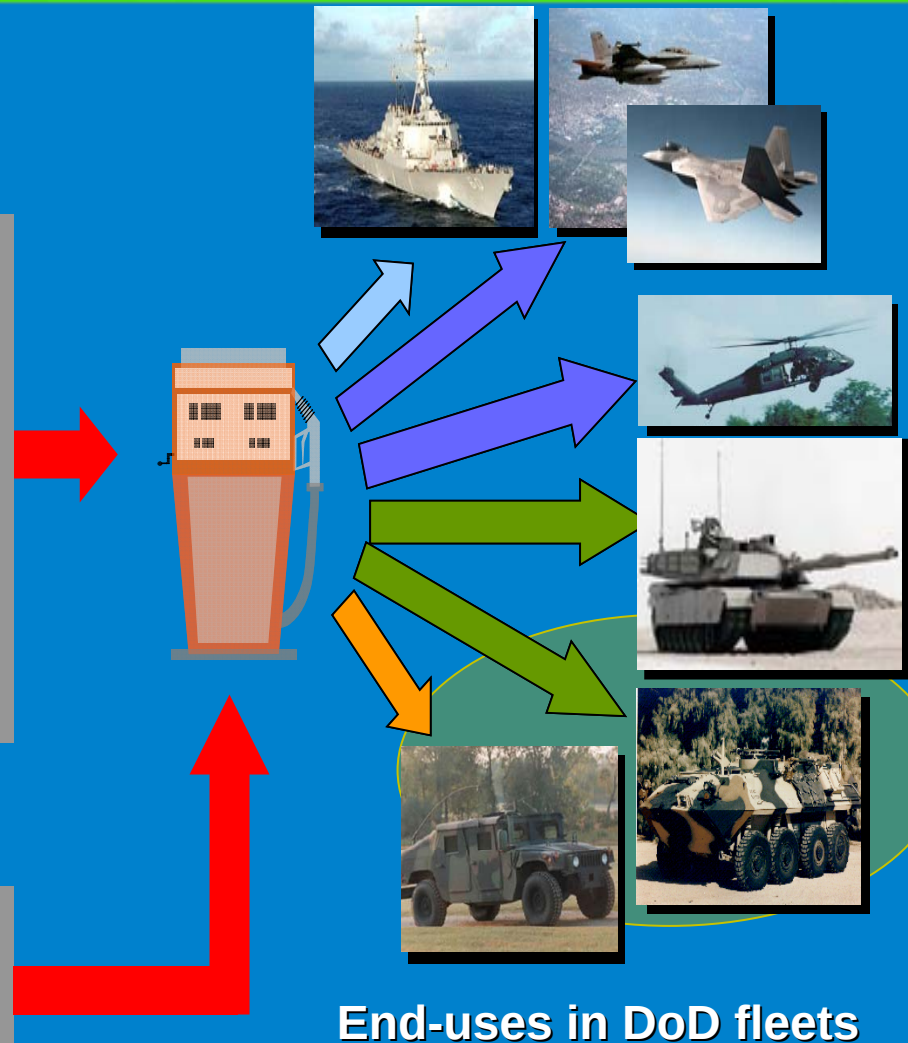
Joint Battlespace Use Fuel of the Future (JBUFF)

Single Battlefield Fuel

- JP-8/F-34
 - MIL-DTL-83133
- JP-5/F-44
 - MIL-DTL-5624
- Jet A-1/F-35
 - ASTM D 1655 (U.S.)
 - British Defence Standard [DEF STAN] 91-91 (British military, most of commercial aviation worldwide)

JBUFF

- JP-8/JP-5/Jet A-1 (petroleum)
- FT Iso-Paraffinic Kerosene (IPK)
- JP-8/FT IPK blends (petroleum/FT blend)



End-uses in DoD fleets