Naval Fuels & Lubricants
Cross Functional Team
Research Report

Fuel System Icing Inhibitor Concentration Reduction Study

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EXECUTIVE SUMMARY

Fuel System Icing Inhibitor (FSII) is composed of DiEthylene Glycol Monomethyl Ether (DiEGME). FSII provides fuel system icing and microbial growth protection to aviation fuel systems. The current FSII specification requirement for JP-5 aviation fuel is 0.10-0.15% by volume. The lower use limit for naval aircraft per NAVAIR 00-80T-109 is 0.03% by volume. The goals of this study were to determine if the current specification requirement could be decreased while still providing satisfactory icing and microbial growth protection. A parallel effort was to determine what cost savings could be realized if the injection rate was able to be effectively lowered. Therefore a cost benefit analysis was performed on different injection ranges.

This study employed a multistep approach to arrive at a final recommendation. The first step involved surveying the fleet and distribution system supply points to determine the current operational FSII concentrations, calculate average FSII loss, and if there have been any reported microbial growth incidents. The second step analyzed lower injection rates that ensured satisfactory icing and microbial protection. The third step evaluated the cost savings at the acceptable ranges determined in step 2.

The majority of fleet data came from aircraft carriers. Amphibious assault ships, Coast Guard cutters, and one Naval Air Station (NAS) provided additional data. In order to determine FSII loss throughout the distribution system, two Defense Fuel Supply Points (DFSP) were also surveyed for current FSII levels.

The current FSII levels on the ships are at an average of 0.1048% by volume. This average was derived from a collection of 4910 data points. The two DFSPs provided 155 data points and an average of 0.1307%. The difference between these two averages shows how much FSII is being lost in the fuel transfer process from shore to shipboard end user because the additive is migrating from the fuel into any free water that is encountered throughout the distribution system. No microbial growth incidents were reported at any location at the current FSII levels.

Statistical analysis showed that at these current averages there is a 0.3% probability of the shipboard FSII level dropping below the use limit of 0.03% by volume. New injection ranges were evaluated using the same statistical analysis and the assumptions that nothing would change in the process other than the FSII level. The ranges evaluated were 0.07-0.10, 0.08-0.11, and 0.09-0.12%. These risks of falling below the use limit for the selected ranges were 11.5%, 5.9%, and 3.0%.

DiEGME at the current required injection rates cost approximately $2,800,000 per year. Cost analysis has shown lowering the injection rate can save:

- $900,000 at the 0.07-0.10% range
- $680,000 at the 0.08-0.11% range
- $500,000 at the 0.09-0.12% range

After field data review, analysis of the risks associated with the lowered ranges, and projected yearly cost savings, NAVAIR 4.4.5 recommends lowering the FSII specification to 0.08-0.11vol%. Shipboard FSII data should be collected again one year after the new specification is established to see if the range should be modified.

LIST OF ACRONYMS/ABBREVIATIONS

Aircraft Carrier, Nuclear .... CVN

Defense Fuel Supply Point .... DFSP

Di-Ethylene Glycol Monomethyl Ether .... DiEGME

Fleet Logistics Center .... FLC

Fuel System Icing Inhibitor .... FSII

Amphibious Assault Ship .... LHA

Amphibious Assault Ship .... LHD

Naval Air Station .... NAS

United States Air Force .... USAF

United States Coast Guard Cutter .... USCGC

United States Navy .... USN

United States Ship .... USS

Fuel System Icing Inhibitor Concentration Reduction Study

1.0 BACKGROUND

The current fuel system icing inhibitor (FSII) used by the United States Navy (USN) in JP-5 is di-ethylene glycol monomethyl ether (DiEGME). The chemical structure of DiEGME, shown in Figure 1, illustrates a strong affinity for water. This affinity allows the molecule to easily blend with any free water that may be present in the fuel and prevent it from freezing at temperatures well below 0°C. Dissolved water becomes free water as the fuel temperature decreases. This is due to the fact that intermolecular forces decrease with temperature and the water becomes incapable of staying in solution. Ice formation in aircraft fuel systems could limit fuel flow and may cause a catastrophic failure.

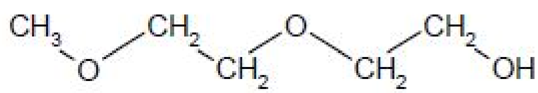

Figure 1: Structure of Di-Ethylene Glycol Monomethyl Ether (DiEGME)

DiEGME has also shown potential to protect against microbial growth and therefore aid in maintaining the cleanliness of the fuel. Microbes can be present in the aqueous phase and without DiEGME's ability to migrate into the water the microbial growth could not be inhibited. A United States Air Force (USAF) study[1] involving effective concentrations of DiEGME as a biostat showed that concentrations in the fuel as low as 0.01% by volume were significant enough to control microbial growth.

DiEGME is currently injected into JP-5 at a concentration range of 0.10-0.15% by volume. The USN minimum use limit in JP-5 is 0.03% by volume. Throughout the supply chain there is a chance for the fuel to come into contact with moisture and the FSII could migrate out of the fuel and into the water. When the fuel is transported to another location contamination countermeasures strip the free water out of the fuel and a small percentage of the FSII is lost. Another USAF study[2] to evaluate the impact of decreased use and specification limits in JP-8 showed that the greatest measured concentration drop between injection location and end user was 0.026% and 97% of the shore bases surveyed showed less than a 0.02% loss of FSII. The chance for the fuel to come into contact with water is much greater within the Navy's shipboard supply systems and therefore the risk of losing FSII increases as well.

FSII injected at the required rate of 0.10-0.15% by volume costs approximately $2,800,000 per year. A cost analysis revealed that if the current JP-5 specification FSII limits were lowered to the same values, 0.07-0.10%, as is currently in the JP-8 specification, then the Navy could save approximately $900,000 per year alone in FSII additive cost.

2.0 OBJECTIVE

The first objective of this study was to determine if the current specification requirement, 0.10-0.15% by volume, of DiEGME into JP-5 could be reduced while still maintaining freezing and microbial growth protection. The second objective was to determine the cost savings at a reduced injection rate.

3.0 APPROACH

This study was initiated by reviewing USAF reports[1/2] involving FSII biostat and anti-icing effectiveness as well as the USAF reduced specification limit of JP-8[3]. The goal was to analyze the USAF findings and determine if the JP-5 FSII specification limits could be modified using USN field data.

The next step in the study was to collect data from aircraft carriers (CVNs) and air capable ships to determine how much FSII was present for the end user. Two DFSP locations, Craney Island and San Diego, were also surveyed to determine how much FSII was in the fuel at this point in the supply chain. The differences in FSII level between the supply points and the end user will allow a determination of the loss of FSII throughout the distribution system.

Fleet and shore locations were also surveyed for potential microbial growth incidents. Any reports of microbial growth would be analyzed for impacts to the risk of lowering the FSII injection range.

Following the data collection, analysis was performed to determine the risk of lowering the specification FSII concentration range. From here the cost savings of reducing the JP-5 FSII specification at several different ranges will be calculated. The risks and savings of 3 lower ranges will be compared and a recommendation will be determined if the current specification should be modified.

4.0 DISCUSSION

This study was completed in four steps as detailed in section 3. Data analysis and risk assessments were performed and a recommendation was reached. The data analysis involved determining weighted averages and standard deviations of FSII concentrations aboard the ships. Using the analyzed data, and by assuming that the FSII concentrations would decrease similarly at lower ranges, the probability of FSII concentrations falling below the use limit of 0.03% for lower specification limits was determined.

4.1 CVN and Air Capable Ship Survey

The fleet was surveyed for current operational FSII concentrations in JP-5. The data acquired was analyzed to find the overall average FSII concentration in the fleet as well as the lowest concentrations experienced and how often those concentrations were present. The responses to the survey included eight CVNs, one LHA, four LHDs, three Coast Guard Cutters

(USCGC), and Naval Air Station (NAS) Corpus Christi. The participating ships are listed in Table 1.

Ship Name	Hull Number
USS Enterprise	CVN-65
USS Dwight D. Eisenhower	CVN-69
USS Abraham Lincoln	CVN-72
USS George Washington	CVN-73
USS John C. Stennis	CVN-74
USS Harry S. Truman	CVN-75
USS Ronald Reagan	CVN-76
USS George H.W. Bush	CVN-77
USS Peleliu	LHA-5
USS Wasp	LHD-1
USS Kearsarge	LHD-3
USS Iwo Jima	LHD-7
USS Makin Island	LHD-8
USCGC Alex Haley	WMEC-39
USCGC Midgett	WHEC-726
USCGC Active	WMEC-618

Table 1: Participating Ships

From these 17 responders 11,567 data points were acquired and had an overall average FSII concentration of 0.0779%. After the initial analysis, CVN-76 reported that the ship had been in port during this survey. In order to keep the FSII data representative of actively operating ships, subsequent analysis discounted the CVN-76 data. This changed the number of data points to 4,910 with an overall average of 0.1048%. This data is displayed in Figure 2. In the smaller population of data points only 83 were at the JP-5 use limit of 0.03% and only 17 were below the use limit. These are frequencies of 1.69% and 0.35%, respectively.

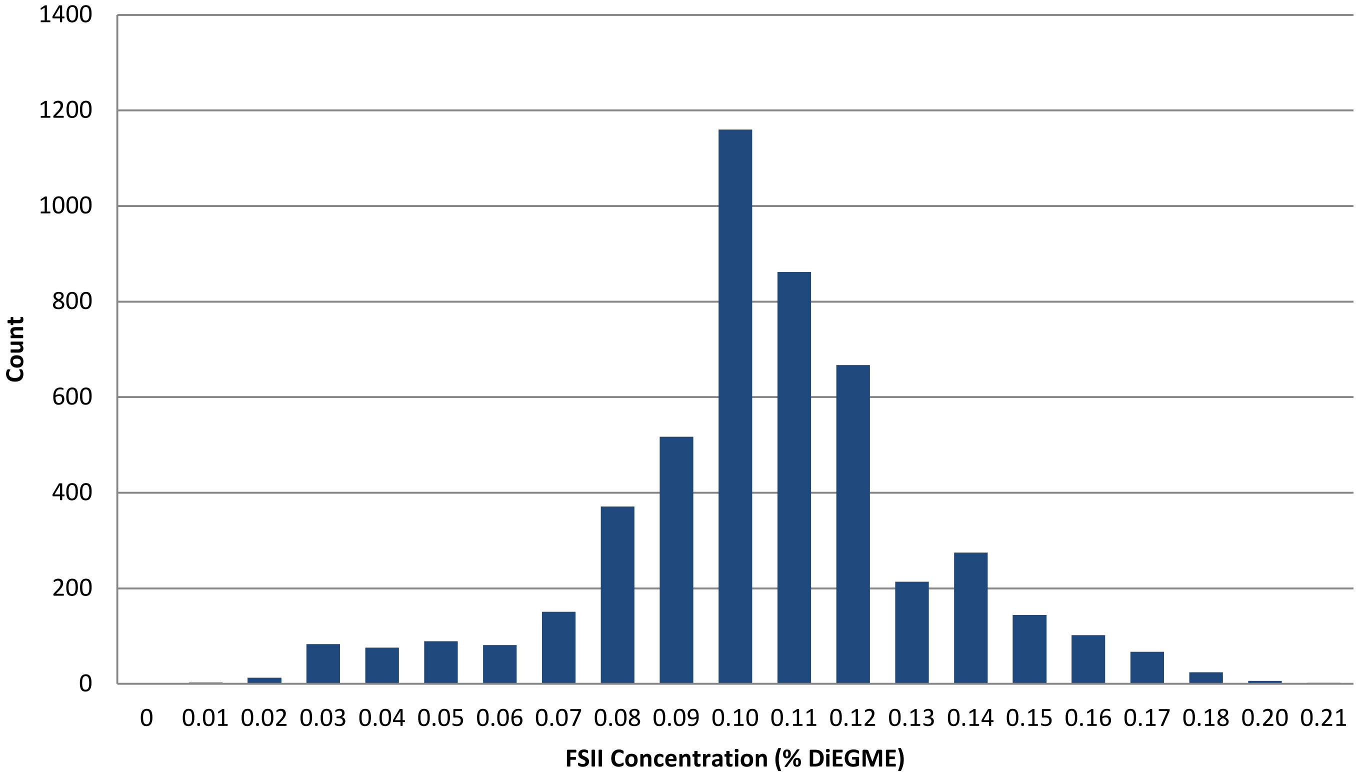

Figure 2: Histogram of Concentrations for All Responses Excluding CVN-76

4.2 DFSP Survey

The two surveyed DFSPs were Craney Island and San Diego. These two locations provided 155 data points and an average FSII concentration of 0.1307%. The data is displayed in Figure 3.

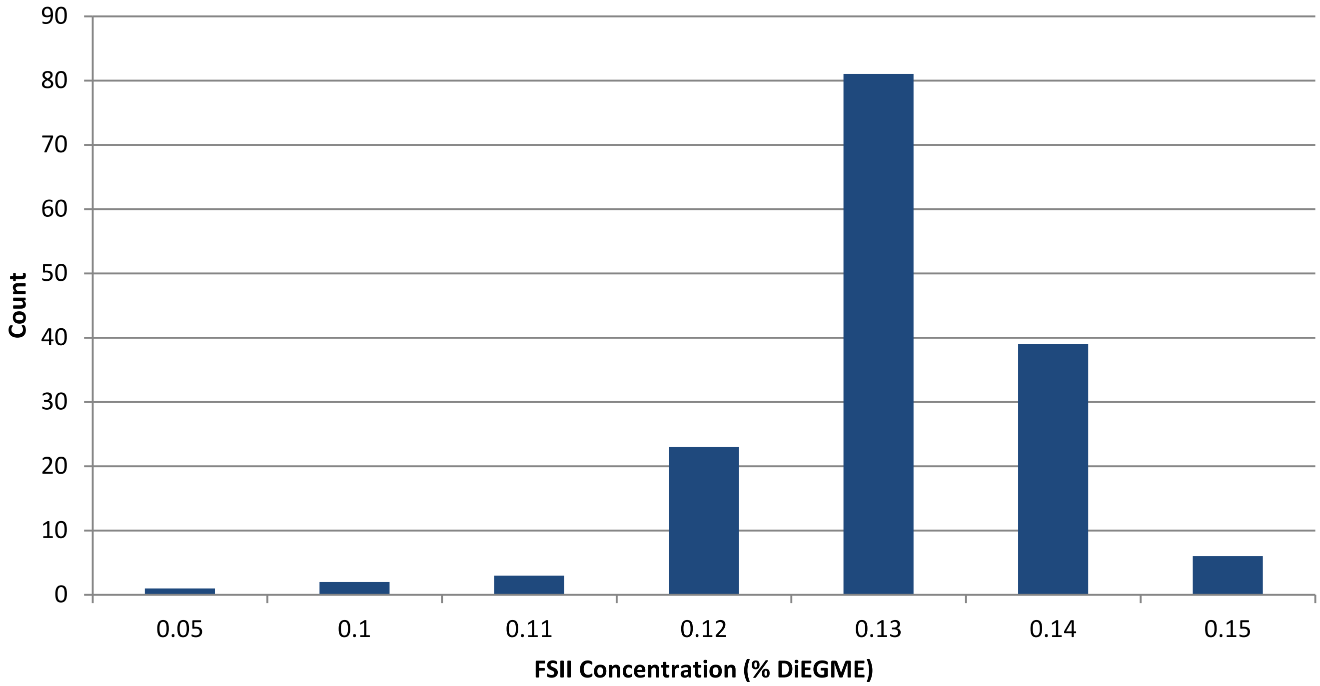

Figure 3: Histogram of Concentrations for DFSP Responses

4.3 Microbial Growth Incidents

Preventing microbial growth is another beneficial aspect of DiEGME. Three ships responded to the survey. The CVN-69 and CVN-75 replied that there had been something that appeared to be microbial growth, but no samples were taken and submitted for testing. Therefore microbial growth could not be verified. The CVN-77 reported no incidents of microbial growth.

All of the Navy Fleet Logistic Centers (FLC) were surveyed to determine if any of the sites had any reported microbial growth incidents. There were no incidents reported from Jacksonville, Norfolk, Pearl Harbor, Puget Sound, San Diego, or Yokosuka. Pearl Harbor reported that low point draining and water checks are performed frequently along with monthly samples to reduce the chance of microbial growth. Puget Sound reported a shipment was never rejected because of microbial growth.

4.4 Risk Analysis

The first step in the data analysis was to find new specification ranges and the risks associated with them. These risks are expressed in the probability of FSII concentrations aboard ships being measured below 0.03% by volume.

The data analysis was based using the following assumptions; 1) fleet and DFSP data were normally distributed and representative of all ship and DFSP data and, 2) DFSPs will continue to inject FSII with the same statistical distribution and precision.

Injectors' precision has increased due to technology so the proposed ranges were modified to 0.07-0.10, 0.08-0.11, and 0.09-0.12% by volume. Any calculations that resulted in a shipboard receipt concentration less than 0.06% by volume was deemed unacceptable because it only gave the ships a 0.03% margin to make sure the fuel was usable.

Using the averages and standard deviations of the data that was collected, the probabilities of the DFSP injections being outside of the specification limits were calculated in conjunction with the probability of a value on a ship being below the use limit. The percent of the current ship average having the mean of the current issue average was also found by calculating the bell curve of the DFSP average, DFSP standard deviation, and the shipboard average. Then, by using the assumption that the injections would remain consistent, injection values were calculated for the proposed ranges. The next calculation involved finding the new shipboard average for each proposed specification range. An additional normal distribution calculation produces the probability that a ship concentration would be below the use limit. Using the normal distribution calculation allows the collected data to be shifted and correspond to each proposed specification range. The results are shown in Table 2 and the current specification is shown for comparisons to be made.

Table 2: Probability of Falling Below 0.03% Use Limit for Reduced Ranges

Probability of Being Below Use Limit of 0.03%	Assumed Injection Concentration (% DiEGME)	FSII Range (% DiEGME)	
		Lower Specification Limit	Higher Specification Limit
0.3%	0.131%	0.10	0.15
3.0%	0.107%	0.09	0.12
5.9%	0.099%	0.08	0.11
11.5%	0.089%	0.07	0.10

The data in Table 3 was calculated using the same method as above. To make this a worst case scenario, the FSII was calculated using the low end of each proposed range. Injections are not likely to occur at these levels because historically FSII is injected in the middle of the specification range to ensure that the fuel meets its specification. The first row in the table is shown to compare the current risk to the three new ones.

Table 3: Probability of Falling Below 0.03% Use Limit for Injection at Low End of Specification

Probability of Being Below Use Limit of 0.03%	Injected at Lower Specification Limit (% DiEGME)	FSII Range (% DiEGME)	
		Lower Specification Limit	Higher Specification Limit
0.3%	0.10	0.10	0.15
10.6%	0.09	0.09	0.12
18.9%	0.08	0.08	0.11
30.3%	0.07	0.07	0.10

The risk reporting matrix below displays the risks associated with keeping the FSII specification at current levels and the proposed ranges. As shown by Table 2 above the risk for the current specification is 0.3% and currently presents minimal or no consequence to performance. This places the current risk level as a 1 for likelihood and consequence. The proposed reduction has a calculated risk of 5.9%. This falls under the 3 category for likelihood. The change would also present a minor reduction in performance or supportability. This is a 2 for the technical consequence category. The matrix shows the current value and the proposed change technical risks in green. The lowest range of 0.07-0.10% by volume has a risk level of 5 for likelihood and 3 for consequence. Given that JP-5 is required to have 0.03% FSII by volume the likelihood of not meeting that requirement at this level is above 10%. The consequence is however not as great considering how few aircraft actually require FSII for their missions. The other range of 0.09-0.12% has likelihood and consequence ratings of 2. The likelihood of falling below the use limit is only 3% and would minimally impact mission performance.

Table 4: Risk Reporting Matrix Values for FSII Reduction Proposal

Likelihood	Technical Consequences
1: <1%	1: Minimal or no consequence to performance
2: ~3%	2: Minor reduction in performance or supportability; can be tolerated with little or no impact to program
3: ~5%	3: Moderate reduction in technical performance or supportability; limited impact on program objectives
4: ~7%	4: Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success
5: 10% or greater	5: Severe degradation in technical performance; cannot meet KPP or key technical/supportability threshold; will jeopardize program success

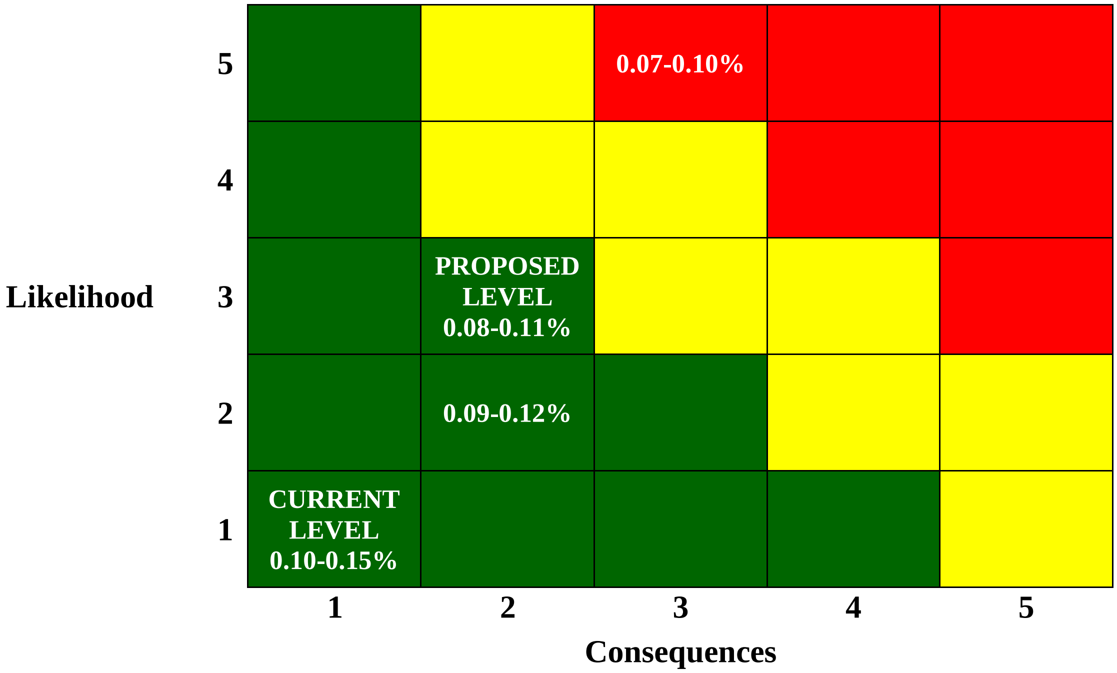

Figure 4: Risk Reporting Matrix for FSII Reduction Proposal

4.5 Cost Savings Analysis

Using the assumption that the DFSP injection rate would be the statistical averages of the proposed ranges, the cost savings analysis could be completed. The following specifics were used to determine the FSII costs in the calculations: 1) $0.008965 is the cost of FSII per gallon of JP-5 and, 2) the USN purchased 311,000,000 gallons of JP-5 in 2012.

Table 5: Cost Savings Analysis for Smaller Injection Ranges

Range of Injection	0.07-0.10%	0.08-0.11%	0.09-0.12%	0.10-0.15%
Injection Rate	0.089%	0.099%	0.107%	0.131%
Cost of FSII	$1,892,164	$2,103,352	$2,288,942	$2,788,155
Savings	$895,951	$684,763	$499,172	$0

5.0 CONCLUSIONS

1. Aligning the JP-5 with the JP-8 FSII injection range of 0.07-0.10% by volume would save the USN $895,951 yearly in FSII additive costs. However, the risk of FSII levels falling below 0.03% by volume use is unacceptable at this injection range.

2. The injection range of 0.08-0.11% by volume represents an acceptable low risk and a yearly cost savings of $684,763 in FSII additive costs.

3. The risk of microbial growth is minimal at all injection ranges that were analyzed based on the effectiveness of FSII as a biostat at concentrations as low as 0.01%.

6.0 RECOMMENDATIONS

1. Provide the conclusions of this study to the fleet and request the fleet feedback on the proposal to reduce the FSII specification injection range in JP-5 from 0.10-0.15% by volume to 0.08-0.11% by volume.

2. Temporarily reduce the FSII specification injection range in JP-5 from 0.10-0.15% by volume to 0.08-0.11% by volume.

3. Monitor shipboard FSII levels and reports of fuel containing less then 0.03% by volume FSII.

4. If shipboard FSII levels remain above 0.03% by volume modify MIL-DTL-5624 FSII injection range requirements to 0.08-0.11% by volume.

7.0 REFERENCES

1. Balster, L.M.T., Vangsness M.D., Bowen L.L., Mueller S.S., and Brown L.M., “Effect of Diethylene Glycol Monomethyl Ether (DiEGME) and Triethylene Glycol Monomethyl Ether (TriEGME) on Microbial Contaminants in Aviation Fuel,” AFRL-RZ-WP-TR-2010-2094, 2010.

2. Regoli, V.M. “Loss of Fuel System Icing Inhibitor Additive During the Transport and Storage of JP-8,” AFPET-TR-14092009, 2009.

3. DeWitt M.J., Zabarnick S., Williams T.F., West Z., Shafer L., Striebich R., Breitfield S., Adams R., and Cook R., “Determination of the Minimum Use Level of Fuel System Icing Inhibitor (FSII) in JP-8 That Will Provide Adequate Icing Inhibition and Biostatic Protection for Air Force Aircraft,” AFRL-RZ-WP-TR-2009-2217, 2009.

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14. ABSTRACT
Fuel System Icing Inhibitor (FSII) is composed of DiEthylene Glycol Monomethyl Ether (DiEGME). FSII provides fuel system icing and microbial growth protection to aviation fuel systems. The current FSII specification requirement for JP-5 aviation fuel is 0.10-0.15% by volume. The lower use limit for naval aircraft per NAVAIR 00-80T-109 is 0.03% by volume. The goals of this study were to determine if the current specification requirement could be decreased while still providing satisfactory icing and microbial growth protection. A parallel effort was to determine what cost savings could be realized if the injection rate was able to be effectively lowered. Therefore a cost benefit analysis was performed on different injection ranges.

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