Microbial Audit

Fuel Dispensing Systems and Underground Storage Tanks at XYZ's City Area Retail Outlets

Prepared for XYZ, Inc.

Prepared by:

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Princeton, NJ

Month, 20XX

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Biodeterioration Risk Survey

Fuel Dispensing Systems and Underground Storage Tanks at XYZ's Retail Outlets

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Executive Summary

On Dates, *Names* and I visited six of XYZ's retail outlets in the City, State Area and performed a field evaluation of the microbial contamination problem that had been described to me by *Names.*

Except for owner operated Station # 1111, where frequent filter-plugging problems had been reported, and Station # 2222, where a customer had to replace his vehicle's fuel filter after purchasing PUL, there had been no complaints of either dispenser performance or product integrity problems in the City Area. Consequently, the survey was intended to provide baseline information regarding conditions in UST with no apparent biodeterioration problems.

The term *biodeterioration risk* refers to the likelihood that biological activities may affect system performance (valve function, filter plugging, etc.), system integrity (corrosion) or product integrity. The survey uses current climate, physical, chemical and microbiological data to formulate the risk projections.

The following Tab summarizes biodeterioration risk ratings by UST:

High Risk	**Moderate Risk**	**Low Risk**
Station # 1111 RUL	Station # 1111 PUL	Station # 6666 RUL
Station # 2222 RUL	Station # 3333 MUL	
Station # 2222 MUL	Station # 3333 PUL	
Station # 2222 PUL	Station # 4444 PUL	
Station # 2222 RUL	Station # 5555 RUL	
	Station # 5555 MUL	
	Station # 5555 PUL	
	Station # 6666 MUL	
	Station # 6666 PUL	
	Station # 7777 RUL	
	Station # 7777 MUL	
	Station # 7777 PUL	

Several follow-up actions are recommended:

- Set up and maintain a database:
  - ∗ Dates, source, volume and fuel grades delivered
  - ∗ Dates and volume of bottom-water removed from each UST (bottom-water pH and alkalinity would also be useful)
  - ∗ Dates of filter changes; volume of fuel filtered between changes.
- Test fuel samples for chemical corrosivity; include biocide treatment as an experimental variable.
- Shock treat the UST at Station (1 gal MicroGard 2000 per 2,500 gal UST capacity). After one-week collect bottom samples. Report gross observations, pH, alkalinity, hardness and microbial contamination levels. A second shock treatment may be needed to disinfect the UST. Biocide should be added just before fuel deliveries.
- Once the retail system has been treated, an ongoing monitoring and preventive treatment program should be implemented. The water chemistry, catalase activity and Liqui-Cult parameters included in this survey should provide the basis for the monitoring program.

Purpose

This project was commissioned to evaluate the contribution of microbial contamination to equipment problems reported at one City Area retail outlets, to survey the current state of microbial contamination at a representative number of apparently problem-free retail outlets, and to make recommendations for remediation and prevention.

Background

In early19XX, a City Area store operator complained of filter plugging problems. Samples sent for analysis demonstrated high levels of microbial contamination.

Gerry Can contacted me in Date to discuss the presumptive microbial contamination problems at the one City Area retail outlet. At that time I recommended a series of simple lab tests to confirm that there were active microbial contaminants in the fuel, bottom-water and filter samples from the retail outlet. Gerry's tests all confirmed active microbial contamination. Based on these findings, XYZ hired BCA to conduct a biodeterioration risk survey at selected City Area retail outlets.

Biodeterioration refers to all commercial loss either caused or mediated by organisms. Microbes (bacteria and fungi) are the active biodeterioration agents in fuels and fuel systems. The Survey assessed current conditions as well as risk levels based on climate, operating practices, retail outlet system design, gross observations and a battery of physical, chemical and microbiological tests. The Survey process was executed in a training mode; empowering XYZ's staff to routinely monitor biodeterioration in the future.

Narrative

ABC, Inc., was kind enough to allow us to use space in their facility to perform our laboratory testing. On Date, we set up our laboratory workspace and organized our field supplies.

On Day +1, We completed a survey at Station # 1111 (Address). Handy Puller, of DEF, Inc. Pulled turbines and filters for us at all locations we surveyed.

We surveyed three stations from the southern City area on 04 August, and three stations from the northern City area on 05 August (Figure 1). On 06 August, we re-sampled from Station # 1111, visited Ican Pumpalot at XYZ's City Area operations office and G. Withtheflow at Supplier's Terminal.

Ima Bighelp completed all dissolved oxygen and pH tests were within a few minutes of sampling. All other tests were run at the Ferrous facility, within eight-hours after sample collection. I completed microbiological tests (requiring up to 48-hours incubation) on 07 August.

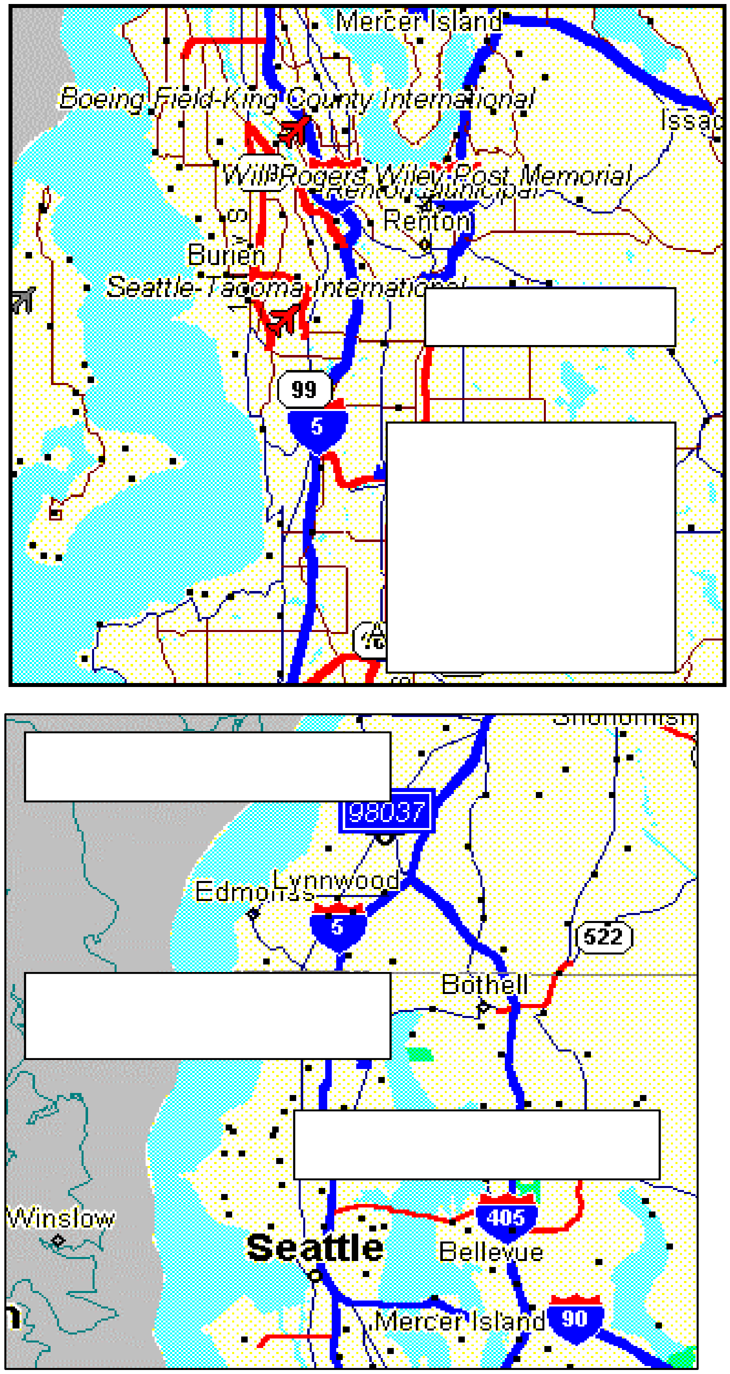

Figure 1. Regional map of City showing locations of XYZ retail outlets surveyed. Upper map shows stations visited on 03 and 05 August. Lower map shows stations visited on 04 August.

Between dates, we visited seven, City Area, retail outlets. We observed systems and drew samples from the locations listed in Table 1.

Table 1. XYZ stations surveyed during 03 to 06 August 1997.

Store No.	Location	Photo #/ view direction	Remarks
1111		#1; NW	Well graded for drainage & rainwater; wells in good condition. No throughput estimate. Customer had complained of poor performance after PUL fill. Found black residue on car's fuel filter. PUL probe: 0.0 in water; actual: 1.75 in.
2222		#2; N	Site at intersection of . Water last pumped 3 to 6 mos. ago. Grading good; wells in good condition. Fill-pipe wells drain to product. MUL & PUL are in split tank. Throughput estimate (gal/mo): xx M gal RUL + yy M MUL + zz M PUL
3333		#3; SE	Well graded for drainage amd rainwater runoff. Throughput estimate (gal/mo): xx M RUL + yy M MUL + zzM PUL.
4444		#4; N	Sub-optimal grading. Well covers in low-spot relative to surrounding ground. Throughput estimate (gal/mo): xx M RUL, yy M MUL; zz M PUL.
5555		#5; N	Good grade for drainage & rainwater runoff. Throughput estimate (gal/mo): xxM RUL, yy M MUL; zz M PUL.
6666		#6; N	Good grade for drainage & rainwater runoff. Throughput estimate (gal/mo): xxM RUL; yyM MUL; zz M PUL. Customer complained of slow fill from dispenser #7.
7777		#7; W	Station has good grade for water runoff. Throughput estimate (gal/mo): xxM RUL; yyM MUL; zzM PUL.

Methods

Summary

Details of each of the test methods used to complete the Survey are provided in Appendix A.

Gross Observations

During my site visit, I photographed various system components, including submerged turbine pumps, pump risers, turbine distribution manifolds, leak detectors, filter housings, filter media and fuel samples. MIC patterns are generally distinguishable from other forms of corrosion. Where appropriate I scrapped, brushed or chipped surfaces to look at the "clean" metal beneath the corrosion deposit. In the case of fuel and bottoms-water samples I noted the color, clarity, phase separation and any unusual odors.

Hava Magnet checked all bottom-water samples for magnetic fines. She also filtered 30 mL of each fuel sample through Gelman, Type A/E (0.3µm) glass fiber filters. After the filters dried overnight, I photographed them and rated them on a five point scale for density and color.

The photographic record and my interpretations comprise the *gross observation* technique.

Microbiological Testing

I performed four types of microbiological tests. The first, a 15 min. assay for the enzyme catalase, provides a rapid estimate of the biodeterioration potential of the microbial population in the sample. The enzyme *catalase* is present in most of the microbes that routinely contaminate fuels and other petroleum derivative products. The amount of catalase roughly reflects both the number of microbes and their relative level of activity (an inactive population will have relatively little catalase per microbial cell). I have been using this test successfully in metalworking fluids since 1982, and in fuels since 1989. Briefly, two portions of sample are placed into reaction tubes. One sub-sample is poisoned, then both sub-samples are treated with a reagent that reacts with the catalase enzyme to generate gas. The reaction tubes are sealed, so that the gas produced can be measured as pressure. The reaction takes 10 -12 min. to run its course, so the tests are read after 15 min. (to reduce experimental error).

The other three tests are broth cultures. The LIQUI-CULT™ test enriches for general aerobic bacteria and fungi. The BART SRB test enriches for sulfate reducing bacteria and the BART IRB enriches for bacteria associated with ferrous metal corrosion. I inoculated the broths on the day samples were collected and observed them after 24, 48 and 72 h.

Chemical Testing

All chemical testing was performed by I.M. Analyst. During the tank survey, bottoms-water samples were tested for pH, dissolved oxygen (DO; percent saturation) total dissolved solids (TDS; g/L), alkalinity (or acidity, as appropriate; mg) and hardness (mg $CaCO_3$/L). A Corning ® CheckMate portable meter was used for pH, DO and TSS measurements. Appropriate HACH test kits were used for hardness, alkalinity and acidity titrations.

Results

Gross Observations

Climate:

Table 2 summarizes 1995 temperature and precipitation data compiled from printouts. The Puget Sound climate is temperate, with Winter daily temperatures averaging 44±2.4 °F and Summer daily temperatures averaging 67±1.9 °F. With approximately 37 in precipitation annually, City is a moderate precipitation area. Overall the climatological contribution to the biodeterioration risk is rated as moderate.

System Component Corrosion:

Photographic data are presented in Appendix B and are organized by retail outlet. All of the stores were equipped with either FE Petro or Red Jacket® submersible turbine pumps and leak detectors.

Based on observed corrosion of system components, the biodeterioration risk at each of the sites, by product system was as follows:

Store #	Fuel Grade	Risk Rating
2222	RUL & PUL MUL	M N.C.[a]
1111	RUL, MUL & PUL	M
3333	RUL & MUL PUL	N.C. M
4444	RUL MUL & PUL	L N.C.
5555	RUL & MUL PUL	N.C. L
6666	RUL & PUL MUL	N.C L
7777	RUL, MUL & PUL	N.C.

a - N. C.: not classified.

The Station # 2222 PUL turbine housing (Photos 8 and 9) was partially rust-covered. A rust colored substance was peeling away from the turbine riser (Photo 10), but the material was non-magnetic. Significant rust covered > 50% of the PUL turbine distribution manifold (Photo 11). At least one dispenser filter (Photo 12) from Station #1111 had been in service since 13 May 1996. Based on estimated monthly RUL throughput rates (xx thousand gal/mo; all RUL dispensers) an estimated 650 thousand to 1 million gal of RUL had passed though the filter. There was no gross evidence of biomass or corrosion product on the filter medium.

Note the PVA-wrapped plastic ball in Photo 12. Theoretically the PVA is water-soluble. When it dissolves, it releases the plastic ball. The ball shuts-off fuel flow through the filter. We tested the water-solubility of this filter's PVA membrane. Apparently aging had substantially reduced its solubility. The membrane did not dissolve when we stirred it in 50 mL of distilled water.

Table 2. Climate data for City, WA

Month	Average	
	Temperature °F	Precipitation in
Jan	41.3	5.10
Feb	44.3	3.67
Mar	46.1	3.77
Winter Avg	43.9	4.18
Std Dev	2.4	0.80
Apr	50.4	2.51
May	56.1	1.84
Jun	61.4	1.59
Spring Avg	56.0	1.98
Std Dev	5.5	0.48
Jul	65.3	0.85
Aug	65.7	1.22
Sep	68.8	1.94
Summer Avg	66.6	1.34
Std Dev	1.9	0.55
Oct	53.5	3.25
Nov	54.3	5.65
Dec	41.6	6.00
Autumn Avg	49.8	4.97
Std Dev	7.1	1.50
Annual Avg	54.1	3.12
Std Dev	2.5	0.46
Annual Total Precipitation		37.39

At Station # 3333, the PUL turbine riser (Photo 13) had the same peeling coating that was noted on the Station #2222 riser. Although corrosion was visible on the CimTek™ Hydrosorb II™ filter-housing base-plates from both RUL and PUL lines at dispenser # 1 - 2 (Photo 14), the elements appeared to be normal (Photo 15).

The RUL turbine riser from Station # 4444 (Photos 16 and 17) is coated with the same material noted above for the other turbine risers. The RUL tank leak detector (FE Petro Model STP-MLD) was covered with a moderate degree of corrosion (Photo 18). The RUL turbine distribution manifold was substantially more corroded than the MUL manifold (Photo 19). RUL, MUL and PUL filter elements from dispenser # 7 - 8 appeared to be normal. These filters had been in service for approximately two-weeks (25 to 50 thousand gal fuel filtered).

The RUL turbine riser at Station # 5555 had the same appearance as the risers described above (Photo 22). The turbine riser adapter (Photo 23) had significant corrosion.

Although the Station #6666 PUL riser was corrosion and deposit free, both the adapter and manifold base were corroded (Photo 24). The PUL dispenser filter appeared to be normal.

At Station # 7777 significant corrosion coated the MUL turbine distribution manifold (FE Petro). Filters pulled from MUL dispenser # 7 - 8 appeared normal (Photo 28).

Significant corrosion coated the filter housing seats on MUL dispenser # 17 at Station # 7777 (Photo 29).

Fuel and Water Samples:

Table 3 summarizes UST configuration and water level data for the five sites surveyed. Tanks trim by the T-end or containing > 1 in bottom-water at the F-end are rated *moderate risk* . The probability of significant, undetected bottom-water accumulation visual is substantially greater in these UST than it is in dry UST, trim by the F-end. The best method for determining a UST's trim (direction of settling) is to draw a bottom sample from each end and compare water levels in the two samples. In order to survey more sites, we decided to pull turbines from one UST per station. We could not determine trim of tanks from which we drew only F-end samples. Only four of 16 UST checked were unequivocally trim by the T-end. Based on comparisons of F-end measurements and probe readings (the probes are generally installed close to the T-end) six UST from which only F-end samples were collected appear to be trim by the F-end.

Table 4 data, fuel sample gross observations, are augmented with Appendix B Photos. Photos 30 through 40 show fuel samples drawn from fill-pipe (F-end) and turbine wells (T-end) of each of the UST surveyed. Biodeterioration may cause fuel and bottom-water darkening. However, this darkening is generally accompanied by substantial sediment accumulation and a well defined third phase (rag layer) between the fuel and water phases. Bottom -water darkening that is accompanied by rag-layer formation is more indicative of biodeterioration.

Chemical Analysis

During the site visit, only bottom-water chemistry was tested.

Water chemistry data are presented in Table 5. Although it’s normal to see some oxygen depletion in bottom-water, microbe-free water will be ≥ 50% saturated with oxygen (oxygen saturation is a function of temperature, atmospheric pressure and the medium; for the water samples tested, 100% oxygen saturation ranged from 5.2 to 8.2 mg D.O./L). In terms of biological oxygen depletion my rule of thumb is:

% Saturation	Bioactivity rating
>50	low
20 to 50	moderate
< 20	high

Total dissolved solids data indicate heavy loadings in all bottom-water samples. Both biological activity and chemical incompatibilities can contribute to high (>1 g/L) TDS concentrations. In conjunction with the other water chemistry data TDS is used to assess biodeterioration risk

Typically, an active microbial population will produce low molecular weight organic acids. These acids are important components of microbially influenced corrosion (MIC) processes. In the absence of buffering chemistry, pH is a good indicator of microbial activity. Bottom-water pH ranged from 6.75 (Station #6666, RUL; F-end) to 8.35 (Station #6666 PUL; F-end).

Table 3. XYZ Seattle Area retail outlet UST data; date

Store No.	Fuel Grade[a]	Capacity (gal)	Constuction (lined or unlined)	Water (in)			Product (in)			Trim (F or T)	Product Temp (°F)	Risk rating (H, M, L)
				Dip stick[b]		Probe	Dip stick		Probe			
				F	T		F	T				
1111	RUL		FRP[c]	<0.1	N.D.[d]	-	60.00	N.D.	58.53	F?	74.3	L
	MUL		FRP	-	-	-	41.50	N.D.	39.61	F?	72.7	L
	PUL		FRP	2.25	2.75	-	45.00	N.D.	42.16	F?	70.6	M
2222	RUL	15,000	FRP	0.25	0.36	1.02	66.50	66.00	66.60	T	72.0	M
	MUL	8,000	FRP	-	-	-	28.25	28.25	32.07	0	68.8	L
	PUL	8,000	FRP	2.25	2.75	2.57	26.75	26.50	27.88	T	67.9	M
3333	RUL	11,000	FRP	-	N.D.	-	55.00	N.D.	52.13	F?	N.D.	L
	MUL	11,000	FRP	0.12	N.D.	-	21.50	N.D.	20.44	F?	N.D.	L
	PUL	11,000	FRP	-	N.D.	-	32.00	29.50	29.72	F	N.D.	L
4444	RUL	12,000	FRP	0.88	-	N.P.e	56.75	57.50	N.P.	T	N.D.	M
	MUL	12,000	FRP	-	N.D.	N.P.	37.00	N.D.	N.P.	N.D.	N.D.	N.C.f
	PUL	12,000	FRP	0.50	N.D.	N.P.	31.75	N.D.	N.P.	N.D.	N.D.	M
5555	RUL		FRP	1.12	N.D.	-	47.00	N.D.	N.D.	N.D.	79.2	M
	MUL		FRP	0.50	N.D.	-	47.50	N.D.	N.D.	N.D.	77.0	M
	PUL		FRP	1.00	N.D.	-	32.50	N.D.	N.D.	N.D.	79.4	M
6666	RUL	9,000	FRP	-	N.D.	-	62.75	N.D.	62.90	F	74.7	L
	MUL	9,000	FRP	1.00	N.D.	-	58.75	N.D.	25.89	F?	76.0	M
	PUL	9,000	FRP	0.75	-	-	41.50		39.78	F	72.2	M
7777	RUL	9,000	FRP	1.50	N.D.	-	21.00	N.D.	21.33	T	73.8	M
	MUL	9,000	FRP	1.75	N.D.	0.63	18.50	N.D.	23.12	T?	71.1	M
	PUL	9,000	FRP	2.00	N.D.	-	25.00	N.D.	23.12	F	70.2	M

Notes:

a. RUL: regular unleaded; MUL: mid-grade unleaded; PUL: premium unleaded.

b. F: fil- pipe; T: turbine-end.

c. FRP: fiber reinforced plastic.

d. N.D.: not determined.

e. N.P.: no probe installed.

f. N.C.: not classified.

Table 4. XYZ Area retail outlet UST bottom sample gross observations; Date.

Store No.	Fuel Grade[a]	F or T[b]	Remarks	Risk rating (H,M,L)
1111	RUL	F	Water (< 1 mL): high TSS; opaque; color: Gardner 7. Fuel: haze: ASTM 1; color: Gardner 2. No rag layer.	M
	MUL	F	No sample drawn.	
	PUL	F	Water: high TSS; opaque; Gardner 7. Fuel: haze: ASTM 2; Gardner 3. No rag layer.	M
		T	Water: none. Fuel: haze: ASTM 3; Gardner 3. No rag layer.	
2222	RUL	F	Water: high TSS; opaque; color: Gardner 4. Fuel: haze: ASTM 3; color: Gardner 6. No rag layer.	M
		T	Water: high TSS; opaque; color: Gardner 8. Fuel: haze: ASTM 3; color: Gardner 3. No rag layer.	
	MUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 2; Gardner 3. No rag layer.	M
		T	Water: high TSS; opaque; Gardner 7. Fuel: haze: ASTM 1; Gardner 3. No rag layer.	
	PUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 2; Gardner 3. No rag layer.	M
		T	Water: high TSS; opaque; Gardner 7. Fuel: haze: ASTM 3; Gardner 3. No rag layer. Globules accumulate in fuel, on surface of interface.	
3333	RUL		Not Sampled	N.C.[c]
	MUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 2; Gardner 3. No rag layer.	M
	PUL	F	Water: high TSS; opaque; Gardner 7. Fuel: haze: ASTM 2; Gardner 3. No rag layer.	M
		T	Not Sampled	
4444	RUL	F	Water: high TSS; opaque; Gardner 10. Fuel: haze: ASTM 2; Gardner 2. No rag layer. Gobules and particulates cover water surface.	M
		T	Water (5 mL): high TSS; opaque; color: Gardner 10. Fuel: haze: ASTM 4; color: Gardner 2. No rag layer.	
	MUL	F	Not Sampled	N.C.
	PUL	F	Water: high TSS; opaque; coloer Gardner 7. Fuel: haze: ASTM 1; Gardner 3. No rag layer. Globules on water surface above interface.	M
5555	RUL	F	Water: high TSS; opaque; Gardner 9. Fuel: haze: ASTM 4; Gardner 3. No rag layer. Surface of interface covered wih fine, easily dispersed particles.	M
	MUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 3; Gardner 3. No rag layer. Surface of interface covered wih < 1 to 2 mm particles.	M
	PUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 6; Gardner 3. No rag layer.	M
6666	RUL	F	Water: None. Fuel: haze: ASTM 1; Gardner 2.	L
	MUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 5; Gardner 2. No rag layer. Globules accumulate in fuel, on surface of interface.	M
	PUL	F	Water: high TSS; opaque; Gardner 8. Fuel: haze: ASTM 3; Gardner 6. No rag layer.	M
		T	Water: high TSS; opaque; Gardner 7. Fuel: haze: ASTM 6; Gardner 9. No rag layer.	
7777	RUL	F	Water: high TSS; opaque; Gardner 10. Fuel: haze: ASTM 2; Gardner 3. No rag layer. Globules & particles accumulate in fuel, on surface of interface.	M
	MUL	F	Water: high TSS; opaque; Gardner 10. Fuel: haze: ASTM 5; Gardner 4. No rag layer.	M
	PUL	F	Water: high TSS; opaque; Gardner 9. Fuel: haze; ASTM 3; Gardner 3. No rag layer. Surface of interface covered wih fine, easily dispersed particles.	M

Notes:

a. RUL: regular unleaded; MUL: mid-grade unleaded; PUL: premium unleaded;
b. F: fill-end; T: turbine-pump end.
c. Not Classified.

While pH data indicate whether a sample is acidic (< 6.5), neutral (6.5 - 7.5) or alkaline (> 7.5) they do not give any indication of a sample's resistance to pH change. Alkalinity and acidity data provide this answer. None of the bottom-water samples from the 15 UST from which water was collected was acidic (< 0 mg $CaCO_3$/ L alkalinity). Typically gasoline tank bottom water alkalinity is >1,000 mg $CaCO_3$/ L. Some petroleum marketers speculate that these high alkalinities are due to $CaCO_3$ carry-over from post-hydro-treatment drying beds at the refinery. However, the more likely explanation is fuel additive partitioning into the water-phase. Diesel tank bottom-water is typically less strongly buffered (alkalinity range: 100 to 500 mg $CaCO_3$/ L. As alkalinity decreased below 1,000 mg $CaCO_3$/ L for gasoline bottom-water, or 100 mg $CaCO_3$/ L for diesel bottom water, the likelihood of acidic metabolite accumulation increases. This translates into increased biodeterioration risk. Alkalinities were ≥ 1,000 mg $CaCO_3$/ L for all bottom-water samples tested.

Aggressiveness Index (A.I.) is computed as the sum of pH + $\text{Log}_{\text{alkalinity}}$ + $\text{Log}_{\text{hardness}}$. It provides an estimate of a water sample's corrosivity. Water with an A.I. <10 is considered corrosive; 10 - 12 is moderately corrosive; >12 is non-corrosive. All UST bottom-water samples tested were non-corrosive.

Fuel filtration testing provides an indication of particulate formation, reflective of decreased oxidative stability. Standard test methods call for gravimetric determination of particulates. However, for preliminary field examination, visual observations of filter residues is adequate. Thirty mL of near-bottom fuel was drawn into a disposable syringe and pressed through a Gelman glass fiber filter (0.3 µm nominal pore size). After drying overnight, filter residues were rated on a scale of 0 (no visible residue) to 5 (black residue). None of the residues exceeded a 3 rating.

Photo 34 shows the filter residues from Station # 1111. Only three of 11 filters had residue ratings >0. Note that after the RUL UST was polished, its filter residue rating dropped from 3 to 0.

Biodeterioration risk rating, based on water chemistry data, considers, in order of importance, A.I., oxygen saturation and TDS. Corrosive water represents a high risk, regardless of D.O. and TDS values. Low oxygen saturation in non-corrosive water represents a moderate risk. Based on the water chemistry data, none of the UST were rated as high risk units. All UST except the following were rated *low risk*:

Moderate Risk UST	
Station # 3333 PUL	Station # 7777 PUL
Station # 7777 MUL	

Microbiological Analyses

Microbiological test data are presented in Table 6. Biodeterioration risk ratings are derived from tests that measure both the presence and activity of microbial populations. Five microbiological test methods were used to make this assessment. Risk rating criteria for catalase activity in bottoms-water samples are:

- < 1 psig: microbial load not significant
- 1 - 5 psig: microbial load significant; can generally be controlled with biocide alone
- > 5 psig: microbial load very high; generally requires both tank cleaning/fuel filtration and biocide application.

Table 5. XYZ City Area UST bottom-water chemistry data; Dates.

Sample ID					D.O.		TDS	pH	Alkalinity	Acidity	Hardness	A.I.	Filterability		Biodet.
Location	Fuel Grade[a]	F or T[b]	Date	F or W[c]	mg/L	% Sat.	g/L		mg $CaC_{O}3$/L		mg $CaC_{O}3$/L	(pH + log Alk + log Hard)	Vol (mL)	retain color	risk (H, M, L)
1111	RUL	F	05-Aug-97	W	1.4	20	6.47	8.16	1,900		110	13			L
				F									30	1	
	MUL	F		W	Not Sampled										L
				F											
	PUL	F		W	Insufficient water to test										L
				F									30	2	
		T		W	Insufficient water to test										
				F									30	3	
2222	RUL before polishing	F	03-Aug-97	W	3.8	35	4.95	7.63	2,400		230	13			L
				F									30	3	
		T		W	Insufficient water to test										
				F											
	RUL after partial polishing	F		W	N.D.	N.D.	2.15	7.24	2,000		280	13			L
				F											
		T		W	N.D.	N.D.	5.02	7.36	2,100		280	13			L
				F									30	3	
	MUL	F		W	N.D.		8.16	7.25	3,000		260	13			L
				F									30	0	
		T		W	Insufficient water to test										
				F									30	0	

Table 5 continued.

Sample ID					D.O.		TDS	pH	Alkalinity	Acidity	Hardness	A.I.	Filterability		Biodet.
Location	Fuel Grade	F or T	Date	F or W	mg/L	% Sat.	g/L		mg $CaCO_3$/L		mg $CaCO_3$/L	(pH + log Alk + log Hard)	Vol (mL)	retain color	risk (H, M, L)
3333	PUL	F		W	1.6	30	5.66	7.96	1,000		100	13			L
				F									30	0	
		T		W	0.4	11	5.65	7.97	1,000		80	13			M
				F									30	3	
4444	RUL	F	05-Aug-97	W	Not Sampled										
				F											
	MUL	F		W	1.6	21	5.64	7.81	2,000		120	13			L
				F									30	1	
	PUL	F		W	Insufficient water to test										
				F									30	1	
5555	RUL	F	05-Aug-97	W	1.9	25	11.10	7.23	2,200		800	13			L
				F									30	1	
	MUL	F		W	Not Sampled										
				F											
	PUL	F		W	2.0	27	6.92	7.77	2,000		310	14			L
													30	1	

Table 5 continued.

Sample ID					**D.O.**		**TDS**	**pH**	**Alkalinity**	**Acidity**	**Hardness**	**A.I.**	**Filterability**		**Biodet.**
Location	Fuel Grade	F or T	Date	F or W	mg/L	% Sat.	g/L		mg CaC_O3/L		mg CaC_O3/L	(pH + log Alk + log Hard)	Vol (mL)	retain color	**risk** (H, M, L)
6666	RUL	F	04-Aug-97	W	1.1	20	12.8	6.75	4,000		260	13			L
				F									30	0	
	MUL	F		W	2.0	23	4.52	7.18	1,800		120	13			L
				F									30	1	
	PUL	F		W	1.3	18	1.66	8.35	1,400		50	13			L
				F									30	0	
7777	RUL	F	04-Aug-97	W	Not Sampled										
				F											
	MUL	F		W	1.1	17	3.71	7.56	2,100		100	13	30	3	M
				F											
	PUL	F		W	1.2	11	4.00	8.12	3,100		90	14	30	0	M
				F											

Table 5 continued.

Sample ID					D.O.		TDS	pH	Alkalinity	Acidity	Hardness	A.I.	Filterability		Biodet.
Location	Fuel Grade	F or T	Date	F or W	mg/L	% Sat.	g/L		mg CaC$_{O}$3/L		mg CaC$_{O}$3/L	(pH + log Alk + log Hard)	Vol (mL)	retain color	risk (H, M, L)
94998	RUL	F	04-Aug-97	W	0.4	19	6.22	7.41	2,100		190	13			M
				F									30	0	
	MUL	F		W	1.8	19	3.37	7.66	1,700		120	13			M
				F									30	0	
	PUL	F		W	2.0	21	5.18	8.08	2,400		90	13			L
				F									30	0	

Notes:

a. RUL: regular unleaded; MUL: mid-grade unleaded; PUL: premium unleaded.
b. F: fill-end; T: Turbine-end.
c. F: fuel; W: water.

For LiquiCult data, risk rating criteria are:

- < 10^3: microbial load not significant
- 10^3 - 10^5: microbial load significant; can generally be controlled with biocide alone
- > 10^5: microbial load very high; generally requires both tank cleaning/fuel filtration and biocide application.

Any detectable SRB or acid producing bacteria recovery constitutes high risk.

Typically, contamination levels are 6 to 8 orders of magnitude greater at the fuel:water interface and fuel:tank wall interface than they are in the bulk fuel, and 4 to 6 times greater than in the bottom-water. Consequently, any detectable microbial contamination in the fuel-phase is significant.

In Table 6, high risk UST are highlighted in yellow. Data indicating high microbial loads are printed in bold, red type. There were no samples positive for sulfate reducing bacteria. Ten UST were rated *high-risk* due to high microbial contamination levels:

Station # 1111 RUL	Station # 3333 MUL	Station # 7777 RUL
Station # 2222 RUL	Station # 3333 PUL	Station # 7777 MUL
Station # 2222 MUL	Station # 4444 RUL	- -
Station # 2222 PUL	Station # 6666 MUL	- -

Five UST were rated *moderate-risk*:

Station # 1111 PUL	Station # 6666 MUL
Station # 4444 PUL	Station # 7777 PUL

The three UST at Station # 5555 and the RUL tank at Station # 6666 were rated *low-risk*.

Table 6. XYZ City Area UST fuel and bottom-water microbiology data; Dates.

Sample ID					Catalase	LiquiCult	BART	BART	Biodet.
Location	Fuel Grade[a]	F or T[b]	Date	F or W[c]	Activity (psig)	(MPN/mL)	IRB (MPN/mL)	SRB (MPN/mL)	risk (H,M, L)
1111	RUL	F		W	24	>1.E+06	N.D.	N.D.	H
				F	0.4	<1.E+02	N.D.	N.D.	
	MUL	F		W	Not Sampled				M
				F	Not Sampled				
	PUL	F		W	N.D.	1.E+05	N.D.	N.D.	
				F	0.6	<1.E+02	N.D.	N.D.	
2222	RUL	F		W	>50	1.E+05	N.D.	N.D.	H
				F	0.4	<1.E+02	N.D.	N.D.	
		T		W	Insufficient water in sample				L
				F	0.2	<1.E+02	N.D.	N.D.	
	MUL	F		W	Insufficient water in sample				H
				F	3.2	1.E+04	N.D.	N	
		S		W	Insufficient water in sample				
				F	1.8	<1.E+02	N.D.	N.D.	
	PUL	F		W	7.6	1.E+04	N.D.	N.D.	H
				F	1.7	<1.E+02	N.D.	N.D.	
		S		W	13.8	1.E+04	N.D.	N.D.	
				F	1.4	<1.E+02	N.D.	N.D.	

Table 6 (continued).

Sample ID					Catalase Activity (psig)	LiquiCult (MPN/mL)	BART IRB (MPN/mL)	BART SRB (MPN/mL)	Biodet. risk (H,M, L)
Location	Fuel Grade	F or T	Date	F or W					
3333	RUL	F		W	Not Sampled				
				F	Not Sampled				
	MUL	F		W	>50	>1.E+06	5	NEG.	H
				F	0.8	<1.E+02	N.D.	N.D.	
	PUL	F		W	20.0	>1.E+06	4	N.D.	
				F	0.8	<1.E+02	N.D.	N.D.	
4444	RUL	F		W	>50	>1.E+06	4	NEG.	H
				F	0.7	<1.E+02	N.D.	N.D.	
		S		W	>50	1.E+06	5	NEG.	
				F	2.2	<1.E+02	N.D.	N.D.	
	MUL	F		W	Not Sampled				
				F	Not Sampled				
	PUL	F		W	1.2	1.E+06	1	NEG.	M
				F	0.4	<1.E+02	N.D.	N.D.	
5555	RUL	F		W	0.4	1.E+04	1	NEG.	L
				F	0.6	<1.E+02	N.D.	N.D.	
	MUL	F		W	1.0	1.E+03	1	NEG.	L
				F	0.6	<1.E+02	N.D.	N.D.	
		S		W	No water in sample				
				F	0.6	<1.E+02	N.D.	N.D.	
	PUL	F		W	0.2	1.E+03	1	NEG.	L
				F		<1.E+02	N.D.	N.D.	
6666	RUL	F		W	No water in sample				L
				F	0.8	<1.E+02	N.D.	N.D.	
	MUL	F		W	>25	1.E+05	1	NEG.	H
				F	0.8	<1.E+02	N.D.	N.D.	
	PUL	F		W	4.5	1.E+04	1	NEG.	M
				F	0.4	<1.E+02	N.D.	N.D.	
7777	RUL	F		W	>50	1.E+05	1	NEG.	H
				F	0.8	<1.E+02	N.D.	N.D.	
	MUL	F		W	>50	1.E+04	2	NEG.	H
				F	0.4	<1.E+02	N.D.	N.D.	
	PUL	F		W	2.8	1.E+04	C	NEG.	M
				F	0.5	<1.E+02	N.D.	N.D.	

Notes:

a. RUL: regular unleaded; MUL: mid-grade unleaded; PUL: premium unleaded;
b. F: fill-end; T: turbine-end.
c. F: fuel; W: water.
d. Sample collected from top of fuel column with bailer sampler.
e. Sample collected mid-way through polishing process.
f. Sample collected after polishing process completed.

In order to determine the extent of biological contamination on filter media and other critical surfaces, a number of filter sections and scrapings were tested microbiologically. Either a 1 cm x 2 cm section of filter medium or ~ 1 gm of scraping material was transferred to each of two HMB reaction tubes containing 10 mL of Liqui-Cult broth. A third portion was used to inoculate a BART SRB tube. One of the duplicate Liqui-Cult broths was tested for catalase activity after 24 hours. The other Liqui-Cult broth and the SRB broth were observed for growth for up to 72 hours.

Table 7 presents the data for the non-liquid samples. Neither of the turbine riser scrapings from Station # 2222 had significant catalase activity. However, the PUL riser material yielded significant Liqui-Cult numbers (10^5 MPN/gm). Several filters had significant (> 1.0 psig) levels of catalase activity. Only two also yielded significant Liqui-Cult recoveries (Station # 2222 MUL and PUL). The Station # 2222 MUL filter had 10^6 MPN/cm^2 but catalase activity was < 1.0 psig. The lack of agreement between Liqui-Cult and catalase activity reflects the importance of using more than one parameter to assess microbial loads in fuel systems.

Table 7. XYZ City Area UST non-liquid sample microbiology data; Dates.

Location	Fuel Grade[a]	Sample Description	Catalase activity (psig)	Liqui-Cult (MPN/cm^2)	BART SRB (Pos./Neg.)
1111	RUL	1 x 2 cm section of filter medium	6.5	<1.E+02	Neg.
2222	RUL	Scraping from turbine riser	0.4	<1.E+02	N.D.
	RUL	1 x 2 cm section of filter medium	1.1	1.E+04	Neg.
	MUL	1 x 2 cm section of filter medium	0.6	1.E+06	Neg.
	PUL	Scraping from turbine riser	0.3	1.E+05	Neg.
	PUL	1 x 2 cm section of filter medium	1.1	1.E+06	Neg.
3333	RUL	1 x 2 cm section of filter medium	1.8	<1.E+02	Neg.
4444	MUL	1 x 2 cm section of filter medium	1.5	<1.E+02	Neg.
5555	PUL	1 x 2 cm section of filter medium	0.3	<1.E+02	N.D.
6666	PUL	1 x 2 cm section of filter medium	0.8	<1.E+02	N.D.
7777	MUL	1x 2 cm section of filter medium	4.4	<1.E+02	N.D.

a - RUL: regular unleaded; MUL: mid-grade; PUL: premium unleaded gasoline.

City Area Fuel Logistics and Service History

Nearly all City Area gasoline is provided by the four refineries located at Cherry Point, WA (ARCO) Ferndale, WA (TOSCO) and Anacortes, WA (Shell and Texaco). Product is transported into City through the Olympics Products Pipe Line System, (OPPL) and delivered to four City Area terminals:

Operator	Location
GATX	City
Superior	Tacoma
TOSCO	Renton
UNOCAL	Tacoma

The OPPL system is fungible and delivers product tenders ordered by petroleum marketers.

On date we visited Randy Operator, his operations are probably similar to operations at the other area terminals. The terminal ships ~ XX thousand bbl per day of RUL and ~ YY thousand bbl of PUL (MUL is blended from RUL and PUL at the rack). All of the terminal's product tanks are gravity feed with floating suction lines. The terminal's tank capacity is as follows:

Grade	Tankage
RUL	thousand bbl
PUL	thousand bbl

The terminal uses {proprietary summary of operations}

The terminal checks for water monthly and draws quarterly (or when needed). They typically collect 500 to 1,500 gal water per draw.

We also met with XYZ's City Area Operations Manager. He summarized product sources for the retail outlets covered in our survey:

Station #	Product Source (Terminal)
1111	{proprietary}
2222	
3333	
4444	
5555	
6666	
7777	

{discussion of relationship between product source(s) and site specific risk assessments.}

Details of all of the service call activities were not available. However, we were provided a summary of know filter changes at the seven stores, over the past 12-months. {proprietary discussion of relationships between filter change frequency and site specific risk assessments}

We did observe considerable variety in filter types used at XYZ's City Area stations. Several of the stations had more than one filter Brand/grade in use. Client is encouraging all locations to use BRAND A filters. Differences in filter media, coupled with subjective assessments of filter plugging compound the diagnostic problem. At most of the XYZ owned stations, service requests are motivated by customer complaints. There is no standard method for measuring dispenser flow-rates. Store managers call for service when one or more customers report slow or arrested pumping. At Station # 1111, Owner/operator estimated the time interval between dispensing meter "clicks" to diagnose decreased flow-rate. Consequently, the perception of filter plugging problems may have little to do with actual flow rate restrictions.

Diagnosis is further compounded by the lack of any consistent data acquisition process. The initial impression at client's offices was that filter plugging problems were restricted to a single site; Station # 1111. The data presented in the preceding Tab and comments made by ***, suggest that the filter plugging phenomenon is more wide-spread than initially thought.

Conclusions and Recommendations

Assignment of biodeterioration risk ratings depends on an assessment of current conditions and system vulnerability. Climate and system configuration address vulnerability. The other observations consider current conditions.

Table 8 summarizes the biodeterioration risk ratings of the 19 UST surveyed during my {date}, site visit. Five UST are at high risk for biodeterioration problems. The remaining nine UST , except for Station # 6666's RUL are at moderate risk. Station 4444's RUL UST received a high risk classification because significant biological activity was present in the filter medium as well as the tank's bottom-water. Total alkalinity (1,900 mg $CaCO_3$/L) was the lowest among RUL bottom-water samples; indicating that organic acid production was significant in this tank.

All three UST at Station # 2222 were rated high-risk. Microbial loads were high and they accompanied other signs of biodeterioration (reflected in moderate-risk component corrosion and bottom sample ratings) . The same logic was used in assigning a high-risk rating to the RUL UST at Station # 1111.

XYZ's regional maintenance program appears to be reactive. Although normal filter life is typically > 500 thousand gal gasoline filtered (> 6 months @ 100 thousand gal per month), a substantial number of filters are being replaced at more frequent intervals. Since neither time intervals nor gal filtered data are captured, XYZ is not in a position to assess the actual average filter performance life at City Area Stations. Call frequencies among the stations surveyed ranged from 8 to 37 during the year preceding this survey. Since it's unclear whether single or multiple filter changes were made during each service call, the average 19 annual calls per station could reflect filter lives ranging from 19,000 to 1.2 million gal filtered.

Table 8. XYZ Seattle Area UST biodeterioration risk summary.

Location (Station #)	UST	Risk rating						
		Climate	Gross observations			Water chemistry	Micro-biology	Overall
			Component corrosion	Tank conditions	Bottom sample appearance			
1111	**RUL**	**M**	**N.C.[A]**	**L**	**M**	**L**	**H**	**H**
	MUL	M	N.C.	M	N.C.	N.C.	N.C.	N.C.
	PUL	M	M	M	M	L	M	M
2222	**RUL**	**M**	**M**	**M**	**M**	**L**	**H**	**H**
	MUL	**M**	**M**	**L**	**M**	**L**	**H**	**H**
	PUL	**M**	**M**	**M**	**M**	**L**	**H**	**H**
3333	RUL	M	N.C.	L	N.C.	N.C.	N.C.	N.C.
	MUL	M	N.C.	L	M	L	H	M
	PUL	M	M	L	M	N.C.	H	M
4444	**RUL**	**M**	**M**	**M**	**M**	**L**	**H**	**H**
	MUL	M	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
	PUL	M	N.C.	M	M	L	M	M
5555	RUL	M	N.C.	M	M	L	L	M
	MUL	M	M	M	M	L	L	M
	PUL	M	N.C.	M	M	L	L	M
6666	RUL	M	N.C.	L	L	L	L	L
	MUL	M	N.C.	M	M	L	H	M
	PUL	M	M	M	M	L	M	M
7777	RUL	M	N.C.	M	M	L	H	M
	MUL	M	M	M	M	L	H	M
	PUL	M	N.C.	M	M	L	M	M

a - N.C.: not classified

Fuel that meets or exceeds quality standards still contains some water and particulate matter. Although these contaminants may be below detection levels in a fuel sample taken at the rack, they concentrated in UST over time. Throughput rates at the seven stations surveyed range from <150,000 to >250,000 gal/mo. Greater throughput reduces settling time, but increases the volume of fuel from which water and sediment can drop out. Even where terminals are using best available technology to deliver quality product at the rack, contamination loads are going to accumulate in UST.

There are a number of actions XYZ can take to minimize the biodeterioration risks and to assess the role of delivered product quality in UST chemical deterioration or biodeterioration.

I recommend several follow-up actions:

- Set up and maintain a database:
    - Dates, source, volume and fuel grades delivered
    - Dates and volume of bottom-water removed from each UST (bottom-water pH and alkalinity would also be useful)
    - Dates of filter changes; volume of fuel filtered between changes.
- Shock treat the UST at Station 2222 (1 gal MICRO GARD 2000 per 2,500 gal capacity). Biocide should be added just before fuel deliveries.
- Once the retail system has been treated, an ongoing monitoring and preventive treatment program should be implemented. The water chemistry, catalase activity and Liqui-Cult parameters included in this survey should provide the basis for the monitoring program.

The database will permit correlation between events and system conditions. The shock treatment test will assess biocide efficacy. Typically quarterly treatments are needed to prevent problem recurrence. The ongoing monitoring program will enable XYZ to make informed ROE-based decisions regarding supplier selection and preventive maintenance procedures.

In order to comply with EPA's Clean Air Act derived regulations, petroleum refiners have had to essentially change the chemistry of the product they produce. More severe refining has necessitated increased use of performance additives; further changing fuel chemistry. Some fuels may be inherently more corrosive than they were in the past. Most grades disperse water more readily than they did formerly. Microbes can survive on water droplets that approximate their own size (1 μm^3). Water films as thin as $^1/_8$ in (4.7 mm) are like an ocean to microbes. Consequently, fuels and fuel systems are generally more susceptible to biodeterioration today than they were prior to the implementation of the June, 1994 revisions to 40 CFR 179 (fuel and fuel additive regulations).

XYZ's best strategy to minimize biodeterioration costs is though local monitoring and prevention.

Date

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