IVEY-SOL®
Surfactant Technology

Ivey-sol® Surfactant Remediation Technology for treatment of petroleum hydrocarbon, chlorinated solvent, PFAS, and Organometallic impacted soil and groundwater

Free of Unwanted By-Products Including:
PFOA, PFAS, 1,4 Dioxane, Dioxins, Furans and Tested and Free of USEPA Regulated Contaminates.

Powering Site Remediation for Over 25 Years

2020 Top 10 Environmental Technology Solution Providers - Award Enterprise Technology Review

2019 CV Best Environmental & Remediation Solutions Award

2018 EBJ Technology Merit Remediation Award

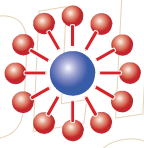
2018 CV Best Environmental Tech Development Company Award

2011 MISTIC Environmental Excellence Award

2011 Roy F. Weston Award Significant Contributions to Field of Industrial Waste Management

2006 North American Frost & Sullivan Award for Technology Innovation

2006 Globe Award for Environmental Innovation and Application



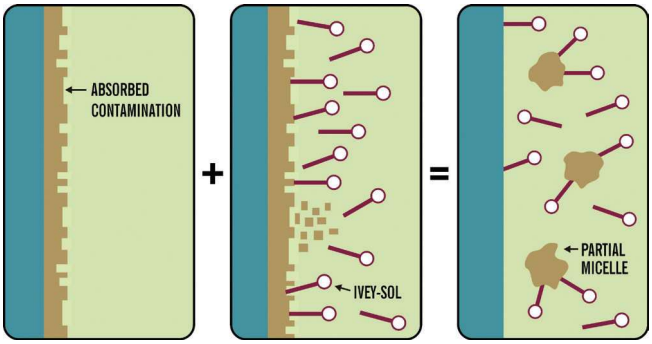
Ivey International Inc.

Today's environmental solutions for a better tomorrow™

ivey-sol.com

IVEY-SOL SURFACTANT REMEDIATION TECHNOLOGY

Ivey-sol® Surfactant Technology is comprised of several patented and/or proprietary non-ionic surfactant formulations (biodegradable) that have the unique ability to selectively desorb sorbed (i.e., absorbed and/or adsorbed) contaminants and make free-product (NAPL) miscible in the aqueous phase for enhanced mass removal (See Mechanism). This includes the broad range of Light Non Aqueous Phase Liquids (LNAPL) like petroleum hydrocarbons (API >10), and the Dense Non Aqueous Phase Liquids (DNAPL) including chlorinated solvents (API <10). Ivey-sol® has also been used for the remediation of recalcitrant compounds within fine to coarse soil textures, marine sediments and fractured bedrock, and within the groundwater table and associated smear-zones and capillary zones, with favorable results.



Ivey-sol® desorbing contamination off the soil surfaces, or from NAPL (i.e. LNAPL and/or DNAPL) layers making them more 'Available' for in-situ or ex-situ remediation. The three (3) main Ivey-sol® application processes that were developed over two (2) decades for enhancing in-situ and ex-situ remediation of: Vapors/VOC, Soil/Bedrock (sorbed), and Groundwater (Dissolved, LNAPL, and Smear-Zone) COC site remediation, are outlined as follows:

SER® SURFACTANT ENHANCED REMEDIATION

In-situ and ex-situ application processes to liberate sorbed and/or LNAPL COC making them more miscible (soluble) and more 'Physically-Available' for mass removal via 'Push-Pull™' or 'Pump & Treatment' type remediation methods.

SEB® SURFACTANT ENHANCED BIOREMEDIATION

In-situ and ex-situ application processes to liberate contaminants making them more 'Biologically Available' for microbial (bacteria) and associated enzymatic degradation. SEB® improves both in-situ and/or ex-situ bioremediation treatment methods.

SEC® SURFACTANT ENHANCED CHEMICALIZATION

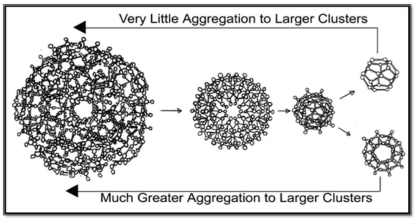
In-situ and ex-situ application processes to liberate contaminants making them more 'Chemically-Available' for chemical REDOX (i.e. Reduction or Oxidation or combined) by chemical agents.

IVEY-SOL® WATER CLUSTER SIZE REDUCTION

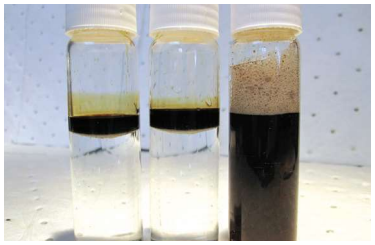
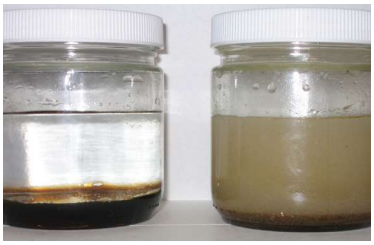
Ivey-sol® surfactants, when introduced into contaminated soil and groundwater regimes, can reduce the surface tension of water from 73 dynes to <30 dynes. This capacity improves the wetting ability, and movement, of the aqueous phase in the soil and groundwater (unsaturated and saturated) zones, and the relative 'Hydraulic Conductivity' (K), while Ivey-sol® is present. Once Ivey-sol® applications are completed the original site conditions return to normal.

The Ivey-sol® surfactants accomplished this by reducing the size and formation of large water-clusters to smaller water-clusters (See below). In doing so, the Ivey-sol® allows the water clusters to become smaller, and to penetrate into less permeable soils such as: clays, silty-clay, silty-sand, sands with silty and clay content to weathered and fractured bedrock, improving NAPL, sorbed and dissolved phase petroleum hydrocarbon and chlorinated solvent remediation.

Ivey-sol® reducing water cluster size for improved transport within fine grain soils.



A variety of Ivey-sol® application images are provided along the footer of this page showing the capacity and efficiency of this technology to enhance vapor, soil and groundwater remediation.

Ivey-sol 106 surfactant is mixed with water, with the addition of a conservative tracer for monitoring purposes, prior to injection.

SURFACTANT TECHNOLOGY ENHANCES REMEDIATION AT CONTAMINATED GRAIN ELEVATOR SITE

By **Eric Dulle** and **George 'Bud' Ivey**

Grain elevators are an enduring symbol of agricultural tradition. Unfortunately, they present environmental problems, due to a legacy of the agricultural industry's use of synthetic chemicals to help grow, store, and transport food. Since the 1970s, for example, grain producers have used fumigants containing chemicals such as carbon tetrachloride (CT) to protect stored grains from fungus and rot.

Fumigants were typically stored in above-ground storage tanks at grain elevator sites, ready for use as needed. As professionals in the remediation industry well know, where there are storage tanks, there are leaks, and where there are leaks, there is the potential for soil and groundwater contamination. Such contamination is the reality at most, if not all, grain elevator sites.

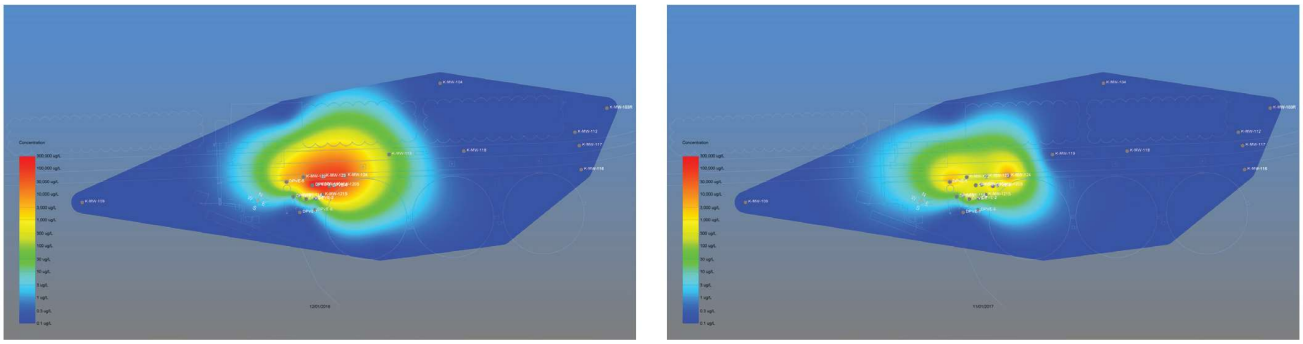
During the 1970s and 1980s, the owner/operator of a still-active grain elevator facility had regularly applied 80/20 grain fumigant (i.e., 80% CT and 20% carbon disulfide), as was common during that era. The fumigant compound was stored in an above-ground storage tank on the property before its removal in the 1990s.

The site entered into a voluntary cleanup and property redevelopment program in 2000, following soil and groundwater detection of fumigant constituents of concern (COCs). These were primarily CT, but also carbon disulfide, chloroform, and methylene chloride. Groundwater impacts extended about 122 m down gradient from the site (the "source area").

To remediate the site, Burns & McDonnell Engineering Company, the consulting engineer for the project, recommended the installation of a dual-phase extraction (DPE) system. It has been operating since 2007.

Remediation options at the site were significantly limited due to access constraints associated with ongoing facility operations, a steep grade change from the access point to the source area, active mainline railroad tracks, and

Originally published in Environmental Science & Engineering Magazine December 2018



Constituents of concern (COC) concentrations in groundwater plume before and after Ivey-sol application.

other utilities and structures throughout the impacted area. Nonetheless, the remediation team was able to successfully and safely install the DPE system, including eight extraction wells, within the source area.

Over the period from 2007 to 2014, the system achieved significant contaminant mass reduction, removing over 4,130 kg of COCs in the vapour and dissolved phases. About 28.5 million litres of groundwater were recovered and treated during this time period.

Evaluations of DPE performance in 2014 found that, while the system had succeeded in removing a very large amount of mass and significantly reducing the lateral extent of the source area, a subset of source-area extraction wells continued to exhibit elevated (i.e., source-level) COC concentrations in groundwater. The system had dramatically reduced source mass and prevented migration of the plume as intended, but a remnant, highly concentrated source still required remediation.

As a result, an additional investigation was conducted using high-resolution site characterization techniques to assess the nature and extent of residual COC mass in the source area. The investigation results indicated significant sorbed-phase COC mass, generally limited to the shallow, sandy interval of an area bound by the DPE wells exhibiting elevated COC concentrations. Historical light non-aqueous phase liquid (LNAPL), heavily impacted with the site COCs, was also identified.

Burns & McDonnell used the data generated by the investigation to evaluate alternatives for expediting the source-area remediation and maximizing the effectiveness of the DPE system. During the course of evaluating alternatives, a presentation at a remediation industry conference, describing a project with similar site conditions, led Burns & McDonnell to believe that surfactant-enhanced extraction (SEE) would be a viable option. The company also had a previous relationship with surfactant technology developer Ivey International Inc. (Ivey) in a separate petroleum remediation project.

Based on these factors, Burns & McDonnell decided to conduct a SEE pilot study in 2015 using the Ivey-sol® 106 (Cl) surfactant formulation, which was specially designed to treat chlorinated solvents at the site. If the pilot study yielded positive results, a full-scale project would follow.

Ivey-sol® SEE surfactant products consist of several patented and/or proprietary non-ionic formulations that can selectively desorb sorbed COCs and render NAPLs miscible in the aqueous phase. Surfactants have a structure with a hydrophilic head and a hydrophobic tail; the hydrophobic tail attracts and attaches to the organic portion of CT and similar molecules, while the hydrophilic head attracts to groundwater, thereby making the CT molecules miscible.

Ivey-sol can do this without emulsifying the COCs, thereby increasing their availability for remediation, while not impacting the performance of wastewater treatment systems.

Ivey's products accomplish three goals. Firstly, surfactants overcome the "limitation" challenges associated with contaminant sorption and solubility. Secondly, they lower the relative surface tension of water, thereby improving its wetting and associated hydraulic conductivity properties. Thirdly, through their selective dissolving of COCs below the critical micelle concentration, the surfactants broaden the range of contaminants that can be treated and enhance physical, biological, and chemical remediation, in situ and ex situ.

According to Ivey, their surfactant products are non-toxic and biodegradable, so they do not persist in the environment after application, which can be

continued overleaf...

"Ivey-sol can make carbon tetrachloride molecules miscible without emulsifying the constituents of concern, thereby increasing their availability for remediation, while not impacting the performance of wastewater treatment systems.

verified with Ivey-sol field test kits and by three USEPA laboratory test methods. Indeed, because they are non-toxic to bacteria, they can also give a boost to natural attenuation.

They have some disadvantages that careful application can overcome. For example, their effectiveness may be diminished if the mixtures freeze during storage, and their deployment may suppress volatile organic compounds, making them less detectable by standard, handheld vapour meters.

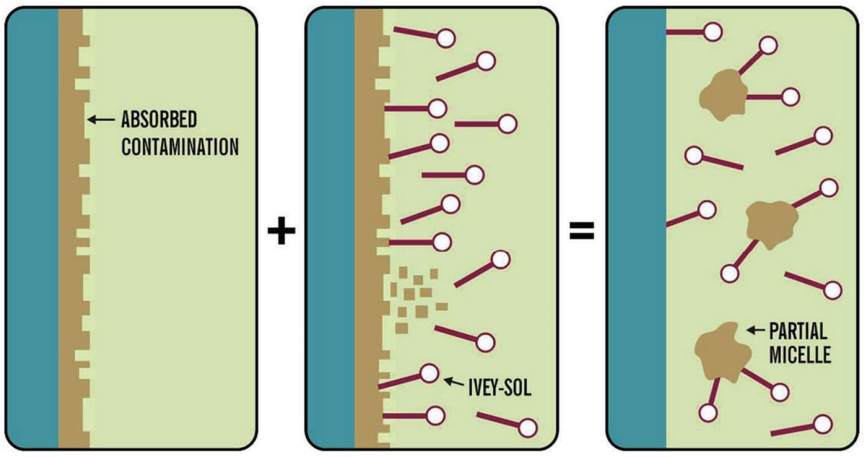
For the pilot study at the grain elevator site, which was conducted in April and May of 2015, Ivey-sol surfactant technology was deployed in single-well "push-pull" tests and multi-well "point-to-point" tests at two DPE system locations and two groundwater monitoring wells. Burns & McDonnell was able to use the existing DPE and well infrastructure to implement the surfactant injection and product recovery, thus minimizing intrusive activities and cost.

Groundwater was encountered at approximately 2.1 m – 2.4 m below ground surface. The lithology within the targeted source zone generally consisted of well-sorted, loose, silty sand to depths ranging from 4 m – 5.2 m below ground surface, underlain by a silty clay. Ivey have found that their surfactant products are effective in site conditions with more varied and complex structure, including course-grained, fine-grained, and higher silt and clay-content soils.

For this pilot, Ivey-sol surfactant was mixed with water in a 1% – 2% solution, which was gravity-fed into two monitoring wells and two DPE wells to achieve a targeted injection diffusion radius and then allowed to remain in the formation for a prescribed residence time.

Overall, concentrations of groundwater and soil vapour recovered by the DPE system, immediately following surfactant flushing, demonstrated increases of up to four times (>400%) more than the average concentrations observed under normal DPE operational conditions.

Based on these positive results, Burns & McDonnell elected to conduct a full-scale Ivey-sol SEE test from August through November of 2016 to address remaining COC mass within the source zone. For the full-scale test, 1,045 litres of Ivey-sol 106 surfactant were mixed with potable water and a conservative tracer for observation of the solution's distribution.



Ivey-sol desorption mechanism operating on soil surfaces or LNAPL layers, making contamination more available for remediation.

Three additional monitoring wells were installed to facilitate surfactant delivery to the northern portion of the source area. Five Ivey-sol SEE phases were conducted to target the portion of the area with the highest COC concentrations, applying point-to-point surfactant delivery to the core source area within the shallow saturated zone, followed by groundwater extraction from the wells that were initially used for surfactant injection. Burns & McDonnell monitored recovery progress via real-time tracer testing and field surfactant test procedures developed by Ivey.

A key result of the full-scale activities was a dramatic increase in COC mass recovery rates. During the short SEE implementation and 12 month monitoring period, the surfactant-enhanced DPE system recovered more than 25% of the total mass that the DPE system had recovered over the previous 10 years. In addition, recovered groundwater concentrations up to 30,000 micrograms per liter (µg/L), more than five times (>500%) the highest concentrations ever observed during DPE operation, were observed during the SEE monitoring period.

Overall, the full-scale SEE test achieved 98% CT reduction in the source area's shallow monitoring wells and 92% reduction in source area DPE wells. Moreover, although not the primary objective of remediation activities, significant reductions in LNAPL thicknesses were observed. The DPE remediation system, enhanced with Ivey-sol 106 (Cl) formulation, successfully recovered the LNAPL product as a serendipitous benefit.

The remediation team estimates that the full-scale SEE system saved about a decade in active remediation time. With the cost of operating and maintaining the DPE system totaling up to $100,000 annually, the potential cost and time savings involved in deploying surfactant technology to complement DPE technology and recover more highly concentrated COC mass are readily apparent. ■

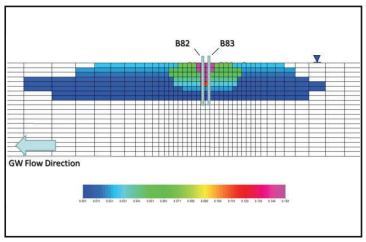
Eric Dulle is with Burns & McDonnell. Email: edulle@burnsmcd.com George "Bud" Ivey is with Ivey International. Email: budivey@iveyinternational.com

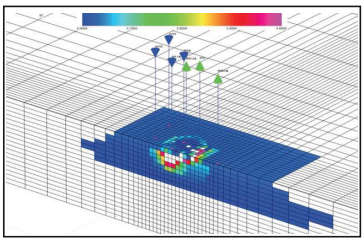
SETUP AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL MULTIPHASE MODEL FOR DESIGN OF IN-SITU REMEDIATION OF JET FUEL WITH SURFACTANT

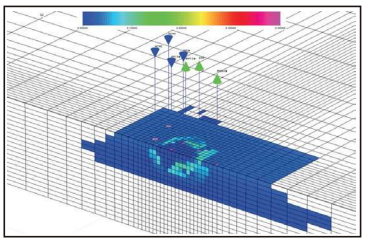
BACKGROUND

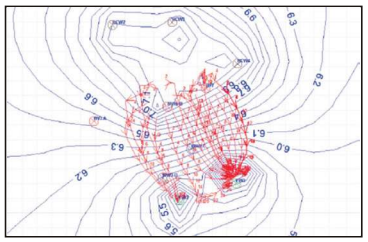
Storage and pumping of jet-fuel have caused a severe contamination of soil and groundwater at a military facility in Denmark. The contamination was detected in 2001. The Danish Defence has conducted a series of investigations and set up a skimmer system, that has recovered approximately 25 m^3 of jet-fuel. In 2005, the recovery stopped, and the remaining jet-fuel is trapped as a residual light non-aqueous phase liquid (LNAPL) comprising approximately 45 m^3 jet-fuel in a 1000 m^2 source area. In the ground water downstream of the source area, there is an extensive diving plume of contaminants.

In part of the source area, the Danish Defence and NIRAS have launched a pilot Scale Surfactant Enhanced Aquifer Remediation (SEAR) in order to demonstrate mobilization of LNAPL from the sediment. The pilot remediation was carried out using non-ionic surfactants (Ivey-sol®) from Ivey International Inc. for injection in a line of injections wells. The mobilized oil and injected surfactants were recovered from a downstream line of extraction wells. The recovered oil/ground water was treated on site, and the treated water was re-injected up-gradient in a line of hydraulic control wells. The effect of the pilot SEAR was monitored by sampling and analyzing the ground water from the extraction wells and by estimation of trapped jet-fuel in an oil-water separator as part of the on-site treatment, supplemented by post soil sampling/analyses from boreholes. The 3 different methods gave different results for the mass balance, and the estimated effect of the pilot remediation ranged from 25 kg to 150 kg of hydrocarbons.









Søren Rygaard Lenschow,
Anders G. Christensen
NIRAS A/S, Allerød,
Denmark

Mette Marie Mygind
Danish Defence, FBE,
Hjørring, Denmark

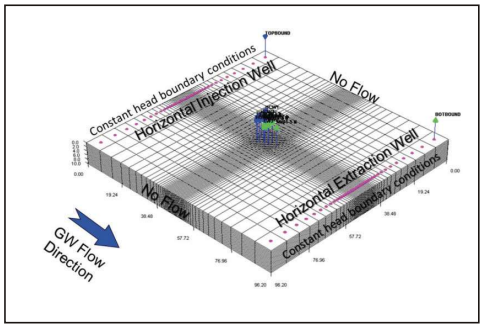
Ahmad Seyedabbasi,
Phillip C de Blanc
GSI Environmental Inc.,
Houston, TX, USA

George Ivey
Ivey International Inc.
Surrey, BC, Canada

WATER BALANCE

- Extraction – 12 m^3/day (0.5 m^3/h)
- Reinfiltration – 8 m^3/day (0.33 m^3/h)
- Injection 0.15 – 1 m^3/day
- Discharge – 4 m^3/day (0.17 m^3/h)
- Hydraulic control – 2 weeks
- 7 injections of Ivey-sol® (0.15 – 1.0 m^3 – 1.3 – 3.0 % surfactants)
- Hydraulic control for 7 weeks post injection

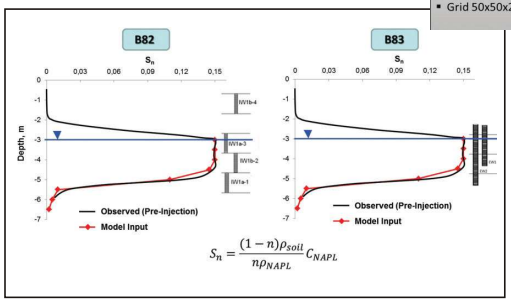
To validate the effect of the Pilot Remediation, GSI Environmental Inc. has set up a three-dimensional numerical multiphase model by using the University of Texas' Chemical Compositional Simulator UTCHEM.



SETUP UTCHEM

- Input – vertical oil saturation based on soil samples

- *dx = dy* = variable
  - Min = 0,5 m (center)
  - Max = 7,7 m (boundaries)
- *dz* = 0,5 m
- 100 m x 100 m x 10 m
- Grid 50x50x200



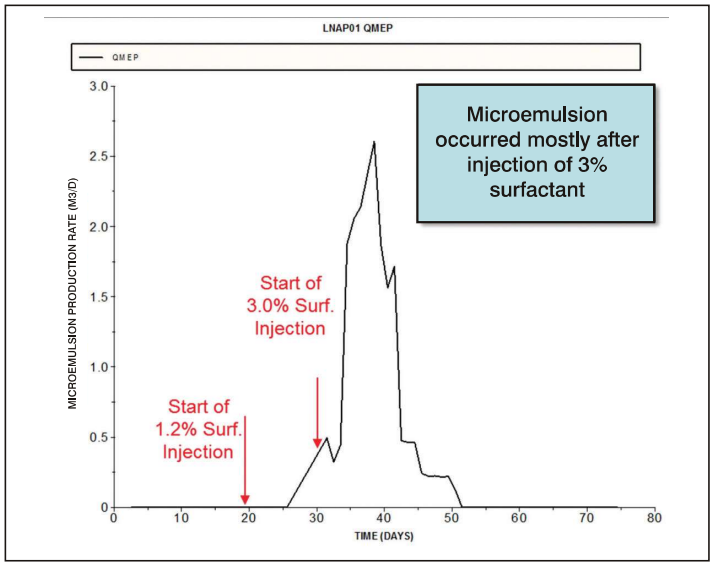
SIMULATIONS UTCHEM

- 70 days – Injections of Ivey-sol® surfactants from day 20 to day 27
- 7 injections of surfactants – 1.3 – 3.0% Ivey-sol®
- Oil saturation as function of time
- Accumulated oil from extraction wells
- Capture of surfactants in extraction wells
- Comparison of simulations with no injection of surfactant

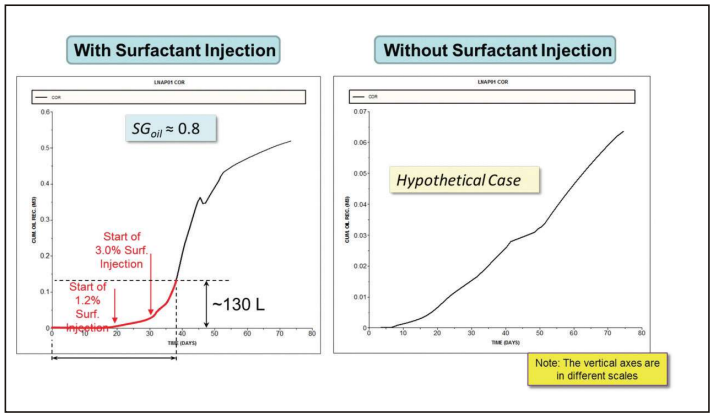
SETUP AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL MULTIPHASE MODEL FOR DESIGN OF IN-SITU REMEDIATION OF JET FUEL WITH SURFACTANT

RESULTS

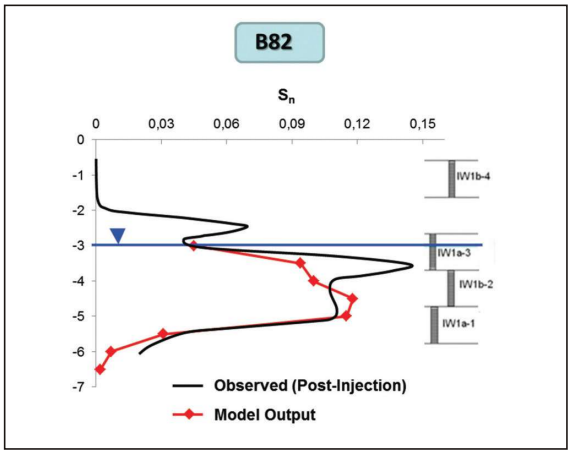
- Formation of micro-emulsion during Pilot SEAR

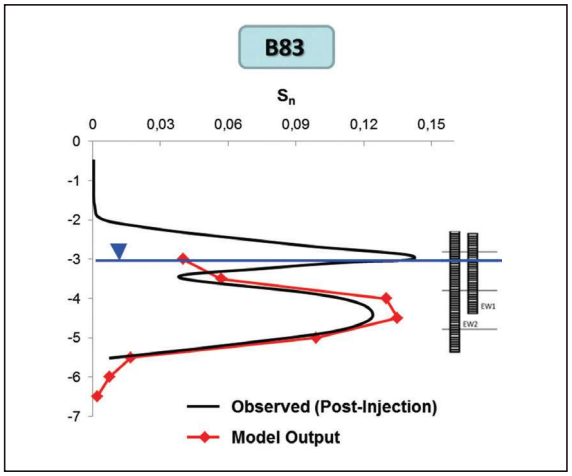


- Accumulated Oil during Pilot SEAR



- Post Oil Saturation in soil





The simulations indicate a removal of 130 kg oil on day 50 and approximately 400 kg after day 70. Simulations without surfactants show a removal of less than 1/10 of the removal achieved when using Ivey-sol® surfactants.

CONCLUSIONS

The UTCHEM model was able to simulate the Pilot SEAR, and injected fluids were contained within the pilot area. Further, the simulations estimated an approximate 10-fold (1000 %) increase of the oil concentration in the extracted ground water relative to a water injection without the use of Ivey-sol® Surfactants. The model also showed that the main process for mass removal during SEAR was production of a micro-emulsion.

The total removal during the Pilot SEAR was by UTCHEM estimated to be 100-400 kg oil compared to 25-50 kg by analysis and measurements of the effluents from the extraction wells, and 50-150 kg based on the change of oil saturation in the soil by analysis of soil samples.

The simulated post-SEAR oil saturation was similar to measured concentrations from post-study soil sampling. The simulations also indicate that most of the Ivey-sol® surfactants was removed during the pilot SEAR and the post pump & treat period.

The setup of the UTCHEM gave an insight into the processes and hydraulics during the pilot SEAR in comparison to a "Black Box" situation, where the remediation technology performance is only evaluated by process and monitoring data, after the remediation is conducted.

The performance of the pilot study provided important lessons of great value for both the design and the documentation of issues in the design and planning of future full-scale remediation.

NIRAS GSI ENVIRONMENTAL Ivey International Inc. "Today's Environmental Solutions For A Better Tomorrow"™

Surfactant Enhanced HVDPE Remediation of Petroleum Contaminated Soil, Bedrock and Groundwater

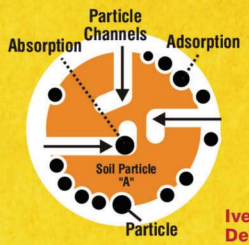
Site Conditions

Remediation Challenge

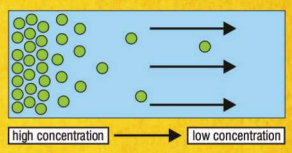
The number one limiting factor for all forms of in-situ remediation is contaminant sorption

Sorption >>>>>Desorption or Diffusion

Absorption vs Adsorption



Diffusion



○ solute

Solute transport is from the left to the right; movement of the solutes is due to concentration gradient (dC/dx).

Ivey-sol® Overcomes Sorption Improving Desorption & Diffusion of Contaminants Increasing Their 'Availability' for Remediation

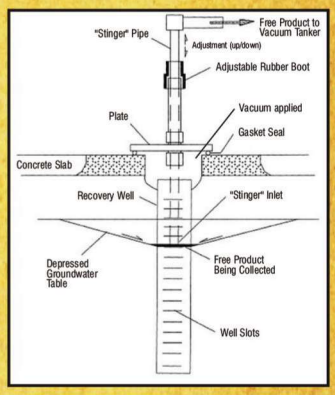
- ★ Recalcitrant petroleum product residuals sorbed in fine grain soils and fractured bedrock
- ★ Persistent concentrations in groundwater after 12 years of remediation – including pumping, HVDPE
- ★ Obtained regulatory approval for Ivey-sol® surfactant application in spring 2009

Pilot Test Approach

Focused Short-Term Surfactant Injection/Extraction to Maximize Recovery

- Ivey-sol® 106 pilot scale injection undertaken over 5 days in July 2009
- Four injection events, one injection well (MW15) and four extraction HVDEP wells (MW2, 7, 8 and 11)
- Five surrounding monitoring wells sampled during pilot
- Mobile HVDPE system capable of 28 inch Hg vacuum and 800 SCFM
- Groundwater HVDEP average recovery rate of 0.24 ppm

- Recalcitrant petroleum product residuals in fractured bedrock
- Persistent concentrations in groundwater after 12 years of remediation – including pumping, HVDPE



HVDPE Extraction Well

Diagram shows radius of influence and potential LNAPL collection

Ivey International Inc.

"Today's Environmental Solutions For A Better Tomorrow"™

www.iveyinternational.com

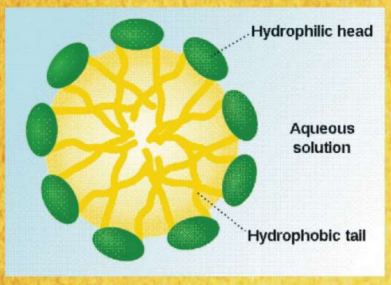
TRC Results you can rely on

707 Wilshire Blvd 32nd Fl | Los Angeles, CA 90017-3599 | T: 213.213.9412 | F: 888.788.5297 | C: 310.570.7069

Christopher d'Sa – E: CdSa@trcsolutions.com | Galen Kenoyer – E: Gkenoyer@trcsolutions.com

Surfactant Chemistry

Surfactant Structure



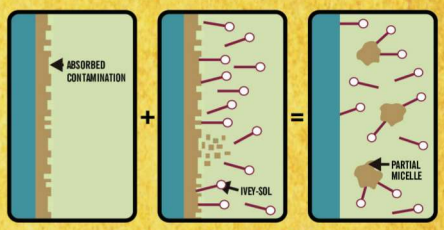
Hydrophilic (water loving) and Hydrophobic (water hating oil-liking) Groupings allow for Mobilization of many Organic Contaminants

Classes of Surfactants

- Anionic: Have one or more negatively (-) charged groupings; commonly used in laundry detergent
- Cationic: Have one or more positively (+) charged groupings, typically poor detergents but well suited for use as germicides, fabric softeners and emulsifiers.
- Amphoteric: Contains both anionic and cationic groupings; prefer neutral pH and found in products such as hair shampoo, skin cleaners and carpet shampoo.
  - *Ionic Surfactants make up >95% of the surfactant used around the world.*
- Non-ionic: Have no ionic constituents or groupings; largest single group of SAA (Surface Active Agent) and have a correspondingly wide range of chemical characteristics. Ivey-sol® surfactant mixtures are non-ionic and have the unique ability to selectively desorb contamination (LNAPL, DNAPL's, PAH, PCB, DCE, TCE, PCE), etc.

Why Ivey-sol® Surfactants?

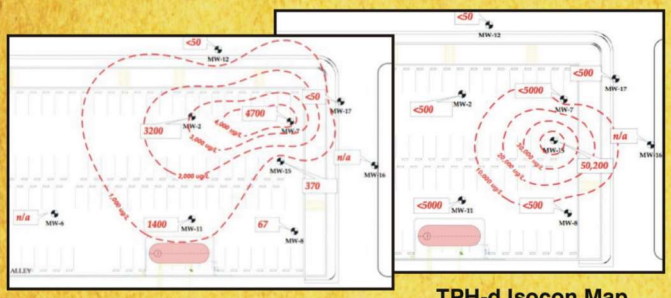
- Improves desorption of target contaminants in soil and groundwater
- Lowers the surface tension of water improving both its wetting and associated permeability (K) properties
- Effective as a stand alone technology for soil and groundwater remediation
- Effective to improve other remediation techniques (i.e., P&T, Soil Washing, Bioremediation, Chemical Oxidation/Reduction)



Ivey-sol® desorbing NAPL mass for increased 'availability' for remediation

Results

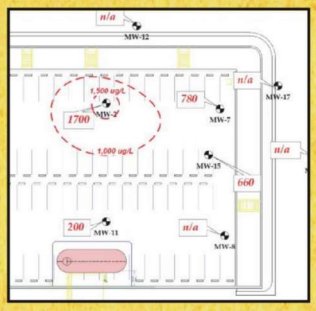
Before and During Test



TPH-d Isocon Map before Pilot Test

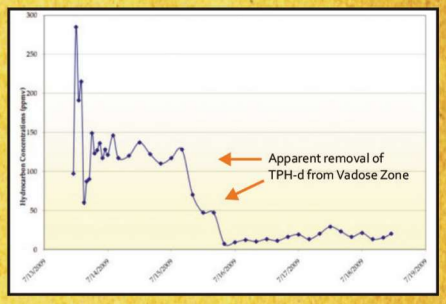
TPH-d Isocon Map 2 hrs after Pilot Test

Post Pilot Test Results



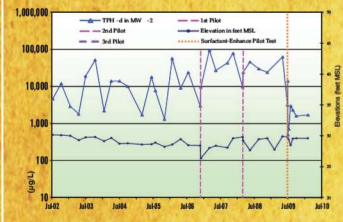
TPH-d Isocon Map 7 months after Pilot Test

HVDPE Vapor Concentrations



MW-2

[9.169 x 10^3mg/day ÷ 1.5551 x 10^3mg/day] x 100% = **590%**

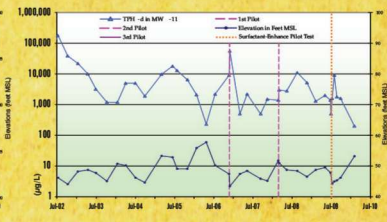


MW-7

[2.1754 x 10^4mg/day ÷ 3.1918 x 10^3mg/day] x 100% = **682%**

MW-11

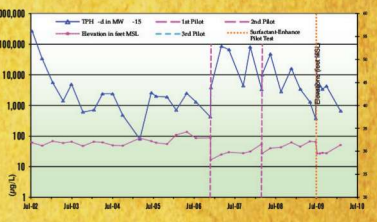
[1.678 x 10^4mg/day – 1.7579 x 10^3mg/day] x 100% = **955%**



MW-15

[4.4107 x 10^4mg/day ÷ 2.7603 x 10^3mg/day] x 100% = **1,598%** Standard Pilot

[3.875 x 10^4mg/day – 2.014 x 10^3mg/day] x 100% = **1,924%** Push-Pull



Conclusions: We increased the TPH_d Mass Recovery Rate by 10x !!!

- Removed TPH-d from vadose zone
- Lowered groundwater concentrations
- Regulatory Agency agree to risk-based closure if concentrations continue to decrease

Pilot Application was a Success!

Ivey International Inc.
"Today's Environmental Solutions For A Better Tomorrow"™
www.iveyinternational.com

TRC
Results you can rely on

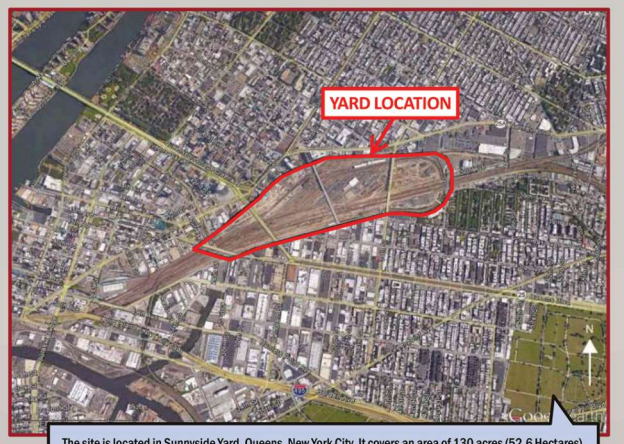
707 Wilshire Blvd 32nd Fl | Los Angeles, CA 90017-3599 | T: 213.213.9412 | F: 888.788.5297 | C: 310.570.7069
Christopher d'Sa – E: CdSa@trcsolutions.com | Galen Kenoyer – E: Gkenoyer@trcsolutions.com

Surfactant Enhanced Recovery of Separate-Phase Petroleum Hydrocarbons

Super Fund Site – Sunnyside Yard, Queens, New York City, USA

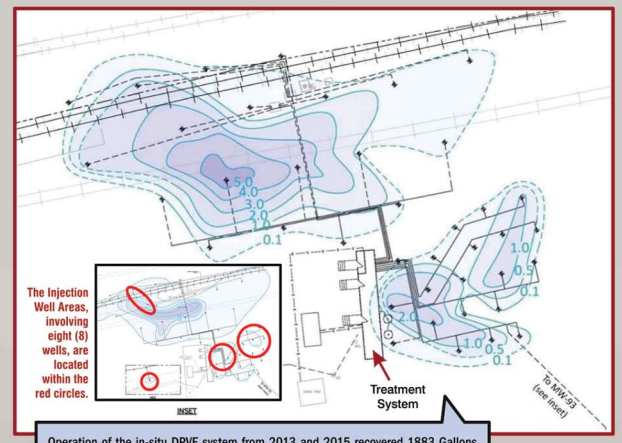
Paper ID: 22600 / Topic: ThS 4c / Author: George Ivey, Ivey International Inc.

SITE HISTORY



The site is located in Sunnyside Yard, Queens, New York City. It covers an area of 130 acres (52.6 Hectares). Has been in service for over 100 years. Site operations resulted in spills impacting the soil and groundwater with petroleum and PCB impacts, with observed phase separated petroleum hydrocarbons (LNAPL) on site. The site is a State Super Fund with six operational areas of remediation. This presentation focuses on the application of Ivey-sol surfactants to eliminate observed LNAPL to Regulatory Standards (<0.1 ft.) within one area of the site, where the existing Dual Phase Vacuum Extraction (DPVE) System was proving in effective.

DUAL PHASE VACUUM EXTRACTION (DPVE) SYSTEM LAYOUT



Operation of the in-situ DPVE system from 2013 and 2015 recovered 1883 Gallons (7,118 L) of product, with 84% of that mass recovery realized within the first five (5) months of system operation. Ongoing DPVE product recovery became asymptotic with diminishing rates of product recovery. Consultant wanted to enhance the product recovery. Bench scale testing of the Ivey-sol surfactant technology showed promise, resulting in regulatory approved pilot scale application presented herein.

Ivey-sol® Surfactant Technology

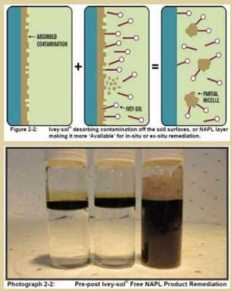
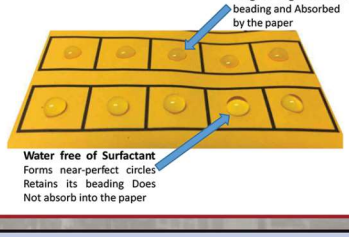


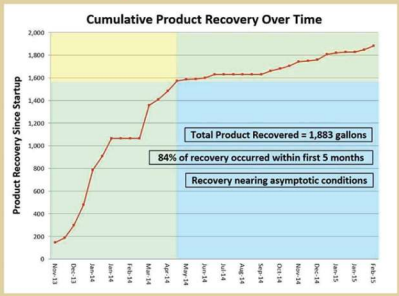
Figure 2-2: Ivey-sol® desorbing contamination off the soil surfaces, or NAPL layer making it more 'Available' for in-situ or ex-situ remediation.

Photograph 2-2: Pre-post Ivey-sol® Free NAPL Product Remediation

Ivey-sol surfactants technology is composed of several proprietary non-ionic surfactant formulations with the unique ability to selectively desorb petroleum hydrocarbons, and/or make phase separated hydrocarbons (NAPL), more miscible in groundwater, below the critical micelle concentration (CMC) not requiring emulsification as shown in the supporting images. In doing so, this makes the phase separated hydrocarbons (NAPL) more Physically-Available for enhanced DPVE mass recovery.

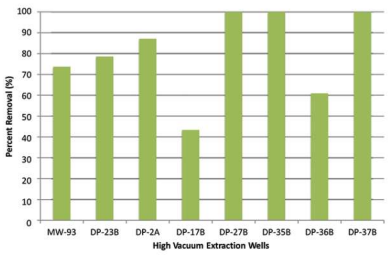


DPVE System Performance



RESULTS AND CONCLUSIONS

SPH (LNAPL) % Mass Removal



Conclusions

- SPH (LNAPL) mass recovery was significantly enhanced by the increase of SPH solubility by Ivey-sol;
- Free product was not observed in the extracted groundwater, and the performance of the groundwater treatment system (O/W + GAC) was not hindered;
- Reduction of SPH (LNAPL) thickness was usually observed within 24 hours of Ivey-sol surfactant injections, and persisted for several weeks or longer (due to opening of obstructed pathways);
- Low concentration ratios of surfactant (1:20 to 1:50) are effective, and higher concentrations do not increase effectiveness as Ivey-sol mechanism works below the CMC (Yielding Cost Savings);
- Low injection volumes or injection rates were generally needed in the injection areas due to the low permeability soil conditions and high groundwater table;
- All treated wells experience significant product mass removal following the three (3) pilot-scale applications. Three (3) of the eight (8) wells experienced 100% product (LNAPL) removal, with the average product thickness reduction of 81% (no rebound observed);
- Based on the success of the pilot scale application, the project was given regulatory approval to go full scale application. [Ivey-sol was also used in other impacted areas on this Super Fund Site aiding the physical, biological and/or chemical strategies being employed].

Pilot Study Methods

A total of three (3) in-situ Ivey-sol surfactant enhanced remediation (SER) applications were completed during the pilot study. This involved the gravity-feed injections of 265 Gal. (1000 L) of 2% Ivey-sol at each of the eight (8) injection well locations (IW). A post injection residence time of 24 hours was allowed before groundwater was extracted at these wells, to recover liberated product mass. Phase Separated Hydrocarbon measurements were completed prior to, during and after the Ivey-sol applications to evaluate the performance. The use of Ivey-sol surfactant field test kits (image provided) allowed the client to observe the location and relative concentration of Ivey-sol surfactant in-situ, and to determine the end-points of extraction associated with each event.

Project Update 2019 – The area treated in this presentation was successfully remediated, exceeding the state's regulatory standards, permitting the desired redevelopment of the area for a modern high speed train facility that has gone into operation.

AMTRAK®

IVEY-SOL Surfactant Technology

Unit 7, 19122 - 27 Avenue, Surrey, BC, Canada V3Z 5T1
Tel: +1 604 538 1168 / info@iveyinternational.com
www.iveyinternational.com

ROUX

Site of July 2019 oil spill in northern Alberta.

SURFACTANT-BASED EXTRACTION PRODUCT HELPS MINIMIZE IMPACTS FROM LARGE SPILL IN ALBERTA

By **George (Bud) Ivey** and **Adam Dunn**

In July 2019, a failure of pump equipment led to the spill of about 320,000 litres of a mixture of crude oil and produced water at an oil storage and processing facility located in remote northern Alberta. As the facility operator reported, approximately 99% of the spilled fluids were recovered, having been contained in an on-site bermed area, which already held about 300 m³ of pooled surface water. Some of the product, however, breached the containment area and was released into the local environment.

Calgary-based Earthmaster Environmental Strategies Inc. was retained to assess cleanup options and implement the remedy for cleaning up the spill. They reported that the liquid product that breached the containment area had flowed down a relatively steep slope (20% – 30% grade) about 180 m to the south-southwest. It was affecting herbaceous vegetation and associated trees and shrubs along its pathway.

An environmental receptor of concern was a small creek flowing near the base of the slope. Released fluids did not enter the creek, but there was some fluid infiltration into the shallow soil horizon and some oil sorption into vegetation and surface debris.

Released fluid consisted of 66 m³ of oil and 254 m³ of salt/produced water. No salt impacts were detected along the spill path, but the contaminants of concern (COC) included hydrocarbon fractions F1 (C6-C10), F2 (C10-C16) to F3 (C16-C34), benzene, toluene, ethylbenzene and xylenes (BTEX).

The steep slope and the presence of merchantable timber, vegetation, leaf litter and organic debris, along with irregular surface contours, presented logistical and safety challenges for efforts to recover the fluid and clean up the area. Further challenges arose as a result of a number of precipitation events, some being significant.

In fact, a storm was predicted to dump about 150 mm of rain two days after the spill. This prompted Earthmaster to delay the selection and implementation of a final cleanup remedy while it prepared for the storm. The firm installed several lined bell-shaped holes to catch runoff

Originally published in Environmental Science & Engineering Magazine June/July 2020

from the rain.

The application of LIDAR (light detection and ranging) remote sensing following the storm, confirmed that the bell holes were properly placed to prevent liquids from reaching the stream. As it turned out, they were also used for the final remedy chosen, which was flushing, or washing, as opposed to excavation and off-site disposal of the affected soil.

Excavation and removal is a common solution for many spills into the environment, but it presented several prohibitive challenges at this site, because of potential environmental damage. Deforestation of the hillside would have brought about erosion problems and a sedimentation threat to the nearby creek. There were cost issues as well, including a requirement to pay upwards of $50,000 or more for the lost timber to the holder of the forest management agreement that covered the hillside.

Bioremediation and chemical oxidation were also deemed to be impractical for this particular spill. Bioremediation would not have addressed spill migration, which threatened the waterway, and ongoing monitoring and laboratory services would have been extended for several years and been very costly. Stoichiometrically chemical oxidation is also very costly when used to address free-product spills. It has the potential to kill vegetation, and requires special PPE handling as a hazardous material.

Fortunately, sampling at the site showed that the oil/water mixture that escaped from the containment area had coursed down the hill rather than penetrated into the soil to any significant depth. So, the consultant decided that it could "do a flush" rather than a "scrape", which, more precisely, was passive and active surface flushing, rather than excavation and off-site disposal.

"Ivey-sol has the unique ability to selectively desorb contamination at low application concentrations from surfaces, including free-product layers.

A surfactant-based remedy was thus deemed optimal, and due to the remediation contractor's familiarity with the Ivey-sol® surfactant product developed and marketed by Ivey International Inc. (IVEY), that product was chosen for the cleanup job. It is biodegradable, pH neutral, non-caustic, non-corrosive, and free of undesirable impurities.

The Ivey-sol surfactant-enhanced extraction (SEE) products consist of a series of non-ionic formulations that can selectively desorb sorbed contaminants and render non-aqueous-phase liquids miscible in the aqueous phase.

SEE products achieve three goals. Surfactants overcome the "limitation" challenges associated with contaminant sorption and solubility. Then, they lower the relative surface tension of water, thereby improving its wetting and associated hydraulic conductivity properties. Finally, through their selective dissolving of COCs below the critical micelle concentration (CMC), the surfactants broaden the range of contaminants that can be treated. Thus, they enhance in situ and ex situ physical, biological and chemical remediation.

These surfactant products are non-toxic and readily biodegradable, so they do not persist in the environment after application. This can be verified with field surfactant test kits developed by IVEY, and by using any of three U.S. Environmental Protection Agency laboratory test methods.

The products have some disadvantages that careful application can overcome. For example, their effectiveness may be diminished if the surfactant/water mixtures freeze during storage, and their deployment may suppress volatile organic compounds, making them less detectable by standard, handheld vapour meters.

Based on the understanding that sorption and free-product formation greatly limit the "availability" of contaminants for remediation, Ivey-sol has the unique ability to selectively desorb contamination at low application concentrations from surfaces, including free-product layers. This means they are more available for physical treatment, as evidenced by this challenging yet positive site application.

The Alberta Energy Regulator approved the use of the Ivey-sol technology at the

continued overleaf…

Views of area near Bell Hole 3 before and after flushing with the surfactant.

spill site. The client preferred it to environmentally destructive excavation alternatives.

At the spill site, the surfactant was deployed in varying concentrations, using various delivery methods in a roughly checkerboard configuration. The first trial was completed using backpack sprayers (with a surfactant-to-water ratio of 1:30), followed by pressure-washing.

There was not enough volume in this trial, however, to move the oil to the recovery bell holes for removal. In order to increase pressure and volume, the surfactant and water were mixed in the tank of a small hydrovac truck at a 1:40 ratio for the second trial and applied using the pressure wand. The oil could be recovered with this application with the right technique, but would splatter if too much pressure was used.

In the third trial, another surfactant-to-water ratio of 1:40 was mixed in the hydrovac truck tank, and the tank hose was used for application rather than the pressure wand. The surfactant effectively washed the oil off the vegetation using this application.

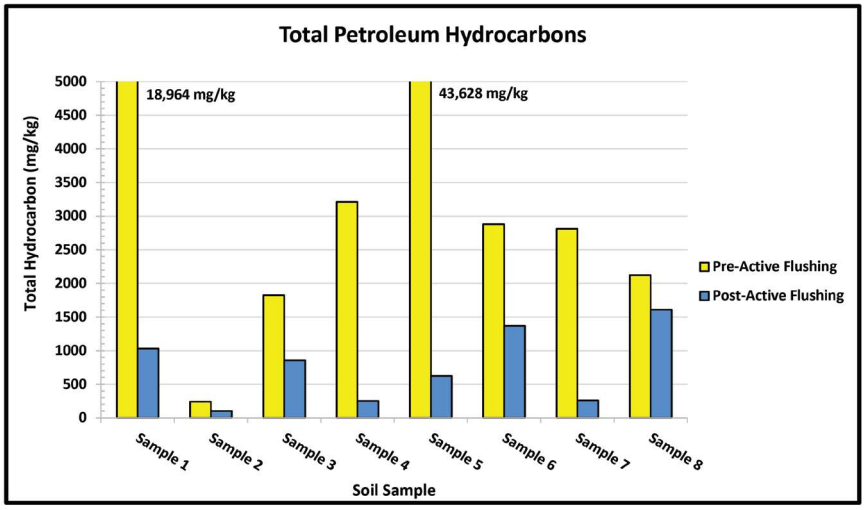
However, there was not enough pressure to move the fluid to the recovery bell holes, and suds were being produced. In order to optimize oil recovery and surfactant usage, ratios of 1:60 and 1:80 were applied and small local trenches were dug to collect and recover fluids.

The surfactant was applied over the course of four days, and the majority of the oil on the hillside was effectively liberated and flushed into the trenches and bell holes for removal. Visual observations indicated that the cleanup operation was generally effective, and soil sampling confirmed these findings.

Earthmaster decided that some heavily impacted areas where the leaf litter and vegetation was saturated with oil did not warrant the amount of surfactant and time required for complete removal. As a result, the contractor completed the remediation via surface soil/vegetation removal in these areas.

The flushing operation did not necessarily save much time compared with the typical spill response operation. But, it did realize significant cost savings in terms of avoiding the removal of merchantable timber on the hillside and the option of excavating and landfilling impacted soil and vegetation.

Cleanup crews flush forested impact site with Ivey-sol® surfactant.



Total PHC Bar Graph.

According to Earthmaster, there were numerous factors affecting project costs, and it was difficult to precisely quantify the cost savings attributable to choosing the flushing operation. The contractor estimates, however, that those cost savings could have been upwards of several hundred thousands of dollars. In light of this consideration, plus the avoidance of environmental damage, the Ivey-sol surfactant-based solution was deemed a sustainable success.

"In July 2019 we were faced with a 320,000 litre crude oil and produced water spill at a facility in northern Alberta," said Adam Dunn, vice president of operations at Earthmaster Environmental. "With our rapid spill response strategy, utilizing the Ivey-sol surfactant remediation technology, we achieved significant time, cost, and environmentally sustainable cleanup benefits, resolving more than 99% of the spill on the hillside." ■

George (Bud) Ivey is with Ivey International Inc. Email: budivey@iveyinternational.com
Adam Dunn is with Earthmaster Environmental Strategies Inc. Email: adam.dunn@earthmaster.ab.ca

**Recently, Ivey International Inc. won a Top 10 Environmental Technology Solution Providers 2020 Award from Enterprise Technology Review, a U.S. media company, in recognition of their technological innovations.*

Originally published in Environmental Science & Engineering Magazine June/July 2020

Ivey International Inc.

"Today's Environmental Solutions For A Better Tomorrow"

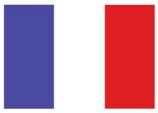
REACH Bulletin

EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation Compliance

ENGLISH

The **IVEY-SOL®** surfactant formulation, and its specific components, are non-ionic polymers and are therefore exempt from REACH registration under Article 2(9). **Ivey International Inc.** is committed to ensuring that end users have the most effective and safe product for environmental remediation and reclamation. We are committed to working with all regulatory agencies to ensure compliance with current standards.

Conformité aux normes d'enregistrement à l'échelle de l'UE, évaluation, autorisation des substances chimiques et des restrictions applicables à ces substances (REACH)



FRANÇAIS

La formule tensioactive **IVEY-SOL®**, ainsi que ses composants spécifiques, constituent des polymères non ioniques et sont par conséquent exemptés d'enregistrement REACH, conformément à l'article 2(9). **Ivey International** s'engage à fournir aux utilisateurs finaux le produit le plus efficace et le plus sûr qu'il soit pour l'assainissement et la récupération environnementale. Nous sommes résolus à travailler avec tous les organismes de réglementation afin de veiller au respect des normes en vigueur.

Conformità al regolamento europeo REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals)

ITALIANO

La formulazione tensioattivi **IVEY-SOL®** e i suoi elementi specifici consistono in polimeri non ionici esenti da registrazione REACH ai sensi dell'articolo 2(9). **Ivey International** s'impegna ad assicurare all'utente finale un prodotto per le bonifiche ambientali efficace e sicuro, e a lavorare con le agenzie di regolazione preposte per assicurare la conformità agli standard in vigore.

Cumplimiento de la Regulación de Registro, Evaluación y Restricción de Químicos (REACH, por sigla en inglés) de la UE

ESPAÑGNOL

La formulación de tensoactivos de **IVEY-SOL®** y sus componentes específicos son polímeros no iónicos y por ello están exentos de registro REACH bajo el Artículo 2(9). **Ivey International** está comprometido a garantizar que los usuarios finales obtengan el producto más efectivo y seguro para la remediación y reclamación ambiental. Estamos comprometidos a trabajar con todas las agencias regulatorias para garantizar el cumplimiento de los estándares actuales.

Einhaltung der REACH-Verordnung (Registration, Evaluation, Authorisation and Restriction of Chemicals) der EU

DEUTCH

Die **IVEY-SOL®**-Tensid-Rezeptur und deren spezifische Komponenten sind nichtionische Polymere und daher gemäß Artikel 2 Absatz 9 von der REACH-Registrierungspflicht ausgenommen. **Ivey International** möchte sicherstellen, dass Endnutzer die effektivsten und sichersten Produkte für Umweltsanierung und Rekultivierung zur Verfügung stehen. Wir arbeiten mit allen Regulierungsbehörden zusammen, um die Einhaltung aktueller Standards zu gewährleisten.

Ivey International Inc.
Unit 7, 19122-27 Ave, Surrey, BC, Canada, V3S 5T1
H.Q. Direct Phone: **+ 1 604 538-1168** / Fax: **+ 1 888 640 3622**
info@iveyinternational.com / www.iveyinternational.com

CLIENT TESTIMONIALS

"We completed an in-situ pilot-scale application of the Ivey-sol® surfactant technology at an industrial site with VC, DCE and TCE chlorinated contamination. We commenced site remediation with MPE with very good results, but eventually the rate of vapor, dissolved, and DNAPL phase mass recovery reduced over time. The introduction of Ivey-sol® significantly increased mass recovery of all phases, leading to our decision to go to full scale, pairing the MPE and Ivey-sol® technologies as an effective remediation strategy for the site"

DENNIS TU, *Executive Director Environment*

AECOM

"We increased the TPH Mass Recovery Rate by 10x, removed TPH-d from vadose zone and lowered groundwater concentrations. Regulatory Agency agreed to a risk based closure if contamination levels continue to decrease" [Site has since achieved regulatory closure]

GALEN KENOYER, *Senior Hydrogeologist*
CHRIS D'SA, *Senior Project Manager*

TRC Results you can rely on

"We accomplished more with $50,000 of Ivey-sol® than we did with the first $500,000 we spent on the site over the previous 4 years. Ivey-sol® Increased our average rate of contaminant recovery by >409%"

DANIEL SMITH, *Hydrogeologist*

HCR HANDEX CONSULTING & REMEDIATION, LLC

"At an EU military site the UTCHEM model was able to simulate the Pilot SEAR and that injected fluids were contained within the pilot application area. Further, the simulations estimated an approximate 1000 % increase in jet-fuel oil mass recovery with the application of the Ivey-sol® surfactant technology, compared to water injections without Ivey-sol®. The model also showed that the main process for mass removal during SEAR was production of a micro-emulsion."

SOREN RYGAARD LENSCHOW, *Project Manager*

NIRAS

"Given the complex nature of in-situ remediation projects, the most appropriate technologies need to be versatile and able to be adapted to various soil types and site-specific hydrogeological conditions. We have found the suite of Ivey-sol® surfactant products, and processes, to be very adaptable, affordable, and effective for the desorption and recovery of significant contaminant mass at our sites"

J. PETER MISENER, *Chairman*

GROUNDFORCE ENVIRONMENTAL INC Solutions for Earth

"We have been operating a dual-phase vacuum extraction (DPVE) system at an active grain elevator for approximately 9 years to address a groundwater source area consisting of carbon tetrachloride, carbon disulfide, and chloroform. In 2015, Burns & McDonnell conducted a pilotscale application of Ivey-sol® surfactant in an effort to enhance DPVE efficiency and recover the remaining source area contamination at the site. The pilot study indicated significant increases in contaminant mass removal. As a result, Burns & McDonnell conducted a full-scale surfactant application, consisting of up to 275 gallons of surfactant mixed to approximately 1 to 2 percent by volume, to the source area in late 2016. The introduction of the Ivey-sol surfactant significantly increased dissolved-phase mass removal and the effects of this increase on DPVE efficiency were observed up to 6 months after the application. During both the pilot and fullscale phases, existing DPVE infrastructure was utilized to complete the surfactant delivery and recovery, thus significantly reducing the cost of remediation. Burns & McDonnell was very pleased in the performance of the Ivey-sol® surfactant and continued support by Ivey-sol® staff"

ERIC DULLE, *PE, Project Manager*

BURNS McDONNELL

"Ivey-sol® has been proven highly effective at remediating both oil-based contamination and chlorinated solvents in a variety of different soil types, ranging from sands to clays. Given the current need for innovative and cost-effective cleanup technologies, usage of Ivey-sol® will significantly increase in the upcoming years"

BRUCE TUNNICLIFFE, *President*

VERTEX Environmental Inc.

"Ecologia applied the Ivey-sol 108 surfactant product using an in-situ multi-well sweep application to enhance the rate of LNPAL recovery at an active factory site. The Ivey-sol applications permitted a significant reduction in the LNAPL saturation, leading to a reduction in LNAPL mobility by approximately 3 orders of magnitude. We are, and have been, very pleased with the efficacy, ease of use and reliability of the Ivey-sol remediation technology at our project sites"

DAVID HOLMES *BSc (Hons), MSc, PhD, MCIWEM, C.WEM, CSci Technical Manager - Ecologia Environmental Solutions Limite*

Ecologia experts on the ground

"The in-situ application of the Ivey-sol® surfactant technology significantly increased the DNAPL and BTEX mass recovery from the impacted soil and groundwater on-site. We were very pleased by these results leading to our recommending a full scale site application as a rapid and cost effective method to achieve site clean-up"

MARTIN BEAUDOIN, *Project Engineer*

SANEXEN SERVICES ENVIRONNEMENTAUX INC.

"We used a combination of Ivey-sol® technology and soil excavation. It certainly saved us the headache of having to do more by way of foundation excavation. The result was the important thing. Ivey-sol® was a good add-on to the original excavation and we got the results we wanted"

MIKE ROY, *Senior Claims Adjuster*

Plant Hope ADJUSTERS LTD. EXPERTS EN SINISTRES

"In July 2019 we were faced with a 320,000 liter crude oil and produced water spill at a facility in northern Alberta. With our rapid spill response strategy, utilizing the innovative Ivey-sol® surfactant remediation technology, we achieved significant time, cost, and environmentally sustainable cleanup benefits, resolving more than 99% of the spill on the hillside. We and our client were very pleased with the outcome of this project"

EARTHMASTER ENVIRONMENTAL STRATEGIES INC

"After excavation and bio-piling of the soil, the surfactant enhanced bioremediation (SEB®) treatment was applied and the bio-pile was covered. Daily aeration was done during the treatment period. After only 12 weeks, samples were taken from the bio-pile showing that the remediation of the fuel-oil and PAH contamination was completed to the BC Environmental Standards and safe for reuse on-site"

TONY ROBSON, *Director Mining & Equipment*

QUINSAM COAL

Ivey-sol Surfactant Remediation Technology
Is Still Winning Innovation Awards, because
Ivey International realized…

…it was that simple.

Ivey International Inc. overcame the fundamental challenges to rapid cost effective site remediation of petroleum hydrocarbons, chlorinated solvents, and PFAS, by not only stepping out of the box, we redesigned it.

The dedicated support and the innovative minds of our employees, research partners and clients have allowed us to reach our corporate goal of being recognized as; 'Today's Environmental Solutions for a Better Tomorrow'.™

For more information about Ivey International's Innovative Remediation Technologies, visit www.ivey-sol.com, call **+1 604-538-1168**, or email us at info@iveyinternational.com

GOODSPEED
ENVIRONMENTAL SERVICES
info@goodspeedsa.co.za
www.goodspeedsa.co.za
+27 72 245 1395

IVEY-SOL®
Surfactant Technology
www.iveyinternational.com
info@iveyinternational.com
+1 604-538-1168