

60% SRS[®]-M Small or Large Droplet Emulsified Vegetable Oil (EVO) Substrate for the Treatment of Mixed Chlorinated Solvents and Metals like Chromium (Cr⁶⁺)

United States Patent# RE40,448

Oxidized metals like hexavalent chromium - Cr(VI), molybdenum- Mo(VI), selenium - Se(IV, VI), and uranium - U(VI) can be reduced to forms that are typically less mobile and toxic. Terra Systems SRS[®]-M is designed for the treatment of metals like hexavalent chromium and other oxidized metals like Mo(VI), Se(IV, VI), and U(VI) in a mixed chlorinated solvent plume. SRS[®]-M contains a proprietary food grade reductant compound plus the standard ingredients of our patented 60% SRS[®] Family of emulsified vegetable oil substrates. The proprietary reductant reacts directly with the oxidized metals to reduce them. SRS[®]-M provides a readily degradable carbon (lactate) to rapidly generate reducing conditions and a long-lasting carbon source (soybean oil) to maintain the reducing conditions.

Table I: SRS[®]-M Small or Large Droplet Emulsified Vegetable Oil Substrate Specifications

Ingredient	Percent	Description	Benefit
Food Grade U.S. Grown Soybean Oil	60%	Terra Systems operates its own state-of-the-art manufacturing facility.	Long lasting slow release source of carbon and hydrogen, consistent product quality, uniform droplet size, neutral pH, QA/QC lab on floor to check product before shipment.
Proprietary Food Grade Reductant	<4%	Reductant reacts directly with oxidized metals to reduce them.	Reduction of metals like Cr ⁶⁺ up to 95% faster than with carbon substrate alone
Food Grade Sodium or Potassium Lactate	4%	Rapidly biodegradable soluble substrate	Fast release source of carbon and hydrogen to rapidly generate anaerobic conditions
Proprietary Food Grade Nutrients	<1%	Proprietary organic and inorganic nutrients such as yeast extract, nitrogen and phosphorus.	Nutrients have been demonstrated to support the growth of the anaerobic microbial population.
Proprietary Food Grade Emulsifiers and Preservatives	7.5%	Proprietary nonionic emulsifier	Maximum radius of influence (nonionic emulsifier) or maximum retention the aquifer (anionic emulsifier)
Vitamin B ₁₂	<1%	At least 250 µg/L of Vitamin B ₁₂	He et al. 2007 demonstrated Vitamin B ₁₂ to be an important micronutrient to enhance dechlorination activity with 25 µg/L providing maximum stimulation
Median Oil Droplet Size (microns)	NA	0.6 µm for SRS [®] -SD or 5 µm for SRS [®] -FRL	Maximum radius of influence (0.6 µm droplet) or retention in the aquifer (5 µm droplet)
pH	6.5 - 7	6.5 - 7	Optimum microbial activity



How it Works: SRS[®]-M Emulsified Vegetable Oil (EVO) Substrate acts as a reductant when applied to oxidized metal contaminated aquifers. Using SRS[®]-M and its breakdown products, the microbial population removes the oxygen, nitrate, sulfate and other competing electron acceptors and depresses the redox potential where the conversion and precipitation of the hexavalent chromium or other metals can be achieved. The slow release characteristics of SRS[®]-M allow reducing conditions to be maintained for a long period of time (up to 36 months) with a single application. This makes SRS[®]-M a very cost effective aquifer treatment when compared to other remediation alternatives for mixed chlorinated solvent and metal plumes.

Application: Terra Systems **patented**, nutrient enriched, proven slow release SRS[®]-M emulsified vegetable oil substrate with a **proprietary food grade reductant** is ideal for sites with both chlorinated solvents (PCE, TCE) and Cr⁶⁺ or other metal contamination. The slow release characteristics of SRS[®]-M maintain reducing conditions for up to 36 months with a single application thus *“killing two birds with one product”*.

Customers: SRS[®]-M is used extensively by consultants working with current and former semiconductor plants and private firms and the Air Force, DOD, Navy, and EPA to cost effectively remediate mixed chlorinated solvent and metals sites. For example at a government naval base in Coronado, CA the site is contaminated with TCE at concentrations of >20 mg/L and >50 mg/L hexavalent chromium. Conventional EVO supported reduction of the hexavalent chromium over 80 days in a microcosm study, but not dechlorination of the TCE after 140 days. In combination with bioaugmentation and a new formulation of SRS[®] with a proprietary abiotic reductant, the hexavalent chromium was reduced within one day and complete biodegradation of the TCE occurred in 35 days. Field pilot and full scale injections showed that the combination of SRS[®]-M and bioaugmentation culture could reduce the hexavalent chromium completely and biodegrade the TCE to ethene.

Manufactured vs. Field Emulsion

In the early days of in-situ bioremediation when Terra Systems first patented the technology, it was common to bring the water, emulsifiers, oil, and other ingredients to the site and using trash or other pumps to mix the ingredients together to form an emulsion. It soon became apparent that poor emulsion consistency and a broad range of droplet sizes resulted in inadequate and uneven distribution when injected. This resulted in higher long-term costs due to higher reinjection frequency and higher substrate volumes to adequately make contact with the COC.

Don't be *“penny wise and pound foolish”*.

Consider:

- ✓ The labor and equipment time and cost of mixing in the field.
- ✓ The need to mix the nutrients and Vitamin B₁₂ longer to achieve consistency.
- ✓ The cost of inadequate distribution due to droplet size and emulsion inconsistency
- ✓ The inability to accurately determine if you have 100% emulsification.
- ✓ The lack of QA/QC in the field

- Terra Systems owns and operates a state of the art US based manufacturing plant with an in-house quality control laboratory for strict quality assurance of the emulsion, droplet size and pH.
- SRS[®]-M arrives at the site “*injection ready*” with all the ingredients – soy bean oil, proprietary reductant, Vitamin B₁₂, proprietary nutrients, sodium or potassium lactate and anionic emulsifier(s) already blended together.
- At the PM’s request, Terra Systems will blend 2-8 g/L of sodium bicarbonate into the SRS[®]-M during manufacturing to counter the acids produced during the fermentation process in the aquifer. This is especially beneficial for marginal pH aquifers of pH 5 – 6.

The product development cycle for SRS[®]-M took several years and included:

- ✓ Literature research
- ✓ Formulation design
- ✓ Laboratory testing of the formulations
- ✓ A treatability study using groundwater and saturated soil from the actual site.
- ✓ A pilot test



- SRS[®]-M optimizes the naturally occurring biodegradation system by supplying the rate limiting factor (in this case hydrogen) in the degradation of CVOC’s, certain pesticides/herbicides, perchlorate, and immobilization of certain metals (hexavalent chromium, molybdenum, selenium, and some radionuclides).
- SRS[®]-M can be manufactured in our plant with a **small droplet size of 0.6 μm** and a nonionic **emulsifier** for maximum radius of influence in the subsurface or with a large droplet size of **5 μm** and an **anionic emulsifier** for maximum retention in the subsurface.
- Terra Systems holds United States Patent #**RE40,448** for the use of emulsified vegetable oil for remediation of chlorinated solvents.
- The soy bean oil is grown in the United States and provides a **slow release** biodegradable carbon source, which promotes long-term biological activity.
- SRS[®]-M comes **standard** with **biostimulating vitamins** like Vitamin B₁₂, which He et al. 2007 demonstrated is an important micronutrient to enhance dechlorination activity.
- SRS[®]-M contains proprietary organic and inorganic nutrients such as yeast extract, nitrogen and phosphorus, which have been demonstrated to support the growth of the anaerobic microbial population.
- SRS[®]-M comes with **at least 4% sodium** or **potassium lactate** a quick release biodegradable substrate, which helps to “*jump start*” bacterial growth.
- SRS[®]-M emulsified vegetable oil substrate has been validated by the Florida DEP, California Water Board and others.
- SRS[®]-M contains only non-toxic food grade materials, which results in green, sustainable remediation.

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- Potassium Lactate can be substituted for Sodium Lactate if required in California or Florida.

Packaging: Terra Systems patented SRS[®]-M can be shipped in 5-gallon buckets, 55-gallon drums, 275-gallon IBC totes, 275-gallon cardboard totes or bulk tankers.



If the *Dehalococcoides* are not present or are in small numbers Terra Systems **TSIDC[®]** Bioaugmentation Culture can also be injected.

