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# OIL SLICK TREATMENT AND BIODEGRADATION PROCESS

## A. TOXICITY OF PETROLEUM OIL

OILS FROM DIFFERENT FIELDS CAN VARY WIDELY IN TOXICITY TO MARINE ORGANISMS, DEPENDING ON THEIR COMPOSITION. THE VOLATILE COMPONENTS ARE GENERALLY MORE TOXIC THAN THE HEAVIER FRACTIONS. THE RING STRUCTURE AROMATIC FRACTIONS ARE MORE TOXIC THAN THE ALIPHATIC OR PARAFFINIC COMPONENTS. THE LOWER MOLECULAR WEIGHT MORE VOLATILE AROMATIC FRACTIONS, SUCH AS BENZENE OR TOLUENE, ARE MORE TOXIC THAN THE CONDENSED RING STRUCTURES SUCH AS ANTHRACENE. THE INTERMEDIATE CHAIN LENGTH PARAFFINIC COMPONENTS ARE THE LEAST TOXIC.

THE MOST SERIOUS DAMAGE TO MARINE LIFE FROM PETROLEUM OIL OCCURS NEAR THE SURFACE, WHERE THE HIGH CONCENTRATION OF OIL DAMAGES PELAGIC FLOATING EGGS AND MARINE ORGANISMS, IN SHALLOW ESTUARYS OR MARSHES WHERE OIL CAN BE ADSORBED AT CONSIDERABLE CONCENTRATION IN THE MUD, OR ON THE SHORE LINE. IN EACH CASE THE HIGH CONCENTRATION OF OIL IS A MAJOR CAUSE OF ITS DAMAGE TO MARINE LIFE.

THE MORE TOXIC VOLATILE FRACTIONS ARE LARGELY LOST BY EVAPORATION FROM AN AGING OIL SPILL AT THE SURFACE IN A FEW DAYS. THE SAME VOLATILE FRACTION IS MORE SOLUBLE IN SEA WATER THAN THE HEAVIER FRACTIONS AND IS LARGELY REMOVED FROM DISPERSED OIL DROPLETS BY SOLUBILIZATION WITHIN A MATTER OF HOURS. IF THE DISPERSED OIL HAS BEEN RAPIDLY DILUTED WITH SEA WATER TO LOW CONCENTRATIONS, THIS SOLUBILIZED PORTION WILL CAUSE NO PROBLEM TO MARINE LIFE.

## B. RATIONAL FOR THE ARA CHEM SYSTEM OF DISPERSION

THE TOXICITY OF BOTH OIL AND DISPERSANTS TO MARINE ORGANISMS IS A FUNCTION OF BOTH CONCENTRATION AND TIME OF EXPOSURE. UNDER FIELD CONDITIONS OF DISPERSION, THE CONCENTRATION OF OIL AND DISPERSANT SHOULD BE DROPPING CONTINUOUSLY WITH TIME. THUS, THE POTENTIAL DAMAGE OF OIL AND DISPERSANT TO MARINE ORGANISMS HAS A VERY STRONG DEPENDENCE ON THE RATE OF DILUTION WITH SEA WATER OF BOTH THE OIL AND THE DISPERSANT. A DISPERSION METHOD WHICH RESULTS IN RETAINING A RELATIVELY CONCENTRATED OIL DISPERSION NEAR THE SURFACE FOR A CONSIDERABLE PERIOD OF TIME WOULD POSE A MUCH GREATER RISK OF DAMAGE TO MARINE LIFE NEAR THE SURFACE THAN A METHOD WHICH VERY RAPIDLY DILUTED THE DISPERSED OIL AND DISPERSANT TO VERY LOW CONCENTRATIONS.

UNFORTUNATELY, THE STANDARD TEST METHODS FOR TOXICITY OF OIL SEPARATELY, DISPERSANT SEPARATELY, AND BOTH TOGETHER DO NOT DUPLICATE FIELD CONDITIONS BY MEASURING TOXICITY UNDER CONDITIONS OF CONTINUOUS DILUTION. THUS, SUCH TESTS MAY PREDICT POORLY POSSIBLE DAMAGE TO MARINE ORGANISMS UNDER FIELD CONDITIONS OF DISPERSION, PARTICULARLY FROM THE TOXIC OIL. IN PARTICULAR, SLOW DILUTION OF THE DISPERSED SURFACE OIL AT THE HIGH OIL CONCENTRATIONS NEAR THE SURFACE MAY CAUSE DAMAGE TO SURFACE PELAGIC MARINE LIFE. ALSO, INCOMPLETE DISPERSION BY SLOW WAVE ACTION CAN RESULT IN RESIDUAL TAR BALLS, WHICH, IF DENSE, CAN SINK TO THE BOTTOM CAUSING BOTTOM DAMAGE.

## C. ORIGIN OF GOLD CREW

THE ORIGIN OF THE PREDECESSORS OF GOLD CREW GO BACK SOME 25 YEARS. AT THAT TIME THE PACIFIC FLEET OF THE U. S. NAVY, BERTHED IN SAN DIEGO BAY, HAD A SEVERE PUBLIC RELATIONS PROBLEM. THE AIRCRAFT CARRIERS, CRUISERS AND DESTROYERS SEVERAL TIMES A WEEK HAD LARGE ACCIDENTAL SPILLS

OF FUEL OIL INTO THE BAY. CONSIDERABLE DAMAGE HAD BEEN DONE TO SECTIONS OF THE SHALLOW BOTTOM OF THE BAY AND TO MARINE LIFE BY THEIR EFFORTS TO DISPERSE OR REMOVE THE OIL SPILLS. UNFORTUNATELY, THE SHALLOW, ALMOST LAND-LOCKED SAN DIEGO BAY WAS A NURSERY GROUND FOR FISH AND HAD BECOME A VERY IMPORTANT AQUATIC PLAYGROUND FOR TOURISTS. THE NAVY HAD A SEVERE PUBLIC RELATIONS PROBLEM FROM THEIR OIL SPILLS.

NAVY PERSONNEL RESPONSIBLE FOR HANDLING THE PROBLEM REQUESTED ARA CHEM, INC., TO TRY TO DEVELOP A WATER-BASED OIL SPILL DISPERSANT AND A METHOD OF APPLICATION THAT WOULD ELIMINATE THE DAMAGE TO MARINE LIFE THAT THEY WERE CAUSING IN THE BAY.

ANALYSIS OF THE SITUATION CONVINCED US THAT THE DAMAGE WAS CAUSED MORE BY THE DISPERSED OIL THAN IT WAS BY THE DISPERSANT. WE URGED THE NAVY REPRESENTATIVES TO DO EVERYTHING POSSIBLE TO LESSEN THE FREQUENCY OF OIL SPILLS. DUE TO THE NARROWNESS OF THE BAY AND THE FREQUENT CROSS WINDS BLOWING THE OIL ASHORE AND UNDER PIERS, PHYSICAL RECOVERY OF OIL WAS DIFFICULT. WE FELT THERE WAS ONLY ONE APPROACH THAT MIGHT BE SUCCESSFUL. THE OIL WOULD HAVE TO BE DISPERSED RAPIDLY AND FAIRLY COMPLETELY AND ALMOST IMMEDIATELY DILUTED WITH AS LARGE A VOLUME OF SEA WATER AS POSSIBLE. THIS WOULD GIVE A VERY SHORT EXPOSURE OF MARINE LIFE TO THE INITIAL HIGH CONCENTRATION OF DISPERSED OIL AND QUICKLY DILUTE BOTH OIL AND DISPERSANT TO HARMLESS LOW LEVELS.

WE WORKED IN COLLABORATION WITH THE U. S. NAVY FOR THE NEXT SEVERAL YEARS AND HAD LOTS OF OIL SPILLS ON WHICH TO TRY OUT VARIOUS METHODS AND HUNDREDS OF FORMULATIONS. OF COURSE, IT IS NO LONGER POSSIBLE TO DEVELOP A DISPERSANT SYSTEM BY THE FIELD METHOD SINCE THE HIGH FREQUENCY OF SPILLS NO LONGER EXISTS. EVENTUALLY, WE WERE SUCCESSFUL AND DEVELOPED THE PREDECESSORS OF GOLD CREW AND OUR PATENTED SYSTEM OF APPLICATION. THE WATER-BASED CONCENTRATE OF GOLD CREW IS INJECTED INTO A FIRE HOSE AT A HIGH INITIAL DILUTION WITH SEA WATER AND APPLIED AS A HARD, COARSE

SPRAY TO THE SURFACE OF THE SPILL. THIS LITERALLY TEARS UP THE SURFACE, EMULSIFIES OR DISPERSES THE OIL ON CONTACT, AND, WITHIN A FEW SECONDS DILUTES THE EMULSIFIED OIL AND DISPERSANT TO NON-TOXIC LEVELS THROUGHOUT THE TOP SEVERAL FEET OF SEA WATER. WAVE ACTION AND BROWNIAN MOVEMENT THEN CONTINUE TO DISPERSE AND FURTHER DILUTE THIS OIL IN THE WATER COLUMN.

THE MOST DIFFICULT PROBLEM DURING THESE YEARS WAS TO FIND INGREDIENTS THAT WOULD QUICKLY MIGRATE TO AND FORM A PROTECTIVE COATING ON THE OIL DROPLETS WITHIN THE FEW SECONDS AVAILABLE. THIS WAS NECESSARY TO PREVENT THE DISPERSED DROPLETS FROM AGGLOMERATING AND THEN REFORMING THE OIL LAYER AT THE SURFACE.

DURING THE YEARS WE OPERATED IN SAN DIEGO BAY, WE DISPERSED AN AVERAGE OF 50 LARGE OIL SPILLS A YEAR IN THIS NARROW, LONG, SHALLOW, ALMOST LAND-LOCKED BAY. SEVERAL OF THESE SPILLS WERE APPROXIMATELY 50,000 GALLONS EACH AND ONE WAS 80,000 GALLONS. WE DISPERSED THE 80,000 GALLONS OF FUEL OIL AMONG MANY SCHOOLS OF SMALL NURSERY FISH NEAR THE SURFACE. OUR OPERATIONS WERE CLOSELY MONITORED BY MARINE BIOLOGISTS. THESE BIOLOGISTS CHECKED FOR AND NEVER FOUND ANY OIL IN THE BOTTOM MUDS FROM OUR OPERATIONS AND THEY CHECKED MANY TIMES AND NEVER FOUND ANY DAMAGE TO MARINE LIFE OF ANY KIND. THUS, UNDER THESE EXCEPTIONALLY ADVERSE CONDITIONS, USING OUR GOLD CREW AND OUR APPLICATION SYSTEM, WE DISPERSED LARGE QUANTITIES OF TOXIC OIL WITHOUT ANY DAMAGE TO THE ENVIRONMENT.

## D. BIODEGRADABILITY OF GOLD CREW

THE RIVER DIE-AWAY TEST[1] WAS RUN ON GOLD CREW IN SAN FRANCISCO BAY WATER. THE GOLD CREW WAS 97% BIODEGRADED IN 20 DAYS AND HAD A HALF LIFE OF 3 1/2 DAYS IN SEA WATER.

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[1] *C. Hammerton, J. Appl. Chem., 1955, pp. 5 and 517*

## E. BIODEGRADATION OF OIL IN SEA WATER

A GREAT DEAL OF RESEARCH WORK HAS BEEN PUBLISHED ON THE MICROBIAL DEGRADATION AND UTILIZATION OF HYDROCARBONS AND CRUDE OIL IN THE SEA. ONE OF THE MOST PROLIFIC RESEARCHERS IN THIS AREA HAS BEEN PROFESSOR CLAUDE ZO BELL, PROFESSOR OF MICROBIOLOGY, AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY AT SAN DIEGO, CALIFORNIA.[2]

BY FAR THE MOST IMPORTANT PROCESS IN REMOVING DISPERSED OIL FROM THE SEA IS BIODEGRADATION BY MICROORGANISMS, PARTICULARLY BY BACTERIA. THIS IS PRIMARILY AN OXIDATION PROCESS USING DISSOLVED OXYGEN IN SEA WATER. THE UTILIZATION OF HYDROCARBONS BY ANEROBIC SULFATE-REDUCING BACTERIA HAS BEEN REPORTED. BUT THIS PROCESS WOULD ONLY BE IMPORTANT IN BOTTOM MUDS WHICH HAVE BECOME CONTAMINATED WITH OIL AND WHERE THE OXYGEN HAS BEEN DEPLETED. SOME OIL APPEARS TO BE REMOVED FROM THE SEA BY INGESTION BY THE NUMEROUS SPECIES OF PROTOZOANS AND OTHER MUD EATERS OR FILTER FEEDERS ON THE OCEAN FLOOR. PROBABLY THE INTESTINAL BACTERIA OF SOME OF THESE ANIMALS OXIDIZE THE INGESTED OIL, CONTRIBUTING TO THE NUTRITION OF SOME SPECIES.

NEARLY ALL KINDS OF HYDROCARBONS FROM PETROLEUM OIL IN THE PARAFFINIC, OLEOFINIC AND NAPHTHENIC SERIES CAN BE DEGRADED BY MANY SPECIES OF BACTERIA, PARTICULARLY IN MIXED CULTURE. FEWER BACTERIAL SPECIES CAN ATTACK THE MORE TOXIC AROMATIC HYDROCARBONS, PARTICULARLY THE MORE TOXIC LOWER MOLECULAR WEIGHT MEMEBERS OF THIS SERIES, SUCH AS BENZENE AND TOLUENE. HOWEVER, MIXED CULTURES OF BACTERIA WHICH CAN DEGRADE EVEN THESE HIGHLY TOXIC COMPOUNDS HAVE BEEN REPORTED.

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[2] C. E. Zo Bell, "Microbiol Modification of Crude Oil in the Sea", *Proc. Conf. on Prevention and Control of Oil Spills*, Sponsored by Amer. Pet Inst. and Fed. Water Pollution Control Admin., New York, N.Y. Dec. 15, 1969.

THE MICROBIOL OXIDATION OF HYDROCARBONS NEARLY ALWAYS PROCEEDS THROUGH THE USUAL METABOLIC PATHWAYS TO WATER, CARBON DIOXIDE, BIOMASS (MICROBIOL CELL MATERIAL), AND A LARGE NUMBER OF OTHER END PRODUCTS. THESE OTHER PRODUCTS INCLUDE AN EXPANSIVE ARRAY OF ORGANIC ACIDS, LIPIDS, ESTERS, COMPLEX ALCOHOLS, KETONES, ALDEHYDES AND POLYSACCHARIDES.

IN FACT, WHEN PETROLEUM OIL WAS LOW PRICED, SOME FIFTEEN OR TWENTY YEARS AGO, FERMENTATION PROCESSES WERE DEVELOPED FOR THE COMMERCIAL PRODUCTION OF MICROBIOL BIOMASS FROM PETROLEUM OIL HIGH IN PARAFFINICS FOR ANIMAL AND HUMAN FOOD. THE POSSIBILITY OF PRODUCING SUBSTANTIAL QUANTITIES OF LOW COST FOOD FOR FOOD DEFICIENT AREAS, SUCH AS AFRICA, WAS HIGHLY PUBLICIZED FOR SOME TIME. SEVERAL SMALL-SCALE DEMONSTRATION FERMENTATION PLANTS WERE CONSTRUCTED. UNFORTUNATELY, RISING COSTS OF OIL ELIMINATED THE POSSIBILITY OF LOW COST FOOD FROM THESE PROCESSES.

HUNDREDS OF SPECIES OF BACTERIA, YEASTS, AND FUNGI HAVE BEEN FOUND THAT CAN OXIDIZE AND UTILIZE ONE OR MORE KINDS OF OIL COMPONENTS. THESE HYDROCARBON OXIDIZERS ARE WIDELY DISTRIBUTED IN SOILS IN OIL FIELDS, SUMP WATERS, AND COASTAL AREAS THAT HAVE BEEN SUBJECTED TO POLLUTION BY PETROLEUM. THE PRESENCE OF THESE MICROORGANISMS HAS BEEN DEMONSTRATED IN SEA WATER SAMPLES COLLECTED FROM HARBORS, BAYS AND ESTUARIES IN MANY PARTS OF THE WORLD.

MICROORGANISMS THAT CAN BIODEGRADE OIL ARE COMMON IN SEA WATER ALONG THE CONTINENTAL SHELVES. THEY RANGE IN CONCENTRATIONS (IN 10 ML. SAMPLES) FROM ZERO TO MORE THAN 10,000 MPN (MOST PROBABLE NUMBER) OF OIL-OXIDIZING BACTERIA PER ML. (MILLILITER). MOST OF THE 10 ML. SAMPLES COLLECTED IN THIS AREA WILL CONTAIN OIL-OXIDIZING BACTERIA. IN THE OPEN SEA BEYOND THE CONTINENTAL SHELVES, OIL-OXIDIZING BACTERIA ARE LESS COMMON, AND USUALLY ARE FOUND IN LESS THAN FIVE PERCENT OF THE 10 ML. SAMPLES TESTED.

YEASTS AND MOLD FUNGI ARE MUCH LESS COMMON IN THE SEA THAN BACTERIA. IF FOUND, THEY NORMALLY WOULD BE IN INSHORE WATERS.

MUD SAMPLES IN ESTUARIES AND ALONG COASTAL AREAS SUBJECT TO OIL POLLUTION FREQUENTLY WILL CONTAIN VERY HIGH LEVELS OF OIL OXIDIZING MICROORGANISMS. THESE MUDS MAY RANGE UP TO OXIDIZING MPN MICROORGANISM COUNTS OF 100 MILLION TO ONE BILLION PER ML. THIS DEMONSTRATES THAT WHEN THE PETROLEUM OIL FOOD IS AVAILABLE FOR OIL-OXIDIZING BACTERIA, THE BACTERIAL CONCENTRATIONS CAN BUILD UP TO VERY HIGH LEVELS.

CRUDE OIL FROM DIFFERENT FIELDS SHOW LARGE DIFFERENCES IN COMPOSITION AND PHYSICAL PROPERTIES. MOST CRUDE OILS IN ADDITION TO CONTAINING MANY DIFFERENT TYPES OF HYDROCARBONS DIFFERING IN TOXICITY AND BIODEGRADABILITY ALSO CONTAIN SMALL QUANTITIES OF OXYGENATED, NITROGENOUS, AND FREQUENTLY, SULFUR COMPOUNDS. THESE LARGE DIFFERENCES IN COMPOSITION ACCOUNT FOR MUCH OF THE CONSIDERABLE DIFFERENCES IN THE RATE OF BIODEGRADATION OF THE VARIOUS CRUDE OILS. DIFFERENCES IN BIODEGRADATION RATES ALSO ARE DUE TO DIFFERENCES IN SPECIES OF OIL-OXIDIZING BACTERIA PRESENT.

SINGLE PURE STRAINS OF MICROORGANISMS ARE RARELY ABLE TO BIODEGRADE CRUDE OIL. INSTEAD, BIODEGRADATION IS THE RESULT OF COOPERATION BETWEEN MANY STRAINS OF BACTERIA PRESENT IN MIXED CULTURES. THIS IS BECAUSE MOST MICROBIOL SPECIES ARE HIGHLY SPECIFIC IN THE PARTICULAR CONSTITUENTS OF PETROLEUM OIL THAT THEY CAN ATTACK. THE PRODUCTS OF ONE SPECIES THEN BECOMES THE SUBSTRATE FOR A SECOND SPECIES TO UTILIZE. THIS MAY CONTINUE UNTIL THE OIL IS LARGELY SOLUBILIZED, OR PRODUCES PART OF THE BIOMASS IN THE MICROORGANISMS. THE MICROORGANISM SPECIES THAT ATTACKS EACH OF THE VARIOUS BIODEGRADATION PRODUCTS IS JUST AS IMPORTANT TO THE DEGRADATION AS THE SPECIES THAT CAUSES THE INITIAL BREACH IN THE PETROLEUM CONSTITUENT MOLECULE. AS A RESULT OF THIS COOPERATIVE BIODEGRADATION EFFORT, USUALLY 20 TO 30 SPECIES OR VARIENTS OF MICROORGANISMS CAN BE DETECTED

IN EACH EXPERIMENT INVOLVING BIODEGRADATION OF OIL IN SEA WATER.

THE RATE OF BIODEGRADATION OF OIL IS SUBJECT TO MANY VARIABLES. BUT EVEN UNDER THE ADVERSE CONDITIONS OF AN EXPERIMENT IN WHICH 100 ML. PORTIONS OF CRUDE OIL WERE STORED ON TOP OF SEA WATER IN CYLINDERS, NEARLY ALL OF THE OIL WAS UTILIZED IN NINE WEEKS AT AMBIENT TEMPERATURES. OF COURSE, IF THE OIL HAD BEEN DISPERSED TO GIVE A MUCH GREATER SURFACE AREA, IT WOULD HAVE BIODEGRADED FASTER. THIS UTILIZATION WAS SHOWN TO BE DUE TO MICROORGANISMS BY ADDING A LETHAL CONCENTRATION OF TRICRESOL PRESERVATIVE WHICH PREVENTED THE DISAPPEARANCE OF THE OIL.

HIGH CONCENTRATIONS OF SOME COMPONENTS OF PETROLEUM OIL MAY BE BACTERICIDAL. IN AQUEOUS MEDIA AS LITTLE AS 0.01 PERCENT OF TOLUENE, PHENOL, OR CRESOL MAY INHIBIT THE GROWTH OF SENSITIVE MICROORGANISMS. HOWEVER, THERE ARE ALWAYS SPECIES OF MICROORGANISMS WHICH CAN GROW IN THE PRESENCE OF MUCH HIGHER CONCENTRATION OF THESE TOXIC INGREDIENTS. SOME OF THESE MICROORGANISMS WILL EVEN UTILIZE UP TO 0.1 PERCENT OR MORE OF THESE TOXIC MATERIALS AS A SOURCE OF ENERGY FOR GROWTH. FOR EXAMPLE, SEVERAL STRAINS OF PSEUDOMONAS AND ACHROMOBACTER HAVE BEEN SHOWN TO UTILIZE BENZENE, TOLUENE, OR CRESOL AS A SOLE SOURCE OF ENERGY FOR GROWTH. BIODEGRADATION PRODUCTS INCLUDED ACETIC ACID AND PYRUVIC ACID.

THE RAPID DISPERSION OF OIL TO HIGH DILUTIONS BY GOLD CREW IN A MINUTE OR LESS WOULD DILUTE THESE TOXIC COMPONENTS OF CRUDE OIL WITH SEA WATER TO HARMLESS CONCENTRATIONS.

MOLECULAR CONFIGURATION IS THE MOST IMPORTANT FACTOR DETERMINING THE RATE OF BIODEGRADATION OF OIL COMPONENTS. PARAFFINS OR ALKANES ARE ATTACKED BY A GREATER VARIETY OF MICROBIOL SPECIES AND MORE RAPIDLY THAN EITHER NAPHTHENIC OR AROMATIC FRACTIONS. NORMAL PARAFFINS ARE DEGRADED MORE RAPIDLY THAN BRANCHED CHAINS. NORMAL PARAFFINS WITH 10 TO 18

CARBON ATOMS WOULD BE BIODEGRADED THE MOST RAPIDLY OF ANY COMPONENT. THE LONGER CHAIN PARAFFINS ARE MORE SLOWLY BIODEGRADED PROBABLY BECAUSE OF THEIR LOWER SOLUBILITY IN WATER. WHEN DISPERSED AS AN EMULSION, WAXES ARE QUITE RAPIDLY SOLUBILIZED BY SOME MICROORGANISMS.

WHILE UNSATURATED COMPOUNDS ARE DEGRADED MORE SLOWLY THAN SATURATED, SOME MICROORGANISMS PREFERENTIALLY ATTACK UNSATURATED COMPOUNDS. AMONG AROMATIC RING COMPOUNDS INTRODUCING ALKYL OR PARRAFFINIC SIDE CHAINS SPEEDS UP DEGRADATION. THUS, TOLUENE IS MORE EASILY BIODEGRADED THAN BENEZENE. THE SATURATED NAPHTHENIC RING COMPOUNDS ARE MORE RAPIDLY BIODEGRADED THAN THE UNSATURATED AROMATIC RING GROUPS.

THE COMPLETE BIOOXYDATION OF 1 MG. OF HYDROCARBON TO $CO_2$ AND $H_2O$ REQUIRE A BOD, OR BIOLOGICAL OXYGEN DEMAND, OF THREE TO FOUR MG. OF OXYGEN PER MG. OF HYDROCARBON. HYDROCARBON-OXIDIZING MICROORGANISMS IN MOST CASES REQUIRE DISSOLVED OR FREE OXYGEN. IN CONTAMINATED BOTTOM MUDS WITH INTENSE MICROBIOL ACTIVITY, OXYGEN MAY BE A LIMITING FACTOR. THEN THE RATE OF BIODEGRADATION DEPENDS ON THE RATE OF OXYGEN REPLENISHMENT FROM THE SURFACE OR RELEASE OF OXYGEN BY PHOTOSYNTHETIC ACTIVITY OF PLANTS AND ALGAE.

OCEAN WATER DISSOLVED OXYGEN CONCENTRATION AT SATURATION RANGE FROM SIX TO 11 MG. PER LITER. THIS MUCH OXYGEN IS ADEQUATE FOR THE COMPLETE OXIDATION TO CARBON DIOXIDE AND WATER OF TWO TO FOUR MG OF CRUDE OIL.

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