
Oil Beneath the Water Surface and Review of Currently Available Literature on Group V Oils: An Annotated Bibliography

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Oil Spill Hot Topics Bibliography #1



Introduction

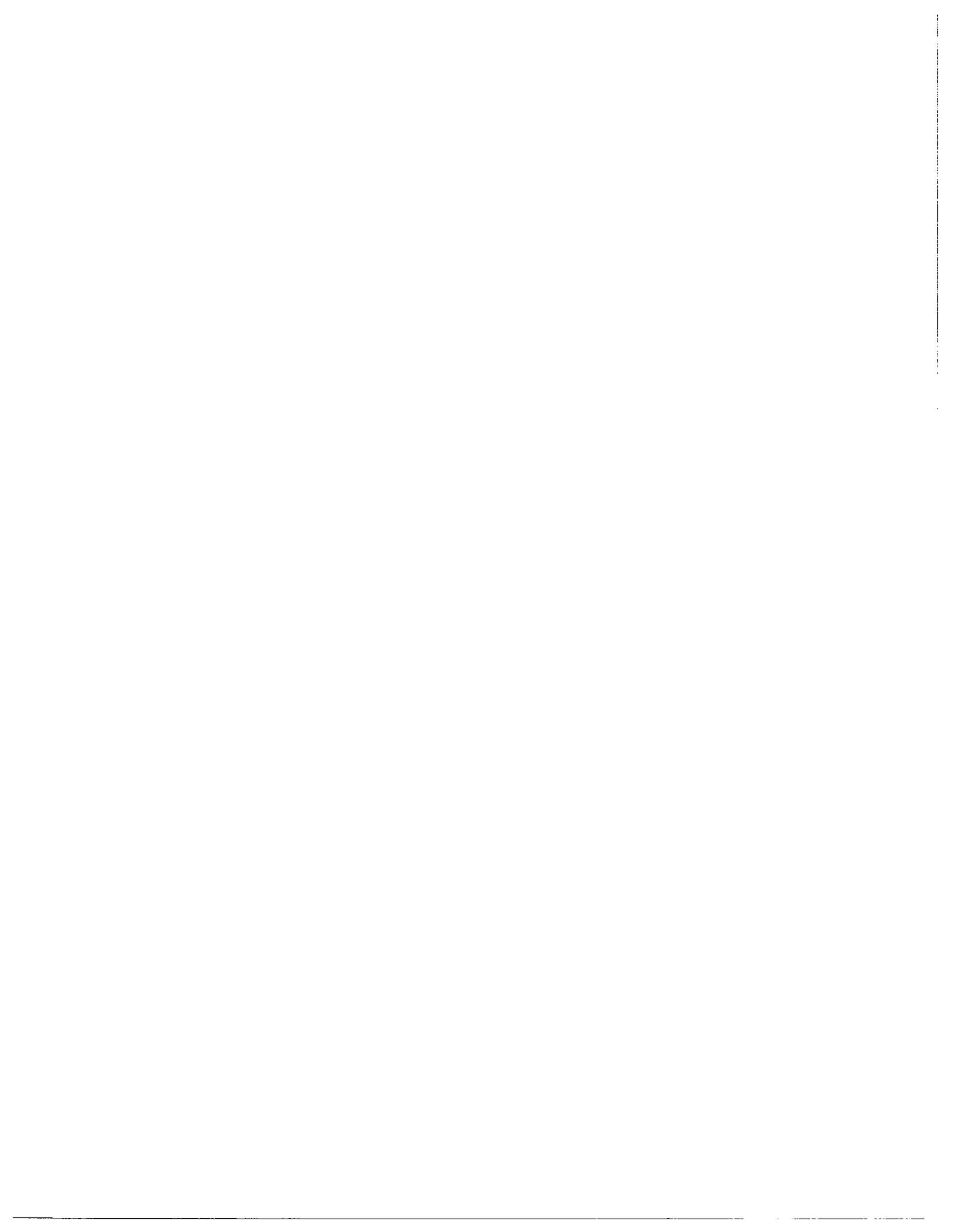
NOAA conducted this literature review in an effort to better understand the new generation of oil products called Group V oils or low-American Petroleum Institute (API) gravity oils (LAPIO). We found many instances where oil slicks had sunk, submerged temporarily, or been overwashed by the water surface they were floating on. We also found many cases where oil mixed with suspended or wind-blown sediments. Also, several cases are included where an explosion or fire produced a heavier-than-water residue that sank. Thus, the original scope of this report was expanded to include all the reported cases of these phenomena, regardless of the reported cause.

Group V, or LAPIO, oils are those oils with a specific gravity of 1.00 or greater, which corresponds to an API gravity of 10 or less. Of the case studies found here 32 percent are confirmed as having product involved with an API gravity of 10 or less. Another 19 percent are very close to being Group V oils in their fresh state, although they soon weather and change properties after being spilled. Another 23 percent have no information regarding the gravity of the oil involved, and 26 percent are definitely not Group V products.

The major factors affecting the sinking or apparent sinking of oil are turbulence and buoyancy. If oil is heavier than water, it will not float. Similarly, if something happens to the oil to make it heavier (extreme heating, sedimentation, etc.) it will sink. Under turbulent conditions oil can get mixed down into the water, resurfacing under calmer conditions, or agglomerating to sediments and eventually sinking. No assumptions are made here, merely statements of the facts or suppositions as they were presented in the literature.

This report is meant to be an aid to organizations involved in heavy oil spill contingency planning, regulation development, and emergency response. The goal is to provide much more useful information than can be gleaned from any single reference list. Notes describe each reference to help readers determine the usefulness of the reference for their current needs.

The following table lists oil spills where oil was reported to occur below the water surface with the reason for the occurrence and any countermeasures used to mitigate it. Many informative papers and reports discuss the various phenomena that lead to oil sinking below the water surface. Most of the papers and reports found here are easily obtainable and are of some value in studying these areas of oil spill response.



Oil-spill incidents with oil reported below the water surface.

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<p><i>Alvenus</i> (tanker)</p> <p>Alejandro & Buri (1987) Curl et al. (1992) Michel & Galt (1995) Pavia et al. (1984)</p>	grounding	7/30/84	Merey crude Pilon crude API 13.8 & 17.3	oil mixed with sand after stranding onshore	vacuum truck, cement pump, heavy machinery, screens (unsuccessful)
<p><i>AMOCO Cadiz</i> (tanker)</p> <p>Castle et al. (1995) Curl et al. (1992) D'Ozouville et al. (1979) Gundlach et al. (1978)</p>	grounding	3/16/78	Arabian light Iranian light Bunker C API unknown	oil dispersed by strong winds; contaminated sediments deposited on seafloor	none mentioned
<p><i>Apex 3512</i> (barge)</p> <p>Byron (1995) Cutter (1995)</p>	collision	10/11/95	Slurry oil API -5	oil heavier than receiving water (fresh-water river)	sonar (unsuccessful) diaper drop (successful) ponars (successful) submersible pumps & divers (successful)
<p><i>Arrow</i> (tanker)</p> <p>Buckley et al. (1974) Buist & Potter (1987) Curl et al. (1992) Farmer & Li (1994) Forrester (1971) Gundlach et al. (1978) Owens & Rashid (1976) Scarratt & Zitko (1972)</p>	grounding	2/4/70	Bunker C API 15.4	oil mixed with suspended sediments without stranding first	no action taken

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<p><i>Morris J. Berman</i> (barge)</p> <p>Benggio (1995) Burns et al. (1995) Cutter (1994a) Cutter (1994b) Cutter (1994c) Cutter (1994d) Etkin (1995) Michel et al. (1995) Petrae (1996) Ploen (1995) Ross (1994) Ross (1995a) Ross (1995b) Scholz et al. (1994a) Scholz et al. (1994b) Stanton (1995)</p>	grounding	1/7/94	#6 fuel oil API 9.5	oil mixed with suspended sediments without first stranding onshore	divers with snares, bags, and pumps (effective) dredging (effective) vacuum trucks (ineffective)
<p><i>Betelgeuse</i> (tanker)</p> <p>Curl et al. (1992) Grainger et al. (1984)</p>	explosion	1/8/79	Arabian light API 36.5	burn residue sank	dredging (limited to areas where dredging would not cause damage)
<p><i>Bouchard B155</i> (barge)</p> <p>Benggio (1994b) Castle et al. (1995) Cutter (1993) Cutter (1994c) Levings & Garrity (1995) Michel & Benggio (1994) Michel & Galt (1995) Michel et al. (1995) Ocean Systems International (1994) Scholz et al. (1994a) Scholz et al. (1994b)</p>	collision	8/10/93	#6 fuel oil API 10.5	oil mixed with suspended sediments both with and without stranding first	VTUs (successful near mangrove areas and catchment areas but not offshore) ROXANN (promising, but results not confirmed due to weather) divers (successful) diaper drop (not successful) aerial surveillance (successful)

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<i>Braer</i> (tanker) Farmer & Li (1994) Pearce (1993)	grounding	1/4/93	Gulfaks crude API 29.3	oil dispersed by hurricane-force winds; contaminated sediments deposited on seafloor	no action taken
<i>Eleni V</i> (tanker) Blackman & Law (1980) Curl et al. (1992)	collision	5/6/78	heavy fuel oil API 14.4-19	oil mixed with suspended sediments without stranding first	no action taken
<i>Florida</i> (barge) Blumer et al. (1970) Blumer et al. (1971) Blumer & Sass (1972) Castle et al. (1995) Gundlach et al. (1978) Hampson & Sanders (1970) Michael et al. (1975) Teal et al. (1992)	grounding	9/16/69	#2 fuel oil API unknown	oil dispersed by gale force winds; contaminated sediments deposited on seafloor	no action taken
Hasbah 6 (well) Curl et al. (1992) Ryan (1983) van Oudenhoven (1983)	blowout	10/2/80	heavy crude oil API 18-19	oil mixed with sand deliberately applied in response	sand application (ineffective)
<i>Haven</i> (tanker) Castle et al. (1995) Curl et al. (1992) Cutter (1991) Martinelli et al. (1995) Michel & Galt (1995) Moller (1992) Ocean Systems International (1994) Tripaldi (1993) Tripaldi et al. (1993) Turbini et al. (1993)	explosion	4/11/91	Iranian heavy API 31	burn residue and oil fractionated by extreme heating sank	divers-manual removal vacuum pumps (effective)

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<i>Honam Jade</i> (tanker) Michel & Galt (1995) Moller (1992) Purnell (1995)	grounding	2/28/83	Arabian heavy API unknown	burn residue sank	trawls (ineffective)
Ixtoc I (well) Buist & Potter (1987) Curl et al. (1992) Farmer & Li (1994) Gundlach et al. (1981) Michel & Galt (1995) Payne & Phillips (1985)	blowout	6/3/79	Ixtoc crude API unknown	formed tarmats at toe of beach after mixing with beach sediments	no action taken
<i>Katina</i> (tanker) Buist & Potter (1987) Farmer & Li (1994) Koops (1985)	collision	6/7/82	heavy fuel oil API 10.7	oil weathered then sank with sediment involvement	no action taken
<i>Kurdistan</i> (tanker) Buist & Potter (1987) Curl et al. (1992) Dawe et al. (1981) Duerden & Swiss (1981) Farmer & Li (1994) Vandermeulen & Buckley (1985)	hull failure and ice	3/15/79	Bunker C API unknown	no explanation given	no action taken
Lake Winona (facility) Fremling (1981)	equipment failure	4/15/79	#6 fuel oil API 12 (mix)	oil heavier than receiving water (fresh-water lake)	pumping vacuum trucks (effective)
<i>MCN-5</i> (barge) Curl et al. (1992) Cutter (1988) Kennedy (1988) Michel et al. (1995) Scholz et al. (1994b) Yaroch & Reiter (1989)	capsized and sank	1/31/88	HCGO API -1.2 IFO and Marine Diesel (API 31)	oil heavier than receiving water (salt water)	dispersed by strong bottom currents diaper drop technique (effective)

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
Mizushima (facility) Nicol (1976)	tank rupture	12/18/74	Bunker C API unknown	oil mixed with sediments prior to entry into water	no action taken
<i>Mobiloil</i> (tanker) Curl et al. (1992) Kennedy & Baca (1984) Michel et al. (1995) Park (1985) Pavia (1984) Scholz (1994b)	grounding	3/19/84	#6 fuel oil API 12.6 heavy residual API 11.3 industrial fuel oil API 5.5	oil heavier than receiving water (fresh-water river)	dispersed by strong currents diaper drop technique (effective)
Nowruz (well) Curl et al. (1992) Galt et al. (1983) Michel & Galt (1995)	collision and war	2/10/83	crude oil API 22	oil mixed with wind-blown sediment	no action taken
<i>Oregon Standard/ Arizona Standard</i> (tankers) Castle et al. (1995) Chan (1973) Conomos (1975) Curl et al. (1992) Payne & Phillips (1985) Smithsonian (1972)	collision	1/18/71	Bunker C API 9.6	oil weathered then sank with sediment involvement	no action taken
<i>Peck Slip</i> (barge) Curl et al. (1992) Gundlach et al. (1979) Michel & Galt (1995) Robinson (1979)	grounding	12/19/78	Bunker C API 18.5	oil mixed with suspended sediments without stranding first	no action taken

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<i>Potomac</i> (tanker) Buist & Potter (1987) Farmer & Li (1994) Grose et al. (1979) Michel & Galt (1995) Petersen (1978)	collision and ice	8/5/77	Bunker C API 13.5 (mix)	light fraction evaporated then particles flaked off and sank	no action taken
<i>Presidente Rivera</i> (tanker) Curl et al. (1992) Levine (1990) Wiltshire & Corcoran (1991)	grounding	6/24/89	#6 fuel oil API 17.4 high pour point	oil picked up sand after stranding and then sank	booms (limited) vacuum trucks (ineffective) supersucker trucks (ineffective) clamshell bucket dredges and hopper barge (effective) suction and/or weir skimmers (ineffective) belted incline plane skimmer (ineffective) stern trawl net (effective)
<i>Sansinena</i> (tanker) Castle et al. (1995) Curl et al. (1992) Hutchison & Simonsen (1979) Kolpack et al. (1978) Michel et al. (1995) Scholz (1994a) Scholz (1994b) Soule & Oguri (1978) Soule et al. (1978) White & Kopeck (1979)	explosion	12/17/76	Bunker C API 8.46 - 8.80	oil heavier than receiving water (salt water)	suction pumping system (effective)
Santa Barbara Channel (well) Curl et al. (1992) Gundlach et al. (1978)	blowout	1/28/69	California crude API 10.3 - 13.2	oil mixed with suspended sediment in river runoff plume	no action taken

Oil-spill incidents with oil reported below the water surface (continued).

Spill Name, Source, and Citations	Reported Cause of Incident	Date of Spill	Product(s) Involved	Mechanism of Oil Below the Water Surface	Response Method(s) Used and (Success?)
<i>SFI 33</i> (barge) Anonymous (1990) Nelson (1991)	hull buckled	8/12/90	#6 fuel oil API 6.5	oil heavier than receiving water (salt water)	divers (ineffective)
<i>Thuntank 5</i> (tanker) Buist & Potter (1987) Farmer & Li (1994) Purnell (1995)	grounding	12/21/86	heavy fuel oil pour point 12° C API unknown	oil weathered then sank with sediment involvement	bailers (ineffective) pumps (ineffective) divers (somewhat) suction nozzle w/steam jets (effective)
<i>Urquiola</i> (tanker) Curl et al. (1992)	collision and fire	5/12/76	Arabian light API 33.4 Bunker API unknown	fractionation by extreme heating	no action taken
<i>Vesta Bella</i> (barge) Curl et al. (1992) Genwest Systems (1991) Henry (1991) Levine et al. (1991) Michel & Galt (1995) Van Den Berg (1992)	sinking (cause unknown)	3/6/91	#6 fuel oil API 4.6-10 (estimated)	oil picked up sand after stranding and sank just offshore of beaches	no action taken

Alejandro, A.C. and J.L. Buri. 1987. M/V *Alvenus*: Anatomy of a major oil spill. *Proceedings of the 1987 Oil Spill Conference, April 6-9, 1987, Baltimore, MD, Washington D.C.*: API. pp 27-32.

Paper summarizing the response to the *Alvenus* grounding and oil spill in the Calcasieu River Bar Channel, Louisiana on July 30, 1984. Sunken oil patches were encountered in the nearshore surf zone caused by the absorption of suspended sediments. A high-capacity vacuum truck, cement pump, heavy machinery, and manual recovery using a screen were used to recover the submerged oil, which reiled the beaches daily. All these methods proved ineffective.

Anonymous. 1990. Offshore Texas has third oil spill of summer (1990). *Oil & Gas Journal* 88(34): 38

Article summarizes spill activity in the offshore Texas area, including a barge SFI-33 that spilled 500 barrels of #6 fuel oil into the Houston Ship Channel on August 12, 1990. The barge buckled and the spilled oil sank to the bottom. Divers with submersible pumps and suction leads were used to clean up the submerged oil reported to be two feet thick in some areas.

Anonymous. 1994. Solidifying oil could stem tanker spills. *Motor Ship* 75(889): 48

Information on an oil solidifying process for potential use in spill situations. The solidifying agent could be used in the leaking hold of the ship, on the slick, on the shoreline, or on small patches of nearshore oil. The cost would be about \$2.50 per liter for the application, which would solidify about one gallon of oil. The solidified mass is then supposed to be able to be separated back into its original components.

Ault, J.S., M.A. Harwell, and V. Meyers (eds.) 1995. *Technical Support Document for the Comparison of the Ecological Risks to the Tampa Bay Ecosystem from Spills of Fuel Oil #6 and Orimulsion®* Miami: University of Miami. 4 volumes.

This is part of a six-volume report for the Cooperative Oil/Orimulsion Spill Assessment Program (COSAP). It compares ecological risks of fuel oil #6 and Orimulsion® using Tampa Bay, Florida as the example. The report covers physical transport and mixing; modeling; physical and chemical fate processes; effects on seagrasses, mangroves, and fishes; toxicology assessment; acute toxicity; soil ingestion effects on wildlife; endocrine and genetic effects; biological effects on dorset sheep and brown pelicans; a decision support system; and chemistry of each fuel.

Benggio, B.L. 1994a. *Diaper Drop Technique for Locating Submerged Oil*. Presented at Group V Working Group meeting, 12/15/94. 1 pp.

Handout presented at a Group V working group meeting describing one simple method for locating submerged oil using an ordinary disposable diaper.

Benggio, B.L. 1994b. NOAA Response Report: Barge *Bouchard 155*. *Oil and Hazardous Materials Response Reports, October 1992-September 1993*. Seattle: Hazardous Materials Response and Assessment Division, NOAA. pp 69-74.

This is the NOAA SSC summary report for the *Bouchard B155* collision and oil spill near Tampa Bay, Florida in August 1993. Included is an incident summary, behavior of the spilled material, countermeasures and mitigation, special interest issues, and NOAA activities at the scene.

Benggio, B.L. 1994c. *Photobathymetry for Submerged Oil*. Presented at Group V Working Group meeting, 12/15/94. 3 pp.

Handout presented at a Group V working group meeting describing a photographic mapping technique usable for the detection and mapping of submerged oil.

Benggio, B.L. 1995. NOAA Response Report: Barge *Morris J. Berman*. *Oil and Hazardous Materials Response Reports, October 1993-September 1994*. Seattle: Hazardous Materials Response and Assessment Division, NOAA. pp 133-140.

This is the NOAA SSC summary report for the *Morris J. Berman* grounding and oil spill near San Juan, Puerto Rico in January 1994. Included is an incident summary, behavior of the spilled material, countermeasures and mitigation, special interest issues, and NOAA activities at the scene.

Benoit, S. 1994. *Orimulsion® trials, July 12-14, 1994*. Mulgrave, Nova Scotia: Emergency Services Center. 8 pp.

Paper summarizing observations and testing setup parameters of trials to determine the cleanup possibilities for spills of Orimulsion® in both fresh- and salt-water environments. Tests were conducted at the Emergency Services Center in Mulgrave, Nova Scotia, Canada in July of 1994. Conclusions were: 1) the oil immediately sank, and stayed there, in fresh water; 2) the oil sank and resurfaced in salt water and continued to do so for a week; 3) sorbent pads and netting worked better than skimmers for recovery, although the netting only worked well on the surface oil.

Bitor. 1994. *Orimulsion® tanker transportation manual, version 1.1*. Orinoco, Venezuela: Bitor. 35 pp. + appendix.

The Bitor Orimulsion® tanker transportation manual gives information and guidance, on the properties of Orimulsion® as well as tanker size and equipment requirements, loading operations, transportation, discharge operations, cargo inspection and sampling, and safety regulations geared for the transportation industry.

Bitor America Corporation. Appendix I: Orimulsion®. *Bitor America Corporation Corporate Response Plan, Volume 1*. Boca Raton, FL: Bitor America Corporation. pp. I-1 to I-32.

The Bitor Corporate Response Plan Appendix describes Orimulsion®, its behavior in fresh water and salt water, buoyancy, destabilization, and fate. It also describes the detection, treatment, containment, and recovery of Orimulsion® spills. In addition, toxicity data included states the toxicity of Orimulsion® is less than either #6 fuel oil or crude oil.

Bitor America Corporation. 1995. *Compilation of environmental field and laboratory studies on Orimulsion®*, its constituents, and fuel oil #6 conducted by Intevep. Boca Raton, FL: Bitor America Corporation.

This report is a compilation of studies performed for Bitor on Orimulsion®. It includes laboratory studies on the fate and behavior and toxicity of Orimulsion® compared to #6 fuel oil. It also has field studies on the effects of Orimulsion® on mangroves, biofouling communities, and sandy communities.

Bitor America Corporation. *Orimulsion® containment and recovery test*. Draft, 10/1/96. Boca Raton, FL: Bitor America Corporation. 24 pp.

This is a proposal for Orimulsion® containment and recovery tests off the coast of Venezuela. The purpose is to test special booms for the containment of Orimulsion® spills, the efficiency of forced adhesion and flotation system (FAF), and the behavior and effectiveness of bitumen skimmers in the recovery of bitumen from the water surface.

Bitor America Corporation. *Orimulsion®: a new fuel*. Boca Raton, FL: Bitor America Corporation. 20 pp.

This is an informational pamphlet from Bitor describing what Orimulsion® is, how it's produced, what its properties are, and what its burning efficiency is.

Blackman, R.A.A. and R.J. Law. 1980. The *Eleni V* oil spill fate and effects of the oil over the first twelve months--1. Oil in waters and sediments. *Marine Pollution Bulletin* 11(7): 199-204

Paper summarizing the fate and effects of the heavy fuel oil (specific gravity .94 to .97) spilled when the *Eleni V* was cut in half by a French freighter on May 6, 1978, off the Norfolk (east) coast of England. Patches of oil on the seabed and floating below the surface were observed. Much of the subsurface oil was not initially detected and subsequently beached in unexpected places.

Blumer, M., G. Souza, and J. Sass. 1970. Hydrocarbon pollution of edible shellfish by an oil spill. *Marine Biology* 5: 195-202.

This paper discusses the pollution of shellfish beds by #2 fuel oil from the barge *Florida* grounded near West Falmouth, Massachusetts on September 16, 1969. Scallops were harvested that reportedly had an oily taste.

Blumer, M., H.L. Sanders, J.F. Grassle, and G.R. Hampson. 1971. A small oil spill. *Environment* 13(2): 2-12.

This paper summarizes information on the barge *Florida* grounding and oil spill off West Falmouth, Massachusetts in September 1969. The #2 fuel oil contaminated bottom sediment 42 feet below the surface by an interaction of wind, waves, and bottom sediment movement.

Blumer, M. and J. Sass. 1972. Oil pollution: persistence and degradation of spilled fuel oil. *Science* 176: 1120-1122.

This paper discusses the results of investigations into the persistence of the spilled oil from the barge *Florida* in the sediments, onshore and offshore from the September 1969 spill near West Falmouth, Massachusetts, and documents the presence of these hydrocarbons two years after the incident.

Brown, H. and P. Nicholson. 1991. The physical-chemical properties of bitumen in relation to oil spill response. *Proceedings of the 14th Arctic and Marine Oil spill Program (AMOP) Technical Seminar, June 12-14, 1991, Vancouver, BC, Ottawa, Ontario: Environment Canada.* 107-118.

A study of the physical and chemical properties of Cold Lake (Alberta) bitumen as would pertain to a spill response involving bitumen or its transported version called Dilbit, a mixture of gas condensate and bitumen. According to this paper, the viscosity and density of this material is critically dependent on the temperature of the water it is spilled into. There are figures provided showing viscosity in relation to temperature, density in relation to temperature, percent of weight loss over time, viscosity vs. weight loss, density vs. weight loss, flash point vs. weight loss, and evaporation over time for three different spill models.

Brown, H.M. and R.H. Goodman. 1989. The recovery of spilled heavy oil with fish netting. *Proceedings of the 1989 Oil Spill Conference, February 13-16, 1989, San Antonio, TX.* Washington D.C.: API. 123-126.

Paper describing testing and results of the use of netting (three different grades tested) to recover spilled bitumen. Tests were conducted in the Esso wave basin in Calgary. The study found the use of netting was effective provided the tow speed did not exceed .3 meters per second.

Buckley, D.E., E.H. Owens, C.T. Schafer, G. Vilks, R.E. Cranston, M.A. Rashid, F.J.E. Wagner, and D.A. Walker. 1974. Canso Strait and Chedabucto Bay: A multidisciplinary study of the impact of man on the marine environment. *Offshore Geology of Eastern Canada, Volume 1: Concepts and Applications of Environmental Marine Geology* (Geological Survey Paper 74-30). Ottawa, Ontario: pp 133-160.

Paper describing the geological environment of Canso Strait and Chedabucto Bay, Nova Scotia, Canada. Detailed mention is made of the *Arrow* oil spill and the oil residues still in the environment from that incident.

Buist, I.A. and S.G. Potter. 1987. Oil submergence. ISSN 0381-4459. *Spill Technology Newsletter* 12: 65-82.

Paper describing conditions under which oil slicks can submerge. Case histories listed are the *Arrow*, *US/NS Potomac*, *Ixtoc I*, *Kurdistan*, *Katina*, and *Thuntank 5*. The suggested cause for the submergence in these cases is low or neutral buoyancy and the formation of particulate oil forms, such as slicklets or blobs.

Burns III, G.H., C.A. Benson, S. Kelly, T. Eason, B. Benggio, J. Michel, and M. Ploen. 1995. Recovery of submerged oil at San Juan, Puerto Rico 1994. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington D.C.:* API. pp 551-557.

This paper describes the submerged oil recovery operations undertaken during the response to the *Morris J. Berman* barge spill in Puerto Rico (January 1994). Operations included divers who performed underwater surveying, recovering, and pumping the estimated 150,000 gallons of submerged oil. Dredging was also undertaken to remove submerged oil in some areas. Vacuum trucks were used throughout the operations in many areas. Overall, the operations were deemed very successful by the Coast Guard. The cost for these operations was about \$8 million.

Byron, I. 1995. *Response notes from NOAA SSC on the Apex 3512 spill of slurry oil into the Mississippi River*. New Orleans, LA: Hazardous Materials Response and Assessment Division, NOAA. 2 pp.

Response notes of the NOAA SSC describing the situation and response to the Apex 3512 spill of slurry oil into the Mississippi River on October 11, 1995. The slurry oil is described as having an API gravity of -.5 and the spill quantity is listed as approximately 4,600 barrels. It also describes the survey process and the response methods employed to locate and recover the product spilled, including the use of divers, submersible pumps, and sorbent (diaper) drops.

Campbell, K.S. and E.P. Rahbany. 1991. *Guidelines for use of low-API gravity fuel oils*. Final Report, February 1991. Denver: United Engineers & Constructors for Electric Power Research Institute (EPRI).

A study for the Electric Power Research Institute (EPRI) to provide electrical utilities with information regarding the use of Group V fuel oils as a replacement for conventional (Group IV) fuel oils. The report covers several issues of importance in spill response including properties of the oils and spill prevention and control. The report contrasts the Group IV and Group V characteristics and covers the basic response options associated with a spill of Group V oil.

Castle, R.W., F. Wehrenberg, J. Bartlett, and J. Nuckols. 1995. Heavy oil spills: out of sight, out of mind. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA*. Washington D.C.: API. pp 565-571.

This paper covers the sinking or submergence of oil, the factors influencing this phenomenon, and the properties and movement of sunken or submerged oil. A decision tree with the various methods of response is also included. Case studies referenced in this paper include the *Oregon Standard/Arizona Standard* collision, the barge *Florida*, the *AMOCO Cadiz*, *Sansinena*, *Haven*, and *Bouchard B155*.

Cekirge, H.M., S.L. Palmer, K. Convery, and L. Heri. 1996. State-of-the-art modeling capabilities for Orimulsion® modeling. *Proceedings of the 19th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta*. Ottawa, Ontario: Environment Canada. pp 805-820.

Paper discussing the status of modeling Orimulsion® spills in marine environments. It also presents the model ORI SLIK as a potential solution for modeling such spills.

Chan, G.L. 1973. A study of the effects of the San Francisco oil spill on marine organisms. *Proceedings of the 1973 Oil Spill Conference, March 13-15, 1973, Washington, D.C.*, Washington, D.C.: 741-781.

Paper discussing the effects on marine organisms of the Bunker C oil spilled when the *Oregon Standard* and the *Arizona Standard* collided in San Francisco Bay on January 18, 1971. The oil was a "two-cut mixture" of asphalt and a lighter oil. The reported API gravity of the mixture was 9.6. This spill caused significant damage to mussel beds.

Clark, B., J. Parsons, C. Yen, B. Ahier, J. Alexander, and D. Mackay. 1987. *A study of the factors influencing oil submergence*. EE-90. Ottawa, Ontario: Environment Canada. 77 pp.

A study that used wooden blocks instead of oil to determine under what conditions oil will submerge instead of floating on the water surface. The report concludes that submergence is influenced by oil density relative to water, by turbulence, and by the size of the slick.

Conomos, T.J. 1975. Movement of spilled oil as predicted by estuarine nontidal drift. *Limnology and Oceanography* 20: 159-173.

This article explains the physical conditions present that caused oil to sink after the collision of the *Oregon Standard* and *Arizona Standard* in San Francisco Bay, January 1971. The causes are listed as a combination of the weathering of the spilled Bunker C oil and its mixing with bottom sediments. The article also includes references to other reported instances of sunken oil during this incident.

Curl, H. et al. 1992. *Summaries of Significant U.S. and International Spills: Oil Spill Case Histories, 1967-1991*. Report No. HMRAD 92-11. Seattle: Hazardous Materials Response and Assessment Division, NOAA. 434 pp + Hypercard disk.

This volume contains summaries, or case histories, of many of the incidents covered in this report, including the *Alvenus*, *AMOCO Cadiz*, *Arrow*, *Betelgeuse*, *Eleni V*, *Hasbah 6*, *Haven*, *Ixtoc I*, *Kurdistan*, *MCN-5*, *Mobiloil*, *Nowruz*, *Oregon Standard / Arizona Standard*, *Peck Slip*, *Presidente Rivera*, *Sansinena*, *Santa Barbara Channel*, *Urquiola*, and *Vesta Bella*. The summary includes the behavior of the oil, countermeasures and mitigation, and other special interest issues.

Cutter Information Corporation. 1988. Sunken barge north of Puget Sound presents major spill threat. Arlington, MA: *Oil Spill Intelligence Report XVIII(39)*: p. 1

This article covers the sinking of the barge *MCN-5* near Anacortes, Washington in January 1988. It incorrectly lists the product as heavy glycol gasoil rather than heavy cycle gas oil (HCGO) but does include information on specific gravity (1.086 to 1.09). According to information gathered at the time, the product was expected to sink, which it did. This article also talks about the strong currents where the barge sank that were ultimately responsible for dispersing the spilled product.

Cutter Information Corporation. 1989. Uruguayan tanker spills 300,000 gallons of #6 fuel oil in the Delaware River. Arlington, MA: *Oil Spill Intelligence Report XII(27)*: 3-4

This article covers the grounding and subsequent spill of #6 fuel oil into the Delaware River from the *Presidente Rivera* in June 1989. The oil was observed to float just below the water surface and appear occasionally on the surface.

Cutter Information Corporation. 1990. Loading barge spills 21,000 more gallons into Texas channel. Arlington, MA: *Oil Spill Intelligence Report XIII(33)*: 7-8

This short article does not name the barge but it covers the *SFI-33* tank rupture and spill into the Houston Ship Channel in August 1990. It states that 10 percent of the oil was recovered and the rest sank to the bottom. Dredging operations to try and recover the sunken product had begun at the time of this article.

Cutter Information Corporation. 1991. Debate continues over oil left in *Haven*. Arlington, MA: *Oil Spill Intelligence Report XIV(21)*: p. 5

This article covers the debate about what the actual disposition of the oil spilled following the explosion and fire aboard the *Haven* is. Estimates of total spilled, total burned, etc. were very contentious. Italian officials thought burn residue was sitting on the bottom but a decision on response methods had not been made.

Cutter Information Corporation. 1993. Workers resume beach cleanup in Tampa. Arlington, MA: *Oil Spill Intelligence Report XVI(41)*: p. 4

This short article covers the resumption of cleanup efforts after submerged oil patches washed ashore following heavy weather. This cleanup effort began in August after the collision of three vessels near Tampa Bay, Florida, with the *Bouchard B155* being the barge that spilled the product that eventually submerged.

Cutter Information Corporation. 1994a. Puerto Rico spill: submerged oil complicates beach cleanup. Arlington, MA: *Oil Spill Intelligence Report XVII(4)*: 2-5

This article covers the current state of the response to the *Morris J. Berman* oil spill near San Juan, Puerto Rico. It mentions the complications to the cleanup effort caused by submerged oil and some of the methods used to attempt to recover the product.

Cutter Information Corporation. 1994b. USCG to dredge lagoon in Puerto Rico to remove submerged oil. Arlington, MA: *Oil Spill Intelligence Report XVII(5)*: 1-2

This article talks about the dredging operations begun by the Coast Guard to remove submerged oil from a lagoon in front of the Hilton and Radisson hotels in San Juan, Puerto Rico. This oil, spilled by the barge *Morris J. Berman*, complicated cleanup efforts when it submerged, washed up, and reiled beaches.

Cutter Information Corporation. 1994c. LAPIOs and submerged oil present new response challenges. Arlington, MA: *Oil Spill Intelligence Report XVII(45)*: 2-3

This article covers new response challenges being encountered due to low-API gravity (LAPIO), or Group V, oils and the unique problems associated with response to

spills involving these products. Reference is made to the *Morris J. Berman and Bouchard B155* spills and submerged oil incidents involved in both cases.

Cutter Information Corporation. 1994d. Spill Followup: *Morris J. Berman* response costs and oil fates. Arlington, MA: *Oil Spill Intelligence Report Special (12/15/94)*: 2 pp.

This article covers the response costs and oil fates for the *Morris J. Berman* oil spill near San Juan, Puerto Rico in January 1994, including costs for submerged oil recovery and an estimate of the amount of submerged oil recovered.

Cutter Information Corporation. 1995. Responders face challenges in cleaning "sinking" oil on Mississippi. Arlington, MA: *Oil Spill Intelligence Report XI(6)*: p. 1

This article describes the response to a slurry oil spill from the barge *Apex 3512*. The spill was caused by a collision between two tugs on the Mississippi River in Louisiana. The oil is stated to be a Group V oil but no API gravity or physical properties are listed. Various techniques employed to locate and recover the oil are listed, including the use of the diaper drop technique and submersible pumps.

D'Ozouville, L., M.O. Hayes, E.R. Gundlach, W.J. Sexton, and J. Michel. 1979. Occurrence of oil in offshore bottom sediments at the *AMOCO Cadiz* oil spill site. *Proceedings of the 1979 Oil Spill Conference, March 19-22, 1979, Los Angeles, CA*. Washington D.C.: API. 187-192.

Paper describing the occurrence of sunken oil patches during the response to the *AMOCO Cadiz* oil spill in Brittany, France in March 1978. Oil was incorporated into the bottom sediments in the bays of Morlaix and Lannion. Samples were taken using the box-coring technique.

Dawe, B.R., S.K. Parashar, J.P. Ryan, and R.D. Worsfold. 1981. The use of satellite imagery for tracking the *Kurdistan* oil spill. Technology Development Report EPS-4-EC-81-6. Ottawa, Ontario: Environment Canada. 31 pp.

A study to determine the effectiveness of using satellite imagery for tracking and monitoring the oil after the *Kurdistan* spill of March 15, 1979. The report makes mention of oil found floating just below the surface of the water.

Delvigne, G.A.L. 1987. Netting of viscous oil. *Proceedings of the 1987 Oil Spill Conference, April 6-9, 1987, Baltimore, MD*: 115-122.

This paper describes tests using different grades of netting to recover viscous oils and water-in-oil emulsions. Netting effectiveness seems to be dependent on the viscosity of the oil in combination with the method of netting used. There was some leaking involved, but the recovery percentage overall was good.

Duerden, F.C. and J.J. Swiss. 1981. *Kurdistan*: an unusual spill successfully handled. *Proceedings of the 1981 Oil Spill Conference, March 2-5, 1981, Atlanta, GA*: 215-220.

Paper summarizing operations following the *Kurdistan* breakup and oil spill in March 1979 in Cabot Strait, Canada. Mention is made of subsurface oil that reappeared and reiled shorelines causing untold problems for response teams. Since they were

often unable to find the oil on overflights and surveys, response teams just waited for the oil to adhere to something and cleaned up afterwards.

Eastern AeroChem, Inc. 1995. *Orimulsion*. Tampa, FL: Eastern AeroChem, Inc. 4 pp.

This is a brief summary of technical reports regarding the properties and characteristics of Orimulsion®. Mention of a proposal to transport the crude bitumen rather than the emulsified product and emulsify it at the receiving terminal is included.

Etkin, D.S. 1995. *Case Study: The Morris J. Berman Oil Spill*. ISBN 1-57484-020-7. Arlington, MA: Cutter Information Corporation. 135 pp.

This is an in-depth case study of the *Morris J. Berman* grounding and oil spill near San Juan, Puerto Rico in January 1994. It contains a short chapter on the behavior and properties of Group V or low-API gravity oils (LAPIO) as well as a chapter on the response operations for submerged oil. It has many other chapters covering all the issues and operations that were involved in the response to this spill and the resulting damages, claims, and court cases.

Farmer, D. and M. Li. 1994. Oil dispersion by turbulence and coherent calculations. *Ocean Engineering* 21: 575-586

Paper discussing the relationship between Langmuir circulation and oil submergence. References are made to the *Braer*, *Arrow*, *US/UN Potomac*, *Ixtoc I*, *Kurdistan*, *Katina*, and *Thuntank 5* spills, which all had reports of subsurface oil for one reason or another.

Fingas, M. 1992. Fate, weathering, and modeling research: A Canadian perspective. *Proceedings From the First International Oil Spill R&D Forum*, McLean, VA: 67-72.

Briefly describes the status of sinking and overwashing research in Canada. States that without field data to validate laboratory tests, there is no real way to tell if the predictions of these tests are realistic.

Fingas, M.F. 1994. Chemistry of oil and modeling of spills: *Journal of Advanced Marine Technology Conference* 11: 41-63.

This paper briefly describes the sinking of oil, with the noted causes being either sedimentation of oil droplets or sinking en masse, which would include overwashing.

Forrester, W.D. 1971. Distribution of suspended oil particles following the grounding of the tanker *Arrow*. *Journal of Marine Research* 29(2): 151-170.

This paper describes oil particles found in the water column in Chedabucto Bay, Nova Scotia following the grounding of the *Arrow* in February 1970. The origin, distribution, and transport of these particles is discussed. The particles are thought to have traveled as far as 250 kilometers from the source.

Frank Ayles & Associates Ltd. 1995. *Report on Orimulsion® pollution control testing carried out at OSSC, Southampton, UK, 28 November-2 December 1994*. London, England: Frank Ayles & Associates.

This report summarizes pollution control testing carried out at the Oil Spill Service Centre in the United Kingdom. It includes studies done on Orimulsion® recovery and containment, and cleanup countermeasures effectiveness. The report includes conclusions and recommendations for preparation of contingency plans involving Orimulsion®.

Fremling, C.R. 1981. Impacts of a spill of #6 fuel oil on Lake Winona. *Proceedings of the 1981 Oil Spill Conference, March 2-5, 1981, Atlanta, GA: 419-422.*

Summary of the impacts of a #6 fuel oil spill into Lake Winona, Minnesota. The 7,400 gallons of residual fuel oil spilled into this fresh-water lake was a nightmare for cleanup crews as sunken patches of oil continued to release globules that appeared as new slicks on the lake's surface. The oil was a mixture of .928 specific gravity oil (30%) and 1.066 specific gravity oil (70%) that separated and caused essentially two spills, one on the surface and one on the bottom of the lake. Approximately 190,000 bluegills were killed as a result of this spill and the general stresses of the spawning season.

French, D.P. and D. Mendelsohn. 1995. Development and application of an Orimulsion®. Spill fate and effects model. *Proceedings of the 18th Arctic and Marine Oil spill Program (AMOP) Technical Seminar, June 14-16, 1995, Edmonton, Alberta, V2: 769-792.*

This paper discusses adaptation of an existing oil spill fate and effects model to account for the post-spill behavior of Orimulsion®. The model initializes the bitumen in Orimulsion® as a series of droplets based on the product specification data supplied by the manufacturer.

Galt, J.A., D.L. Payton, G.M. Torgrimson, and G. Watabayashi. 1983. *Trajectory analysis for the Nowruz oil spill with specific applications to Kuwait*. Seattle: Hazardous Materials Response Branch, NOAA. 123 pp.

Report summarizing trajectory analysis activities for the Nowruz oil field accident and further complications due to the Iran-Iraq conflict. The report discusses the conditions that may lead to some subsurface tarballs and/or patches of oil that could be problematic for those trying to track the movement of the oil from this incident.

Garcia, E.V. and J. Westerlind (moderators). 1992. Discussion Group: "Oil Spills." *Proceedings: 1991 Fuel Oil Utilization Workshop, November 6-7, 1991, San Antonio, TX: pp 4-5 to 4-24.*

Discussion group of Group V and fuel oil end users from various electric utilities, etc. regarding the responsibilities of the spiller in the event of a spill and the implications OPA '90 and various state regulations will have on the industry. A clear look at the industry point of view.

Garcia-Martinez, R., J.J. Rodriguez-Molina, F. Camacho, and P. Mascianglioli. 1996. Oritrack®: A mathematical model for Orimulsion® spills in water. *Proceedings of the 19th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta*. Ottawa, Ontario: Environment Canada. pp 857-868.

Paper describing the Oritrack® mathematical model to simulate Orimulsion® spills in water.

Genwest Systems. 1991. *NOAA Hotline Reports for the Barbuda Barge Incident*. Seattle: Hazardous Materials Response Branch, NOAA.

Unedited response reports from the Vesta Bella oil spill of March 6, 1991, in the Barbuda area of the Caribbean Sea. The spilled product was #6 fuel oil. The observation of tarballs and/or tarmats observed below the water surface at times was attributed to mixing with sediment or turbulence. There was also a tarmat that oiled a submerged patch of seagrass.

Grainger, R.J.R., C.B. Duggan, D. Minchin, and D. O'Sullivan. 1984. Investigations in Bantry Bay following the *Betelgeuse* oil tanker disaster. *Irish Fisheries Investigations 27B*: 1-24.

Report of investigations in Bantry Bay, Ireland following the Betelgeuse explosion, fire, and oil spill of January 1979. Reports are included of sunken patches of oil residue that contaminated bottom trawls and scallop dredges up to 19 miles away. In November and December of 1980 dredging operations were undertaken to clear sunken oil from an area where such deposits were reported. Approximately 30 tons were recovered and more was thought to remain in an area of scallop beds.

Grose, P.L., J.S. Mattson, and H. Petersen. 1979. *USNS Potomac oil spill, Melville Bay, Greenland, August 5, 1977: a joint report on scientific studies and impact assessment by the NOAA-USCG Spilled Oil Research Team and the Greenland Fisheries Investigations, Ministry of Greenland*. Draft Copy, February 1979. Washington: NOAA.

A comprehensive summary report of the fate and effects of Bunker C oil spilled after the USNS Potomac had a tank holed by an iceberg in Melville Bay, Greenland in August 1977. The specific gravity of the spilled oil was initially .96 but increased to 1.027 with weathering effects. There were observations of sinking and submerged oil. The oil is assumed to have sank to the bottom eventually, probably within 50 days of the spill. Due to the depth and other conditions in Melville Bay, the oil is not expected to resurface.

Group V Petroleum Oils Work Group. 1995. *Group V Petroleum Oils: USCG Seventh District Work Group Report*. 17 October 1995. Miami, FL: U.S. Coast Guard Seventh District

This is the summary report from a work group representing the Coast Guard, NOAA, and the State of Florida that gathered to identify special characteristics of, determine prevention measures for, determine special handling and transportation requirements for, identify potential response methods for, and determine additional research and testing needed for Group V petroleum oil spills. The main products studied by this group were GPVRFO (Group V residual fuel oil) and Orimulsion®.

Gundlach, E.R., J.H. Rule, and M.O. Hayes. 1978. Oil in sediments: a synthesis of previous studies and discussion of future research. In: *Coastal Processes Field Manual for Oil Spill Assessment*. Columbia, SC: Research Planning Institute. pp II-1 to II-32.

A chapter describing the interactions of sediments with oil. Included is information from different case histories, including the *Arrow, Florida, Santa Barbara* blowout, and *AMOCO Cadiz*.

Gundlach, E.R., J. Michel, G.I. Scott, M.O. Hayes, C.D. Getter, and W.P. Davis. 1979. Ecological assessment of the *Peck Slip* (December 19, 1978) oil spill in eastern Puerto Rico. *Proceedings of the Ecological Damage Assessment Conference*: pp 303-317.

This is a concise summary of ecological assessments performed during the *Peck Slip* oil spill off eastern Puerto Rico in December 1978. Information is provided on the location of submerged oil pancakes, caused by the oil mixing with sediments, that reoiled the beaches in several areas .

Gundlach, E.R., K. Finkelstein, and J.L. Sadd. 1981. Impact and persistence of Ixtoc I oil on the south Texas coast. *Proceedings of the 1981 Oil Spill Conference, March 2-5, 1981, Atlanta, GA*: 477-488.

Paper summarizing the persistence of oil from the Ixtoc I oil well blowout on south Texas beaches. It includes information on "armored" tarballs observed on the sea bottom in the nearshore zone caused by the mixing of beach sand and sediments with the weathered oil.

Hall, C.J. 1994. *Information Management Report: Barge Morris J. Berman Spill, San Juan, Puerto Rico, 07 January 1994*. Seattle, WA: Genwest Systems for Hazardous Materials Response and Assessment Division, NOAA. 2 volumes.

This voluminous report is a compilation of all information gathered or generated by NOAA during the response to the *Morris J. Berman* oil spill near San Juan, Puerto Rico in January 1994. It includes NOAA Hotline reports, USCG Polreps, overflight maps, trajectory maps, shoreline zone maps, and other information pertaining to the cleanup operations.

Hampson, G.R. and H.L. Sanders. 1970. Local oil spill. *Oceanus* 25(2): 8-10.

This paper is a short, early summary of the barge *Florida* grounding and oil spill near West Falmouth, Massachusetts in September 1969. Trawl surveys were conducted that found 95 percent of the marine life trawled were dead or dying. Preliminary observations were of consistently contaminated sediments at the 23- to 33-foot depth.

Harbert, R.W. 1994. *Notes on Orimulsion® Test, Southampton, UK, 28 Nov-2 Dec 94*. Tampa Bay: U.S. Coast Guard Marine Safety Office. 8 pp.

Notes of Captain Harbert of his observations at the Oil Spill Service Centre (UK) Orimulsion® spill tests.

Harwell, M.A., J.S. Ault, and J.H. Gentile. 1995. *Comparison of the Ecological Risks to the Tampa Bay Ecosystem from Spills of Fuel Oil #6 and Orimulsion®*. Comparative Oil/Orimulsion Spill Assessment Program (COSAP), Volume I. Miami, FL: University of Miami for Florida Power & Light. 177 pp.

This is part of a six-volume report for the Cooperative Oil/Orimulsion Spill Assessment Program (COSAP). This volume compares the ecological risks specific to the Tampa Bay ecosystem, from spills of fuel oil # 6 and Orimulsion®.

Henry, C.B. 1991. *Barge Vesta Bella. Louisiana State University response report: St. Eustatius Refinery Oil Spill Response Incident #89*. Seattle: Hazardous Materials Response Branch, NOAA. 6 pp.

Response report for the *Vesta Bella* oil spill in the Caribbean Sea in March of 1991. The density of the oil was estimated to be in the 1.00 to 1.05 range and an actual sample tested was 1.04.

Hernandez-Carstens, E. and R. Rodriguez. 1991. Orimulsion® a new fuel for power generation. *International Joint Power Generation Conference and Exposition, San Diego, California, October 9, 1991*. 12 pp.

This paper is similar to the Bitor pamphlet on Orimulsion®. It gives a general overview of what Orimulsion® is, where it comes from, how it is produced, and why it will be useful for power generation.

Hutchison, J.H. and B.L. Simonsen. 1979. Cleanup operations after the 1976 SS *Sansinena* explosion: an industrial perspective. *Proceedings of the 1979 Oil Spill Conference, March 19-22, 1979, Los Angeles, CA, Washington, D.C.*: API. pp 429-433.

This paper summarizes cleanup operations after the SS *Sansinena* explosion and oil spill in Los Angeles Harbor in December 1976. Divers found the Bunker C oil on the bottom of the harbor two days after the initial incident, much to the surprise of the response staff who thought the Bunker C was still on the ship. With an API gravity from 8.46 to 8.8, the oil had a specific gravity greater than water and sank. Vacuum trucks, in cooperation with separation tanks mounted on a barge, were first used but were not very effective. Seaward pumps were then used in conjunction with hydraulic cranes and were able to remove the oil patches, although very slowly. The bottom was dredged after the vessel was removed for the final cleanup.

Intevep. 1995. *Compilation of environmental field and laboratory studies on Orimulsion®, its constituents, and fuel oil #6 conducted by Intevep*. Tallahassee: Florida Power & Light.

This is part of a six-volume report for the Cooperative Oil/Orimulsion Spill Assessment Program (COSAP). It is a compilation that includes laboratory studies on the fate and behavior and toxicity of Orimulsion® compared to #6 fuel oil. It also has field studies on the effects of Orimulsion® on mangroves, biofouling communities, and sandy communities.

Johnston, A.J., M.R. Fitzmaurice, and R.G.M. Watt. 1993. Oil spill containment: viscous oils. *Proceedings of the 1993 Oil Spill Conference, March 29-April 1, 1993, Tampa, Florida, Washington, D.C.: API. pp89-94.*

Paper addressing some of the problems associated with attempted boom containment of viscous or heavy oil slicks. It does not address sinking and/or submerged oil issues.

Jokuty, P., S. Whitar, M. Fingas, Z. Wang, K. Doe, D. Kyle, P. Lambert, and B. Fieldhouse. 1995. *Orimulsion®: physical properties, chemical composition, dispensability, and toxicity.* Report Series No. EE-154. Ottawa, Ontario: Environment Canada. 31 pp.

A very concise summary of the physical, chemical, dispensability, and toxicity properties of Orimulsion®, a commercial product that is a combination of bitumen, water, and nonyl phenol ethoxylate, a surfactant. Results show a potential for submergence in close-to-freezing salt water as well as in fresh water. The chemical composition was found to be heavily degraded, which means further degradation should not be expected. Orimulsion® was found to be toxic to various species tested with a water-soluble fraction.

Juszko, B.A. 1985. *Determination of oceanographic factors associated with the subsurface movement of oil.* EE-66. Ottawa, Ontario: Environment Canada. 74 pp.

This report discusses oceanographic conditions conducive to the sinking and/or subsurface movement of oil. The report specifically talks about conditions found in Canadian waters, but could be applied to any area with similar environmental conditions.

Juszko, B.A. and D.R. Green. 1983. Sinking of oil: water density considerations. Ottawa, Ontario: *Spill Technology Newsletter 8: 22-27.*

Summarizes conditions under which oil can sink due to water density vs the specific density of the oil. The paper talks about fresh-water inputs as the force for density changes in the water, and weathering for the changes in the gravity of the oil.

Juszko, B.A., D.R. Green, and M.F. Fingas. 1983. Sinking of oil: water density considerations. *Proceedings of the 6th Annual Arctic Marine Oil spill Program Technical Seminar, June 14-16, 1983, Edmonton, Alberta: 9-13.*

Summarizes conditions under which oil can sink due to water density vs the specific density of the oil. The paper talks about fresh-water inputs as the force for density changes in the water, and weathering for the changes in the gravity of the oil.

Kennedy, D.M. and B.J. Baca (eds.) 1984. *Fate and effects of the Mobiloil spill in the Columbia River.* Seattle: Ocean Assessments Division, NOAA. 99 pp.

An in-depth summary of the scientific response to the Mobiloil grounding and spill in the Columbia River in March 1984. Sections on the movement of oil in the subsurface and river bottom concentrations are included. The bottom concentrations are explained as a combination of the density of the oil combined with an eddy system that formed in

the lee of the ship. In areas where this eddy did not exist, the oil was washed away downstream.

Kennedy, D.M. 1988. NOAA Response Report: *Barge MCN-5. Oil and Hazardous Materials Response Reports, October 1987-September 1988*. Seattle: Hazardous Materials Response Branch, NOAA. pp 144-146.

This is the NOAA SSC summary report for the barge MCN-5 sinking and oil spill near Anacortes, Washington in January 1988. This report summarizes NOAA activities and observations at the scene.

Kitching, H. (moderator) 1989. Low API gravity oils discussion session. *EPRI Fuel Oil Utilization Workshop, November 1988, Palo Alto, CA: 4-5 to 4-11*

Summary of a question-and-answer session on low-API gravity oils at the 1988 Fuel Oil Utilization Workshop. Discussion ranges from concerns about the burning of LAPIO to the concerns for spill prevention.

Kolpack, R.L., R.W. Stearns, and G.L. Armstrong. 1978. Sinking of oil in Los Angeles Harbor, California following the destruction of the *Sansinena*. *Proceedings of the Conference on Assessment of Ecological Impacts of Oil Spills, 14-17 June 1978, Keystone, CO: 378-392*.

This report describes the sinking of the oil from the *Sansinena* explosion in Los Angeles Harbor in 1976 with emphasis on the reason for the sinking being that the oil burned off the higher end sinking immediately due to the weight and specific gravity of the residual portion.

Koops, W., F.J. Sanders, and J.M. Gubbens. 1985. The *Katina* oil spill 1982, combating operation at sea. *Proceedings of the 1985 Oil Spill Conference, February 25-28, 1985, Los Angeles, CA, Washington, D.C.: API. pp 299-306*.

Summary of spill response to the *Katina* oil spill, following a collision on June 7, 1982, off the Hook of Holland. The ship was carrying a mixture of fuel oils with a specific gravity of .9954, which soon weathered to 1.011. Because aerial reconnaissance did not see the oil mass that reportedly floated just below the water surface, beaches were oiled that were not predicted to be impacted.

Lange, H.B. and J.P. Brown. 1993. *Assessment of electric utilities' capability to utilize low API gravity fuel oils*. December 1993. Tustin, CA: CARNOT for Electric Power Research Institute (EPRI) and Fuel Oil Users Support Group. 58 pp. + appendix.

This is an assessment of the utilization potential of Group V oils by electric utilities sponsored by the Electric Power Research Institute (EPRI). A section on spill cleanup issues is useful to spill response personnel to prepare for and respond to spills involving Group V oils. The report has good details about several past incidents and current technologies and their potential applicability to a spill involving these heavy oils. The report also illustrates the point that Group V spills are a case-by-case problem with no guarantees as to the actual behavior of the spilled substance due to the wide variety of substances involved and the unknown environmental variables.

Lee, S.C., D. Mackay, F. Bonville, E. Joner, and W.Y. Shiu. 1989. *A study of the long-term weathering of submerged and overwashed oil*. EE-119. Ottawa, Ontario: Environment Canada. 61 pp.

This study looks at the weathering of heavy crude oils, Cold Lake bitumen, and bunker fuel with an eye on the phenomenon of overwashing and/or submergence of oil masses. The oils used had specific density measurements ranging from .9672 to 1.0075 and API gravity from 13.2 to 9.8. The conclusion of the study is that evaporation and "incorporation of foreign matter" are the most important processes affecting oil density.

Lee, S.C., D. Mackay, F. Bonville, E. Joner, and W.Y. Shiu. 1989. *A study of the long-term weathering of submerged and overwashed oil. Proceedings of the 12th Arctic Marine Oil spill Program Technical Seminar, June 7-9, 1989, Calgary, Alberta, Ottawa, Ontario*: Environment Canada. pp 33-60.

Paper summarizing a study that looks at the weathering of heavy crude oils, Cold Lake bitumen, and bunker fuel with an eye on the phenomenon of overwashing and/or submergence of oil masses. The oils used had specific density measurements ranging from .9672 to 1.0075 and API gravity from 13.2 to 9.8. The conclusion of the study is that evaporation and "incorporation of foreign matter" are the most important processes affecting oil density.

Lee, S.C., W.Y. Shiu, and D. Mackay. 1992. *A study of the long term fate and behaviour of heavy oils*. EE-128. Ottawa, Ontario: Environment Canada. 132 pp.

Study of the weathering of crude and synthetic oils. The oils studied were the same as in a previous study (EE-119) with API gravity ranging from 9.8 to 13.2. The hopes of this study for predicting changes in oil density and viscosity due to weathering were not realized.

Leek, W.R. 1989. *Prevention and control of spills of low gravity fuel oil. Fuel oil utilization 1988 workshop proceedings, New Orleans, LA, 16-17 November, 1988* : 3-227 to 3-241.

A short review of prevention, control, and response issues for electric utilities who choose to utilize low-API gravity fuel oils. The article stresses prevention, but also contains some general information about control and response issues.

Lerch, D.W. 1993. *An application of oil spill recovery technology to response vessel design: the Burrard Cleaner No. 9. Marine Technology* 30:172-177

An article discussing the application of oil spill fate information to the design and construction of an oil spill response vessel, the Burrard Cleaner No. 9, specifically tasked to handle spills of Cold Lake crude, a heavy, thick oil with bitumen as a component. The article includes design specifications, drawings, and testing information.

Levine, E. 1990. *NOAA Response Report: T/V Presidente Rivera. Oil and Hazardous Materials Response Reports, October 1988-September 1989*. Seattle: Hazardous Materials Response Branch, NOAA. pp 41-43.

This is the NOAA SSC summary report for the *Presidente Rivera* grounding and oil spill near Marcus Hook, Pennsylvania in June 1989. This report summarizes NOAA activities and observations at the scene.

Levine, E., G. Van Den Berg, D. Simecek-Beatty, J. Michel, J. Dahlin, and C. Henry. 1991. The role of NOAA's Scientific Support Coordinators during the T/B *Vesta Bella* oil spill. *1st International Ocean Pollution Symposium, La Parguera, Puerto Rico, 29 April-3 May 1991*. 10 pp.

A summary of the scientific support coordinators' role during the *Vesta Bella* oil spill response in the Caribbean Sea in 1991. This was a presentation for a conference on ocean pollution. Mention is made of oil that sank during this incident.

Levings, S.C. and S.D. Garrity. 1995. Oiling of mangrove keys in the 1993 Tampa Bay oil spill. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA* Washington, D.C.: API. pp 421-428.

An article discussing the oiling effects on mangrove keys in Johns Pass, Tampa Bay, Florida after the *Bouchard B155* #6 fuel oil spill there in August 1993. The penetration and persistence of the oil as well as the mortality of both adult and juvenile mangroves are covered in detail.

Mackay, D. 1985. Oil spill processes: evaporation, emulsification, dissolution, and sinking. *Proceedings of the 8th Annual Arctic Marine Oil Spill Program Technical Seminar, June 18-20, 1985, Edmonton, Alberta, Ottawa, Ontario*: Environment Canada. pp 53-58.

Briefly discusses the phenomenon of oil sinking or submergence. The possible causes mentioned are strong downwelling currents, association between oil and mineral matter in the water, and wind waves that cause the oil mass to stay just below the water surface and be continually awash with water.

Mackay, D. and C.D. McAuliffe. 1988. Fate of hydrocarbons discharged in the sea. *Oil & Chemical Pollution* 5: 1-20

This article summarizes the various processes that affect oil spilled into marine waters. It covers spreading, drifting, evaporation, dissolution, dispersion, mousse formation, proteolysis, submergence, biodegradation, shoreline interactions, and ice interactions.

Martinelli, M., A. Luise, E. Tromellini, T. C. Sauer, J.M. Neff, and G.S. Douglas. 1995. The M/C *Haven* oil spill: environmental assessment of exposure pathways and resource injury. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.*: API. pp 679-685.

Summary of environmental assessment of the effects of the oiling following the M/C *Haven* explosion and fire of April 1991 in the Mediterranean Sea off Genoa, Italy. Submerged oil was a response issue due to the fire and the resulting changes in the composition and specific gravity of the oil spilled. It is estimated that 13,500 to 18,000

metric tons of oil was deposited on the seafloor as a result of this incident. Some preliminary effects of the spill are summarized.

Mendelsohn, D.L., H.M. Rines, F.T. Christensen, T. Isaji, D. French, and N. Edwards. 1996. A comparative assessment of the fate and effects of similar Orimulsion® and heavy fuel oil spills in the Milford Have estuary, UK.. *Proceedings of the 19th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta, Ottawa, Ontario: Environment Canada. pp 775-804.*

Paper discussing the findings of a comparative assessment of the fate and effects of similar Orimulsion® and heavy fuel oil spills using Milford Haven (UK) as the location of the simulated oil spills. The spills were modeled using the SIMAP computer program.

Michael, A.D., C.R. Van Raalte, and L.S. Brown. 1975. Long-term effects of an oil spill at West Falmouth, Massachusetts. *Proceedings of the 1975 Oil Spill Conference, March 25-27, 1975, San Francisco, CA: 573-582.*

A paper describing long-term effects of the barge *Florida* fuel oil spill off West Falmouth, Massachusetts in September 1969. Benthic and sediment samples were taken that would correspond with earlier work completed along these lines.

Michel, J. and B.L. Benggio. 1994. *An evaluation of options for removing submerged oil offshore Treasure Island: Tampa Bay oil spill.* Report HMRAD 94-5. Seattle: Hazardous Materials Response and Assessment Division, NOAA. 10 pp.

This report is an evaluation of options for submerged oil removal during the response to the *Bouchard B155* oil spill near Tampa Bay in August 1993. It identifies where the patches of submerged oil were located and the current physical properties, if known, of the oil mats. Recommendations are for better mapping and manual removal of the oil rather than the proposed methods due to environmental concerns.

Michel, J. and B.L. Benggio. 1995. Testing and use of shoreline cleaning agents during the *Morris J. Berman* oil spill. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.: API. pp 197-202.*

Describes the testing process for, and the ultimate use of, shoreline cleaning agents during the *Morris J. Berman* oil spill response in Puerto Rico. The products considered, tested, and used were Corexit 9580, Corexit 7664, and PES-51. Corexit 9580 was the product deemed most likely to have a positive effect and its use was approved in certain areas by the regional response team.

Michel, J., S. Christopherson, and F. Whipple. 1994. *Mechanical protection guidelines.* Seattle: Hazardous Materials Response and Assessment Division, NOAA and USCG National Strike Force. 87 pp.

Includes recommendations for mechanical protection of shorelines during oil spill responses of all types.

Michel, J. and J.A. Galt. 1995. Conditions under which floating slicks can sink in marine settings. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA: 573-576.*

A comprehensive summary of conditions conducive to the sinking or submergence of oil. Past case histories of sinking, sunken, or submerged oil are listed and discussed to explain the likely cause of the phenomenon. Spills used for comparison are *Alvenus, Haven, Potomac, Ixtoc I, Peck Slip, Vesta Bella, Bouchard B155, Morris J. Berman, Nowruz, and Honam Jade*. Conclusions are that heavy crude or residual oils are at risk of sinking and that certain conditions are commonly found in cases where oil falls below the water surface.

Michel, J., D. Scholz, C.B. Henry, and B.L. Benggio. 1995. Group V fuel oils: source, behavior, and response issues. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.: API. pp 559-564.*

A very good summary of current information on Group V fuel oils. A summary of known spills involving Group V oils is included as well as information on observed behavior of spilled Group V oils, including sinking and submergence. Case histories used are the *Sansinena, Mobiloil, MCN-5, Bouchard B155, and Morris J. Berman*.

Moller, T.H. 1992. Recent experience of oil sinking. *Proceedings of the 15th Arctic and Marine Oil spill Program Technical Seminar, June 10-12, 1992, Edmonton, Alberta, Ottawa, Ontario: Environment Canada. pp 11-14.*

A short summary of two theories about the cause of oil sinking. Oil spills involving fires where a residual oil sinks and instances where oil and sediment particles mix in the surf zone are covered, but no other explanations for oil sinking are furthered. The *Haven* incident is used almost exclusively with a short reference to the *Honam Jade* spill.

Morris, P.R., B.W.J. Lynch, J.F. Nightingale, and D.H. Thomas. 1985. Recovery of viscous emulsions from a firm sandy beach. *Proceedings of the 1985 Oil Spill Conference, February 25-28, 1985, Los Angeles, CA, Washington, D.C.: API. pp 193-198.*

Tests were performed to determine the usefulness of different recovery means for removing viscous emulsions from firm sandy beach. The tests were done using a water-in-oil emulsion. Various chemical and mechanical countermeasures were tested. The mechanical countermeasures were the preferred method.

Nelson, C.J. 1991. NOAA Response Report: *T/B SF 133. Oil and Hazardous Materials Response Reports, October 1990-September 1991.* Seattle: Hazardous Materials Response Branch, NOAA. pp 170-172.

This is the NOAA SSC summary report for the barge *SFI-33* hull failure and oil spill near Houston, Texas in August 1990. This report summarizes NOAA activities and observations at the scene.

Nicol, C.W. 1976. *The Mizushima oil spill: a tragedy for Japan and a lesson for Canada*. Environmental Impact and Assessment Report EPS-8-EC-76-2. Ottawa, Ontario: Environment Canada. 26 pp.

Report of observations of C. W. Nicol after the Mizushima refinery in Japan released approximately nine million gallons of heavy Bunker C oil, most of which ended up in the Inland Sea. There were several reports of this oil reaching a negative buoyancy point, sinking, and resurfacing. In all, over 700 miles of shoreline were oiled and oil was reported as far as 70 miles away.

Ocean Systems International. 1994. *Submerged oil location and mapping: an overview of techniques*. St. Petersburg, FL: Ocean Systems International. 6 pp.

A short summary of the techniques used by Ocean Systems International to locate and map submerged oil. It includes information on the ROXANN system that was used on both the *Haven* and *Bouchard B155* spills.

Ostazeski, S.A., G.S. Durell, and A.D. Uhler. 1996. Progress toward the development of micro- and meso-scale methods for predicting the behavior of low-API gravity oils (LAPIO) spilled on water. *Proceedings of the 19th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta, Ottawa, Ontario*: Environment Canada. pp 1-8.

Paper describing the progress of method development for predicting the behavior of Group V oils spilled in the marine environment.

Ostazeski, S.A., P.S. Daling, S.C. Macomber, D.W. Fredriksson, G.S. Durell, A.D. Uhler, M. Jones, and K. Bitting. 1996. Weathering properties and the predicted behavior at sea of a LAPIO oil (weathered No. 6 fuel oil). *Proceedings of the 19th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta, Ottawa, Ontario*: Environment Canada. pp 137-162.

Paper discussing the weathering properties and probable behavior of a Group V oil. Weathered #6 fuel oil is used for the laboratory tests performed.

Owens, E.H. and M.A. Rashid. 1976. Coastal environments and oil spill residues in Chedabucto Bay, Nova Scotia. *Canadian Journal of Earth Sciences* 13: 908-928.

A paper summarizing investigations to determine how much oil spill residue remains in the Chedabucto Bay, Nova Scotia, Canada area following the *Arrow* oil spill in 1970. This incident involved a spill of 4.8 million gallons of Bunker C fuel oil. There were reports of submerged oil during the response to this spill.

Owens, E.H., R.A. Davis, J. Michel, and K. Stritzke. 1995. Beach cleaning and the role of technical support in the 1993 Tampa Bay spill. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.*: API. pp 627-634.

A summary of beach cleaning and shoreline surveys in response to the *Bouchard B155* oil spill near Tampa Bay in August 1993. The process of decision making is covered in

detail, as are cleanup alternatives. Preliminary effects of the selected countermeasures are included.

Park, W.C. 1985. Response to the *Mobiloil* spill incident. *Proceedings of the 1985 International Oil Spill Conference, February 25-28, 1985, Los Angeles, CA, Washington, D.C.*: API. pp 335-340.

A summary of the spill response at the *Mobiloil* grounding and subsequent oil spill in the Columbia River in March 1984 from an industry point of view. It provides a good general overview of the different aspects of the cleanup but does not give much information about the submerged oil present or what was done to clean it up.

Pavia, R., A. Rooney, S. Christopherson, and T. Baxter. 1984. NOAA Response Report: M/T *Alvenus*. *Oil and Hazardous Materials Response Reports, October 1983 -September 1984*. Seattle: Hazardous Materials Response Branch, NOAA.

This is the NOAA SSC summary report for the tanker *Alvenus* grounding and oil spill from near Port Arthur to Galveston, Texas from July to October 1984. This report summarizes NOAA activities and observations at the scene.

Pavia, R. 1984. NOAA Response Report: M/T *Mobiloil*. *Oil and Hazardous Materials Response Reports, October 1983-September 1984*. Seattle: Hazardous Materials Response Branch, NOAA. pp

This is the NOAA SSC summary report for the tanker *Mobiloil* grounding and oil spill near Warrior Rock on the Columbia River in March 1984. This report summarizes NOAA activities and observations at the scene.

Payne, J.R. and C.R. Phillips. 1985. *Petroleum spills in the marine environment: the chemistry and formation of water-in-oil emulsions and tar balls*. ISBN 0-87371-058-4. Chelsea, MI: Lewis Publishers. 148 pp.

A useful reference for the understanding of the processes that lead to the formation of tarballs and emulsions during an oil spill. Reference is made to several of the case histories included in this bibliography, including the Ixtoc I, *Arizona Standard/Oregon Standard*, and *Arrow*.

Pearce, F. 1993. 'Dispersed' oil comes back to haunt Shetland. *New Scientist* 137(1857): 5.

A short article describing the resurfacing of oil-in-water emulsions from the *Braer* grounding and oil spill in the Shetland Islands. Divers found evidence of submerged oil at depths of 60 feet or better.

Peigne, G. and M. Cessou. 1989. Improving the pumping of viscous oil by the use of demulsifiers or by annular water injection. *Proceedings of the 1989 International Oil Spill Conference, February 13-16, 1989, San Antonio, TX, Washington, D.C.*: API. pp 175-180.

A review of testing done as an attempt to improve the pumping effectiveness of viscous oils by the use of demulsifiers or annular water injection. Demulsifiers are

recommended for use whenever skimming operations are undertaken involving viscous oils. This review mentions that the type of demulsifier is important so it can be best matched to the emulsion it is dealing with.

Petersen, H.K. 1978. Fate and effect of Bunker C oil spilled by the USNS *Potomac* in Melville Bay, Greenland, 1977. *Proceedings of the Conference on Assessment of Ecological Impacts of Oil Spills, 14-17 June 1978, Keystone, CO*: pp 331-343.

A comprehensive summary of the fate and effects of spilled Bunker C oil spilled after the USNS *Potomac* had a tank holed by an iceberg in Melville Bay, Greenland in August 1977. The specific gravity of the spilled oil was initially .96 but increased to 1.027 with weathering effects. There were observations of sinking and submerged oil. The oil is assumed to have sank to the bottom eventually, probably within 50 days of the spill. Due to the depth and other conditions in Melville Bay, the oil is not expected to resurface.

Petrae, G. (ed.) 1996. *Barge Morris J. Berman Spill: NOAA's Scientific Response*. HAZMAT Report 95-10, September 1995. Seattle: Hazardous Materials Response and Assessment Division, NOAA.

A summary report of NOAA's scientific support activities related to the spill following the grounding of the barge *Morris J. Berman* near San Juan, Puerto Rico in January 1994.

Pezeshki, S.R., R.D. DeLaune, J.A. Nyman, R.R. Lessard, and G.P. Canevari. 1995. Removing oil and saving oiled marsh grass using a shoreline cleaner. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.*: API. pp 203-209.

Testing was conducted to determine the effectiveness of Corexit 9580 for removing Bunker C oil from Louisiana marsh grass. The goal was to minimize the impact of oil spills on marshes by using Corexit. It was concluded that *Spartina alterniflora* marshes recover better after the application of Corexit than if left alone following a spill.

Ploen, M. 1995. Submerged oil recovery: *Morris J. Berman* spill, San Juan, Puerto Rico. *Proceedings of the Second International Oil Spill Research and Development Forum, May 23-26, 1995, London, England, V1*: pp 165-173.

This paper summarizes submerged oil recovery operations following the *Morris J. Berman* grounding and oil spill near San Juan, Puerto Rico in January 1994. The various techniques employed are discussed and recommendations for future situations and research are listed.

Purnell, K. 1995. *Personal communication to John Kaperick dated 11 July 1995 from Dr. Purnell with International Tanker Owners Pollution Federation (ITOPF)*. 3 pp. + attachments.

This is personal correspondence in response to an inquiry made regarding the *Honam Jade* and *Thuntank 5* incidents. This correspondence contains information on each incident, including the response to each incident and the sinking of the oil in each case, one due to the sinking of burn residue and the other due to the oceanographic conditions

at the time of the incident coupled with the physical properties of the substance spilled. The attachments include general information from the Association of Marine Surveyors on submerged oil detection equipment and techniques.

Robinson, J.H. (ed.) 1979. *The Peck Slip oil spill: a preliminary scientific report*. Draft Report. Boulder, CO: various pagings.

The summary report of the response to the *Peck Slip* oil spill of December 19, 1978, in the area of San Juan, Puerto Rico. The barge was carrying 3.7 million gallons of Bunker C fuel oil at the time of the incident. The amount spilled was estimated at between 440,000 and 460,000 gallons. The API gravity of the *Peck Slip* cargo was measured as 18.5. Oil was reported to be resurfacing from the bottom sediments during this incident.

Ross, R.G. (ed.) 1994. *Tank Barge Morris J. Berman, San Juan, Puerto Rico, January 7, 1994: submerged oil recovery operations*. July 26, 1994. San Juan, PR: U.S. Coast Guard Marine Safety Office. 98 pp. + appendix.

Report of the submerged oil recovery operations that took place during the *Morris J. Berman* oil spill response in San Juan, Puerto Rico. Chapters are authored by various experts in different aspects of the operations and include color photographs, diagrams, and maps.

Ross, R.G. 1995a. Spill response management and the *Morris J. Berman* spill: the FOSC's perspective. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA*, Washington, D.C.: API. pp 687-693.

Article about the organization of the response to the *Morris J. Berman* spill rather than the issues involved; but, it has two helpful figures showing the location of submerged oil deposits and how much oil was recovered using submerged oil recovery operations.

Ross, R.G. 1995b. *Federal On-Scene Coordinator's Report: the response to the T/B Morris J. Berman major oil spill*. San Juan, PR: U.S. Coast Guard Marine Safety Office. 78 pp. + appendices.

This is the FOSC's report of the response to the grounding of the tank barge *Morris J. Berman* near San Juan, Puerto Rico in January 1994. Readers are referred to the *Submerged Oil Recovery Operations* report for detail on those operations. Items in the appendices speak of the need for more stringent requirements for Group V oils and the unique response issues raised when dealing with these products.

Ryan, P.B. 1983. *Hasbah 6: oil companies response to oil pollution in the Arabian Gulf*. *Proceedings of the 1983 Oil Spill Conference, February 28-March 3, 1983, San Antonio, TX*, Washington, D.C.: API. pp 371-375.

A paper describing oil companies' response to the *Hasbah 6* well blowout of October 2, 1980. Fish nets were used during this incident to trap subsurface oil. The fresh oil had an API gravity between 18 and 19, but it quickly weathered to a gravity of 10 and caused many problems. Dispersants were ineffective on this spill.

S.L. Ross Environmental Research Limited. 1987a. *Behaviour and control of spills of Orimulsion®* Ottawa, Ontario: New Brunswick Power. 67 pp. + appendix.

A study conducted for New Brunswick Power that examines the risks for and behavior of spills of Orimulsion® and cleanup measures that could be used if a spill were to happen. The goal of this report is to provide a solid basis for contingency planning and countermeasure development.

S.L. Ross Environmental Research Limited. 1987b. *Transient submergence of oil spills: tank testing and modeling*. EE-96. Ottawa, Ontario: Environment Canada. 61 pp.

A report of wind/wave tank test results and model development for the prediction of various physical processes that can act on an oil slick, including overwashing and submergence. Density of the oils tested ranged from .837 to 1.025 dependent on temperature. The conclusions are that submergence and overwashing are dependent on buoyancy of the slick, viscosity, and sea state.

Sadeghi, K.M., M.A. Sadeghi, L.K. Jang, G.V. Chilingarian, and T.F. Yen. 1992. A new bitumen recovery technology and its potential application to remediation of oil spills. *Journal of Petroleum Science and Engineering* 8:105-117.

This article describes a patented process for recovering bitumen from tar sands by the use of a saponification reaction between long-chain acids in raw bitumen and a fresh alkaline solution aided by ultrasound. The author states the feasibility of use for separating hydrocarbons from beach sands and soils after oil spills is demonstrated, but it was not prominently mentioned beyond the abstract.

Scarratt, D.J. and V. Zitko. 1972. Bunker C oil in sediments and benthic animals from shallow depths in Chedabucto Bay, N.S. *Journal of the Fisheries Research Board of Canada* 29: 1347-1350.

This article describes sampling of shallow sediments and benthic animals in Chedabucto Bay, Nova Scotia two years after the grounding of the tanker *Arrow*. The Bunker C oil was still persistent in these areas at the time of this study.

Schmidt, P.F. 1986. *Fuel oil manual, fourth edition*. ISBN 0-8311-1166-6. New York: Industrial Press Inc. 240 pp.

This is a very informative reference on different aspects of fuel oils including their chemistry, grades, types, gravity, viscosity, properties, composition, distillates, stability, blending, transportation, and storage. This would be a good general reference for anyone involved with fuel oils on a regular basis.

Scholz, D.K., J. Michel, C.B. Henry, and B. Benggio. 1994a. *Assessment of risks associated with the shipment and transfer of LAPIO in St. Johns River, Northern and Central Florida*. HMRAD Report 94-1. Seattle: Hazardous Materials Response and Assessment Division, NOAA. 40 pp. + appendix.

This is a concise summary of chemical and physical properties of Group V oils and response considerations for spills involving these substances. It includes case histories of prior spills and resources at risk information for future spills. The incidents covered are the *Sansinena*, *Mobiloil*, *Bouchard B155*, and *Morris J. Berman*. It is specifically geared toward Group V fuel oils and their use in the St. Johns River area of northern and central Florida but can be used for any Group V oils.

Scholz, D.K., J. Michel, C.B. Henry, and B. Benggio. 1994b. *Assessment of risks associated with the shipment and transfer of Group V fuel oils*. HAZMAT Report 94-8. Seattle: Hazardous Materials Response and Assessment Division, NOAA. 30 pp.

This is a concise summary of chemical and physical properties of Group V oils and response considerations for spills involving these substances. It includes case histories of prior spills and resources at risk information for future spills. The incidents covered are the *Sansinena*, *Mobiloil*, *MCN-5*, *Bouchard B-155*, and *Morris J. Berman*. It is specifically geared toward Group V fuel oils but can be used for any Group V oils.

Scott, J.G. 1983. Development and evaluation of viscous oil recovery equipment. *Spill Technology Newsletter* 8: 28-35.

This paper reviews the development of equipment for the recovery of viscous oils from the water in spill situations. It also evaluates the effectiveness of this equipment. The specific gravity of the emulsion tested was .995. Both test tank and sea trials were done using two prototype skimming modules. The trials proved the ability of these devices to recover viscous oil and water-in-oil emulsions from the water surface.

Seakem Oceanography Limited. 1986. *Oceanographic conditions suitable for the sinking of oil*. Report EPS 3/SP/2. Ottawa, Ontario: Environment Canada. 170 pp.

A comprehensive summary of conditions under which oil can sink. The report was developed using oceanographic conditions present in different areas of Canada, but can be used as a general reference to identify conditions that encourage the sinking behavior of oil. The report divides oils into three categories: very dense, neutral, and less dense and gives examples of previous events where oil sank or was reported to do so.

Smedley, J.B. and R.C. Belore. 1991. *Review of possible technologies for the detection and tracking of submerged oil*. TP 10787E. Montreal, Quebec: Transport Development Centre, Transport Canada. 97 pp.

This report is a review of technology potentially applicable to the detection and tracking of submerged oil. Conditions conducive to the submergence of oil are discussed along with the various technologies available and their potential application to the problem. A proposed shipboard system design and a field trial program are included. The ultimate goal of this report is to lead to the eventual development of an operational system.

Smithsonian Institution Center for Short-Lived Phenomena. 1972. *San Francisco Bay oil spill. Annual Report 1971*. Cambridge, MA: Smithsonian Institution Center for Short-Lived Phenomena. pp 159-160.

This is a short report on the initial information available on the Bunker C oil spill resulting from the collision of the *Arizona Standard* and the *Oregon Standard* in San Francisco Bay on January 18, 1971.

Sommerville, M. *Observations of the behaviour of Orimulsion® released into the sea*. CR 3361. Stevenage, Hertfordshire, England: Warren Springs Laboratory. 7 pp.

Summary of observations of Orimulsion® behavior testing once it is spilled into the water. Results were inconclusive in that the behavior of the bitumen in the Orimulsion® is dependent on several factors including salinity, currents, wind speed, and the size of the spill. It is surmised that viscous oil recovery equipment would be effective in recovering spilled Orimulsion® but mention is also made that it could be very difficult to then clean the equipment used. Evidence was also present that Orimulsion® does not all disperse into the water column, but some resurfaces to form an "intractable bitumen material" that is a definite response issue.

Soule, D.F. and M. Oguri. 1978. The impact of the *Sansinena* explosion and Bunker C spill on the marine environment of outer Los Angeles Harbor. *Marine studies of San Pedro Bay, California part 15*. Los Angeles: Allan Hancock Foundation and the Office of Sea Grant Programs, University of Southern California. 258 pp.

A very good in-depth report of the *Sansinena* explosion, fire, and subsequent oil spill in Los Angeles harbor in December 1976. It goes into detail of the physical and biological effects and reviews effects of other Bunker C incidents. The *Sansinena* incident involved very large amounts of submerged oil that persisted for well over a year following the spill.

Soule, D.F., M.K. Wicksten, J.K. Dawson, M. Oguri, C.R. Feldmeth, and J.D. Soule. 1978. The impact of the *Sansinena* explosion and Bunker C spill on the marine environment. *Proceedings of the Conference on Assessment of Ecological Impacts of Oil Spills, 14-17 June 1978*, Keystone, CO: 393-443.

This is a comprehensive summary of some of the perceived effects of the *Sansinena* explosion, fire, and oil spill on the marine environment in Los Angeles Harbor. Fortunately, the area had been surveyed just two weeks prior to this incident as well as monthly, quarterly, or yearly, depending on the area, for years previous. The report mentions submerged oil patches that were still present one year after the initial spill despite efforts to clean up the sea bottom

Spaulding, M.L., A. Odulo, and V.S. Kolluru. 1992. A hybrid model to predict the entrainment and subsurface transport of oil. *Proceedings of the 15th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 10-12, 1992, Edmonton, Alberta, Ottawa, Ontario*: Environment Canada. pp 67-92.

This paper discusses development of a model for the prediction of entrainment of surface oil into the water column and the subsurface transport of oil. It uses previous

events and tests for data, but has no data on real-time usage and/or the effectiveness of the predictions in these situations.

Stanton, E.M.. 1995. Operational considerations: Tank Barge *Morris J. Berman* spill. *Proceedings of the 1995 International Oil Spill Conference, February 27-March 2, 1995, Long Beach, CA, Washington, D.C.:* API. pp 707-710.

This paper talks about the various types of operations, and the considerations involved in each, during the response to the *Morris J. Berman* spill in Puerto Rico in January 1994. It mentions the submerged oil recovery operations but does not give details.

Suzuki, I. and K. Miki. 1987. Research and development of oil spill control devices for use in cold climates in Japan. *Proceedings of the 1987 International Oil Spill Conference, April 6-9, 1987, Baltimore, MD, Washington, D.C.:* API. pp 349-358.

Review of research and development studies in Japan on various aspects of oil spill response, including evaporation of oil, skimmer effectiveness, portable oil booms, and trawl nets for recovery of submerged oil. The nets were tested in a circulating water channel using emulsified Bunker C oil with a specific gravity of .95 that was then mixed with sand to increase the gravity to 1.03. The nets seemed to be able to recover the viscous oil from beneath the water surface.

Suzuki, I. 1985. The trawling system for the recovery of oils sunk below the water surface. *Proceedings of the 8th Annual Arctic Marine Oil spill Program Technical Seminar, June 18-20, 1985, Edmonton, Alberta:* 157-165.

Review of the recovery of submerged oil using nets study referenced in the above paper. To summarize, the nets were tested using a Bunker C emulsion with a specific gravity of .95 that sand was added to bring the gravity up to 1.03. The viscous result sank below the water surface and the nets were tested with the result being that the nets picked up the oil. However, this system is dependent on the physical properties of the oil that has sunk, the relation between mesh and oil properties, and the scale effect of the net.

Taylor, E., E.H. Owens, and A.B. Nordvik. 1994. A review of mechanical beach-cleaning machines. *Proceedings of the 17th Arctic and Marine Oil Spill Program Technical Seminar, June 8-10, 1994, Vancouver, British Columbia, Volume 1:* Ottawa, Ontario. Environment Canada. pp. 621-633.

A review of mechanical beach cleaning machines for use in oil spill response. This review includes mechanical cleaners and washers, washing/flood systems, and vacuum/suction. This is a summary of a much larger report and database compiled by MSRC on this subject. Generally, it was found that many machines could effectively clean solid substrates and sand shorelines but few are effective on cobble, pebble, or mud substrates. The review also found the shoreline substrate and oil viscosity to be vitally important to equipment performance.

Teal, J.M., J.W. Farrington, K.A. Burns, J.J. Stegeman, B.W. Tripp, B. Woodin, and C. Phinney. 1992. The West Falmouth oil spill after 20 years: fate of fuel oil compounds and effects on animals. *Marine Pollution Bulletin* 24: 607-614.

A paper summarizing results of a study of the barge *Florida* oil spill near West Falmouth, Massachusetts in September 1969. Sediments were sampled 20 years after the spill to determine what the long-term effects, if any, were.

Teas, H.J., R.R. Lessard, G.P. Canevari, C.D. Brown, and R. Glenn. 1993. Saving oiled mangroves using a new non-dispersing shoreline cleaner. *Proceedings of the 1993 International Oil Spill Conference, March 29-April 1, 1993, Tampa, FL, Washington, D.C.:* API. pp 147-151.

Evaluates the effectiveness of Corexit 9580 as a cleaning substance for oiled mangroves. Tests involving the oiling of mangroves with Bunker C oil showed much better results, with less toxicity, for mangroves cleaned with Corexit rather than washed with seawater.

Tripaldi, G. 1993. VLCC *Haven* accident: emergency and recovery operations. *Proceedings of the 1993 Oil Spill Conference, March 29-April 1, 1993, Tampa, FL, Washington, D.C.:* API. pp 185-192 (withdrawn).

This is one of two papers withdrawn from the proceedings of the 1993 Oil Spill Conference. Permission of the author was received for inclusion in this report. The paper covers the response to the *Haven* explosion and oil spill in the Mediterranean Sea off Genoa, Italy in April 1991. Included are exceptional color photographs of the ship on fire as well as aerial views clearly showing submerged oil patches caused by the sinking of the residue of the burned oil.

Tripaldi, G., C. Morucci, and E. Amato. VLCC *Haven*: the biological monitoring program. *Proceedings of the 1993 Oil Spill Conference, March 29-April 1, 1993, Tampa, FL, Washington, D.C.:* API. pp 239-244 (withdrawn).

This is one of two papers withdrawn from the proceedings of the 1993 Oil Spill Conference. Permission of the author was received for inclusion in this report. The paper covers the biological monitoring program following the *Haven* explosion and oil spill in the Mediterranean Sea off Genoa, Italy in April 1991. It describes the extent of sea-bottom pollution from submerged oil patches from the burned oil residue that sank following the fire.

Tsocalis, E.A., T.W. Kowenhoven, and A.N. Perakis. 1994. A survey of classical and new response methods for marine oil spill cleanup. *Marine Technology* 31: 79-93

A comprehensive review of what has been done, what has worked, and what has not in the realm of oil spill response as well as the new technology and the prognosis for the future. Contains a paragraph about the use of netting to recover viscous oils that the authors list as being studied and tested.

Turbini, W., E. Fresi, and F. Bambacigno. 1993. The *Haven* incident: lessons learned with particular reference to environmental damages. *Proceedings of the 1993 Oil Spill Conference, March 29-April 1, 1993, Tampa, FL, Washington, D.C.:* API. pp 179-183.

A "lessons learned" review of the response to the *Haven* explosion, fire, and oil spill off Genoa, Italy in April 1991. The author makes mention of the submerged oil issues but does not talk about what was done, other than to say there are still patches of oil on the bottom. The author states that it was fortunate the oil went to the bottom rather than washing up on the beach.

Uchida, S., H. Takeshita, and Y. Seike. 1977. Development of oil spill recovery ship. *Proceedings of the 1977 Oil Spill Conference, March 8-10, 1977, New Orleans, LA, Washington, D.C.: API.* pp 367-374.

This paper describes the design and testing of an oil-spill recovery vessel capable of recovering heavy oil. The heavy oil is not well defined, other than a short reference to the viscosity of the oil with no mention made of either specific gravity or API gravity.

Van Den Berg, G. 1992. NOAA Response Report: M/B *Vesta Bella*. *Oil and Hazardous Materials Response Reports, October 1990 - September 1991.* Seattle: Hazardous Materials Response Branch, NOAA. pp 46-52.

This is the NOAA SSC summary report for the barge *Vesta Bella* sinking and oil spill near Barbuba, Trinidad in March 1991. This report summarizes NOAA activities and observations at the scene.

van Oudenhoven, J.A.C.M. 1983. The Hasbah 6 (Saudi Arabia) blowout: the effects of an international oil spill as experienced in Qatar. *Proceedings of the 1983 Oil Spill Conference, February 28-March 3, 1983, San Antonio, TX:* 381-388.

A paper describing the Hasbah 6 well blowout of October 1980 and the experiences from it as felt in Qatar. This incident had reports of subsurface oil and fish netting was used in some instances to recover submerged oil patches.

Vandermeulen, J.H. and D.E. Buckley (eds.). 1985. *The Kurdistan oil spill of March 16-17, 1979: activities and observations of the Bedford Institute of Oceanography response team.* Canadian Technical Report of Hydrography and Ocean Sciences No. 35. Dartmouth, Nova Scotia: Fisheries and Oceans Canada. 187 pp.

Report summarizing the response activities and personal observations of the Bedford Institute of Oceanography response team during the *Kurdistan* hull failure and oil spill in Cabot Strait, Nova Scotia, Canada. Several observations are made of oil appearing from nowhere to oil and reoil beaches. In these cases, no previous observation of the oil was made prior to the oiling incident.

Wang, Z. and M. Fingas. 1996. Separation and characterization of petroleum hydrocarbons and surfactant in Orimulsion® dispersion samples. *Proceedings of the 19th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 12-14, 1996, Calgary, Alberta, Ottawa, Ontario:* Environment Canada. pp 115-135.

Paper reports the results of separation and characterization tests performed on Orimulsion® and its surfactant in Orimulsion® dispersion samples.

White, W.W. and J.T. Kopeck. 1979. Oil spill control and abatement techniques used at the SS *Sansinena* explosion site: a Coast Guard perspective. *Proceedings of the 1979 Oil Spill Conference, March 19-22, 1979, Los Angeles, CA, Washington, D.C.:* API. pp 435-434 (printing error).

A summary of techniques used in response to the *Sansinena* explosion, fire, and subsequent spill in Los Angeles Harbor in December 1976. This article mentions the API gravity of the bunker to have been measured at 7.9, which would mean a specific gravity of approximately 1.015. The author states the oil was heavier than water, so it sank. Diving surveys of the bottom area found oil patches up to nine feet deep.

Wilson, D., Y.C. Poon, and D. Mackay. 1986. *An exploratory study of the buoyancy behavior of weathered oils in water.* EE-85. Ottawa, Ontario: Environment Canada. 50 pp.

A study, using a glass-walled tank, of the behavior of weathered oil in water concluding that large quantities of oil can be submerged in the water column just below the water surface. It also gives conditions under which this phenomenon can continue for extended periods.

Wiltshire, G.A. and L. Corcoran. 1991. Response to the *Presidente Rivera* major oil spill, Delaware River. *Proceedings of the 1991 Oil Spill Conference, March 4-7, 1991, San Diego, CA:* 253-258.

Summary of response efforts after the *Presidente Rivera* grounding in the Delaware River in June 1989. More than 300,000 gallons of #6 fuel oil were released into the river. The specific gravity of the oil was reported as .95, which would be an API gravity of approximately 17.9. This oil was a "high-pour" with a pour point of 96 degrees while the water temperature was 72 degrees. The initial booming failed to hold the oil due to entrainment. There were also problems with the eddies in the area causing the oil to sink briefly at times, which made tracking difficult. The consistency of the oil required the use of the OWOCRS system, in conjunction with a dredging/hopper barge system, for cleanup.

Yaroch, G.N. and G.A. Reiter. 1989. The Tank Barge *MCN-5*: lessons in salvage and response. *Proceedings of the 1989 Oil Spill Conference, February 13-16, 1989, San Antonio, TX, Washington, D.C.:* API. pp 87-90.

Paper describing response efforts after the capsizing and sinking of the barge *MCN-5* in the Guemes Channel area of Puget Sound, Washington. The barge sank with 9,800 barrels of heavy cycle gas oil (HCGO) onboard, which has a specific gravity of 1.086. Subsequently, 2,177 barrels of the HCGO were released and stayed on the bottom before the barge could be raised. This oil was dispersed by the currents in the area.

