Utilization of Automated Oil Spill Detection Technology for Clean Water Compliance and Spill Discharge Prevention

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AUTOMATED SPILL ALARM FOR CLEAN WATER COMPLIANCE & DISCHARRGE PREVENTION

ABSTRACT: This paper discusses the development of an oil spill detection and alarm system that provides industry with a reliable, cost-saving mechanism for containing and/or preventing accidental discharges of hydrocarbon-based pollutants.

By utilizing an automated spill detection system, hydrocarbon releases are detected in real-time (analogous to a 'smoke alarm' for oil spills). Early warning and automated response capabilities allow containment of pollution before the environment, wildlife, public waterways, or commercial assets are damaged. This technology provides a new weapon in the pollution prevention arsenal, offering HSE personnel a critical compliance tool in accordance with NPDES, SPCC, and other regulations stipulating spill prevention, planning and response.

This paper details: 1) Development of a reliable, economical, optical, non contact, hydrocarbon pollution detection sensor, the "Slick Sleuth", 2) Performance results drawn from an array of performance tests and real-world deployments, 3) A variety of existing applications and deployment opportunities for which this new technology has proven to provide a reliable, easy-to-use tool for regulatory compliance and realization of cost benefits associated with minimizing spill risk(s).

Design features have evolved to reflect feedback from existing industrial users, as well as input from environmental consultants and regulatory agencies. These key system attributes include: 1) Near-zero maintenance, 2) Micron- level sensitivity for a comprehensive range of oils (from crude-oil to jet-A), and 3) Sensor/system flexibility and adaptability for a wide range of installation settings and application requirements.

Finally we describe how any entity that produces, stores, uses, or transports hydrocarbons, can best employ the detection sensor/alarm to realize cost-benefits, strengthen compliance, and eliminate the expense, environmental damage, and bad publicity inherent with any spill.

I. INTRODUCTION

Oil spills are a global concern and worldwide dependence on fossil fuels and oil derivative products are at historic highs for production, transportation, storage, and consumption. At the same time major offshore spills occasion headline-grabbing attention, while attention is intensifying with respect to oil and petrochemical spills [accidentally] discharged from inland and shore-side sources to inland waterways and along coastlines. In fact statistically, spills to freshwater and inland waterways result in comparable or greater damage than do marine spills [1], but have typically drawn less public attention. It's become evident to us that both offshore and onshore spills are of growing public concern, however innovation of the new methodologies and technologies necessary to protect ourselves and the environment from these sources of oil pollution are being severely outpaced by the growth, demand, and omnipresence of oil. With these premises in mind, the following describes our success in developing and introducing new sensor technology for the prevention, detection, and early warning/containment of oil spills. Our focus is on inshore and freshwater spills, with emphasis on industrial applications. We also examine inland and coastal waterway applications, as well as potential offshore uses.

This paper describes a rugged reliable spill detector that has been field-proven, complies with the US EPA's standard test procedure for evaluating leak detection methods, and is in the process of being patented. Details are provided regarding the scientific principle upon which the sensor is based (theory of operation), the sensor development process over the past few years, numerous applications for which this type of new sensor technology is optimally suited, and discussion of how this new sensor technology may be used to greatest advantage by different industrial entities (best uses and management practices) in a wide variety of applications and environments.

Prevention and early containment of spills benefits everyone: the public at large, stakeholders of watersheds and waterways, business interests (spills are expensive), the ecology of natural habitats, and the environment as a whole. Spill prevention through remote detection provides a proverbial "win-win" solution and, when implemented, greatly reduces the risk of significant spills and substantial harm. This practice is now validated by companies already using this new technology, who are demonstrating that real-time spill detection offers a powerful new tool for preventing and containing spills that would otherwise go undetected.

II. GOALS

In developing an oil spill detection sensor, our goal was to create an early detection mechanism for spills or discharges, accidental or deliberate, for both freshwater and marine environments. Since its inception, the scope of the sensor's design has evolved to address an ever-widening range of applications and system features. However, the fundamental sensor attributes we listed as goals at the outset remain at the core of the design: 1) reliable detection of oil sheens and slicks on water surfaces, 2) non-contact sensor design, facilitating highly-sensitive oil detection without the instrument contacting the target water/effluent, 3) impervious to environmental conditions, 4) remote & autonomous operation, 5) operable in excess of 5-meter range above fluid surface, 6) adaptable and scaleable, 7) easy to install and operate, and 8) a commercially viable, economical, low maintenance sensor package.

III. PRINCIPLE OF DETECTION

Oils are known to fluoresce, and the oil detection sensor we've developed detects the presence of oil by exciting and measuring fluorescence. Fluorescence is an optical phenomenon in which a compound absorbs light at one wavelength and emits it at a longer wavelength [2]. When fluorescent compounds are excited, some of the energy is absorbed through the excitation of electrons to higher energy states. Once the light source is removed the excited electrons fall back to their ground state, giving off light in the process. This process is very similar to what makes glow-in-the-dark materials possible, except it takes place in a much shorter time period. Because some energy is lost as heat in the absorption-emission process, the wavelength of the emitted light is always longer than the wavelength of the absorbed light. Typically the absorbed light is in the ultraviolet range and the emitted light is in the visible range. For example, oils typically absorb light between 300 and 400nm, and emit light in the 450 to 650nm range.

Fluorescence detection, or fluorometry, is by no means new technology in and of itself. Typically, fluorometers use spectroscopy methods for fluorescence detection in the form of flow-through or in-water systems. Often these comprise sophisticated lab-quality instruments, used either for scientific research or as in-line water analyzers, and as such tend to be prohibitively expensive and impractical for use as remotely deployed field units or in networked arrays. The flow-through technique is susceptible to bio fouling and oil staining on the sampling tube/mechanism and thus requires significant attention and ongoing maintenance. In-water sensors are of course subject to bio-fouling and troublesome installation and maintenance issues. By contrast, the design of this new spill detection sensor, while based on the same fluorometric principles, is a downward looking, non-contact, optical sensor, which is installed up to five meters above the target liquid surface and is free of these high-maintenance fouling effects and deployment limitations.

Within this sensor, a high power Xenon lamp is used to produce a high-energy light beam. This light is then filtered and sharply focused into a conical beam so only desired wavelengths of light are projected onto the target area. Any oil present in the target area will fluoresce and subsequently emit light of its characteristic wavelengths. This light is then processed by the sensor's proprietary scanning optics and digital signal processing system, which detects the fluorescence characteristic of oil.

The sensor's detection of oil is predicated upon differential measurement, meaning it is based on anomalous signal return within a target area when oil is present. Normal ambient conditions constitute the baseline reading or 'zero point', and a sensor state of "no oil detected". If oil is present, the signal return is greater than normal ambient conditions, triggering detection and an "oil detected" alarm state. If oil is present in varying amounts, the signal return is proportional to the amount of oil, or PAH/aromatic constituents, detected within the 'viewing' or sampling area.

IV. DEVELOPMENT

Using the basic physical principles of fluorometry, and the list of sensor attributes and objectives, we began the developmental stage by studying the physical characteristics of oil and conducting laboratory experimentation with various light sources, optics, and detectors. We focused our efforts on oils and petroleum-based fluids, commonly referred to as PAH (Poly Aromatic Hydrocarbons) and BTEX compounds (Benzene, Toluene, Ethylene, Xylene), that are either statistically most prevalent, or deemed of greatest concern by the industry (end users) and government experts with whom we consulted. These include but are not limited to: crude, heavy fuel oil (e.g. “Bunker C”), lube oil, motor oil, hydraulic oil, turbine oil, diesel, jet fuel, naphtha, kerosene, mineral oil, various process oils, etc. We’ve also examined numerous food oils such as soybean, corn, and olive.

It is important to note that different brands or types of oil within these major ‘classifications’ (e.g. “diesel fuel-oil”) originate from many different sources, contain various additives, and consist of differing concentrations and compositions. From product to product within a given class of oils there is inherent variability in fluorometric characteristics and how the oil/pollutants will respond or ‘appear’ to the detector when excited with UV light. Rather than expending effort trying to analyze and classify small differences or degrees of variability, our primary focus was given to developing and testing a field sensor that qualifies the presence of a wide range of oils with high reliability.

For purposes of this paper, results are limited to the specific oils tested within the given set of conditions. We do find, however, that results gained from testing specific products against the detector can be used to successfully predict or infer successful detection of ‘related’ oils, regardless of slight variations from product to product. Moreover, for users interested in ‘detectability’ of particular oil(s) of concern, it has become a common exercise to test samples of oil against detectors in the lab, or on site in the field, to verify high probability of detection and to characterize and document detector proficiency for specific oil-based product(s).

Figure 2 illustrates one of our initial characterizations of oils when exposed to a broadband UV light source. The results are from tests performed during the development of the instrument. The tests were conducted using a laboratory light source and receptor, and while we have repeated this test with differing equipment and intent many times since, these results exhibit a representative estimate or benchmark for various oils’ fluorescence in the spectrum when irradiated with a UV light source. For reference, M. Fingas and C. Brown address a more thorough treatment of this topic in their paper entitled “Review of Oil Spill Remote Sensing” [3].

As the result of laboratory experimentation during initial development, a high-powered Xenon strobe was selected for the sensor’s integral light source, and was coupled with a suitable power supply. This same flash and power supply has proven to be highly effective throughout the sensor’s evolution. A key criterion for developing the flash assembly was enough output intensity to enable detection of small surface sheens from a distance of 5 meters above the target surface area. Presently this 5 meter limit is the approximate upper boundary for reliable detection; however ongoing tests confirm that this detection range may be increased in the near future.

Other critical components required for the output/optical subassembly are the parabolic reflector, which focuses/collimates the conical beam onto target area below, and band pass filters, which limit the energy output to the desired spectral range. Each of these components have been integrated, tested, and optimized based on extensive performance testing.

Similar to the development of the sensor’s optical subsystem, a proprietary set of photo detectors have been tested and integrated to provide the necessary receptor attributes that allow for accurate measurement of the presence of oil, based upon performance testing and field trials.

These subassemblies, along with requisite electronics and microprocessor, are compactly integrated within a stainless steel weatherproof enclosure (roughly 10x12x14 inches). The housing is also fitted with valve fittings and a vent, so that an air-purge system may be added to satisfy installation requirements in Class I Division II hazardous locations, such as are common in refineries and terminals. Subsequent sensor integration into an explosion-proof housing for use in Class I Division I environments is now nearing completion.

The initial system was designed for use with alternating current (AC) power, then later modified for operation with an integrated DC power source (e.g. batteries and solar panels) to facilitate deployments in remote settings. For installation convenience and other practical reasons (such as size and mitigation of electro-magnetic interference), the DC power system is now housed in a separate weatherproof enclosure that is collocated with the sensor, or installed away from the sensor to gain optimal exposure to sunlight for solar recharge. Similarly, when wireless communication is used (e.g. spread spectrum radio, satellite, cellular), the communications package is housed with the DC power supply and may be installed for optimal orientation.

Initial prototypes communicated using a basic RS232 protocol and a terminal program such as Windows Hyper Terminal. Typical field applications have since required us to add RS485 capability, as well as analog outputs such as 4-20mA and/or simple dry contact relays (switch closures) for integration with industrial process control systems. The detector's relay outputs may also be wired directly to controllers for uses such as actuating a valve, shutting off a pump, and/or activating audio/visual alarms whenever a spill is detected.

Wireless communication is required for many remote-monitoring applications. The automated detector has been designed to output compatible data, digital or analog, for use with any type of wireless telemetry (radio, cellular, or satellite) for real-time spill monitoring.

During the development period, InterOcean successfully completed proof-of-concept and prototype testing, conducted extensive lab- and field-testing (see Figures 3 and 4), and built first and second-generation production units that incorporated upgrades based on experience gained from real world installations and users. Critical (and much appreciated) feedback was gained from consultation with early customers such as Shell Oil (refinery applications) and Dominion Transmission (remote compressor station applications). They deserve credit for being on the leading edge in their respective industries, successfully implementing this new spill prevention and alert technology.

V. SENSOR PERFORMANCE: RESULTS & LESSONS LEARNED

Many problem-solving opportunities arose during the development process. One of the obvious challenges with an optical sensor is that it must have a clear 'view' of the area to be sampled. If the optical path is blocked, the detector is effectively rendered 'blind'. During testing and field experience we learned that the light beam is unaffected by light haze, smog or fog, but as a rule of thumb if the path interference is too thick for the human eye to see through, it will also affect optical sensor performance. For example we conducted a test using a large chunk of dry ice and tub of water with oil sheen. In this extreme scenario, a visually impenetrable fog was generated, which effectively prevented the sensor from being able to detect the oil sheen below. However this scenario has not existed or been presented as a problem in any existing field installations.

Partial path interference (physical blockage) does not necessarily disable the sensor's ability to monitor and detect oil. For example, in the photograph shown in Figure 5, the sensor is installed such that it is peering through a metal grate into a containment sump below. Although signal return is attenuated about thirty percent in this example (vis a' vis the grates partial blockage/impassability), the signal to noise ratio remains the same as with no grate. That is to say the 30% overall signal loss has no adverse affect on the detector's ability to reliably differentiate between clean and oil-polluted water beneath the grate. A number of users have taken advantage of this capability, while others have simply cut a small window for the sensor to ‘peer’ through in grated-sump applications (refer to Figure 7, below).

While the sensor needs to be mounted roughly perpendicular to the surface below, we have learned that there is a tilt tolerance of about 15°, which helps a great deal with certain applications such as buoy-based installations.

Naturally one of the biggest fears for sensor operators is false detection, and there are a few other substances that do fluoresce in a manner similar to petroleum-based fluids. For example, white paper and white fabrics can trigger a false positive (much as a white t-shirt glows under black light). Fortunately items that may cause false detection are few, and are not prevalent in typical installation environments. In the case of some non-oil substances known to fluoresce, for example fluids containing fluorescing rust inhibitors, varying the detector configuration can eliminate the possibility of a false positive. More common wildlife and debris such as birds, algae, seaweed, sea foam, driftwood, and plastic bags have not been problematic sources of false detection, and to date we have received no reports of any natural phenomenon causing false detection from users with sensors in field operation. Nor have ambient conditions such as sunlight, waves, or water currents been shown to have any adverse affect on detector reliability.

During installation and setup, taking a “baseline” measurement initializes the sensor. This measurement is internally recorded, and is used to establish normal operating conditions (either with clean water, or with a normal level of oily sheen or other chemicals/materials typically present).

As previously mentioned, this quick one-time process establishes the zero point or background level in order to account for ambient conditions, and to provide a baseline that contrasts with anomalous events, which are indicative of oil. Varying water level, such as tide or stormwater, causes this ambient baseline to shift up or down as water periodically rises and falls. In order to account for and cancel out this background shift (in applications where applicable), a feature called “adaptive baseline” is enabled. For example, in a cyclical tidal setting, or in applications where stormwater surge may occur, the adaptive baseline is utilized to normalize the effect.

An unexpected success of the sensor has been its ability to detect emulsified oils. For example, a prospective user was interested in evaluating the sensor’s ability to detect small concentrations of emulsified oil (an interest recently promulgated by a costly pollution incident). They were particularly concerned with the sensor’s ability to detect emulsified oil at a concentration of 0.1%, as this was the concentration of oil which had occurred during the accidental pollution discharge. The customer provided us with samples of various oils, which emulsified almost instantly when added to water. In testing the samples, the sensor easily detected each of the emulsified oils at a concentration of less than 0.1%, and was able to reliably detect one of the emulsified lubricants at a concentration of only 0.001%.

At the prototype stage the sensor was programmed to sample every 30 seconds, based upon preliminary user requirements. This proved to be impractical for installations where water was moving rapidly enough to transport broken spills past the sensor without detection. To overcome this we have since increased the sampling rate and conducted extensive tests using a flume (approx. 7 ft./minute flow rate). Based on our testing results, the sensor is now user-programmable for two higher sampling rate options. For “continuous” sampling a 2 Hz sampling mode is used. In this sampling mode the strobe is fired twice each second and the monitor outputs a value for each sample. Alternatively there is a 5-second sampling mode, in which the strobe takes a burst sample (typically 10 samples at 100msec intervals) once every 5 seconds, and the value output is an average of the periodic burst sample. Similarly the detector can be programmed to sample less frequently, as appropriate.

Another adaptation has been the development of a simple software utility program with which users interface with the detector. Use of the utility program is only necessary during initialization, to change monitoring parameters, or during troubleshooting. The simple point and click GUI allows users to adjust settings for sampling interval, flash rate, baseline measurement, detection offset/threshold, adaptive baseline, operating modes, logging features, etc.

VI. APPLICATIONS

Initial development of this oil spill detection system was based on the perception that spill monitors would be of utility in the coastal/marine environment, and in ports & harbor settings. For example single units or sensor networks could be strategically placed to monitor fuel piers and bunkering facilities, marine terminals, shipyards, naval installations, marinas, stormwater culverts/outfalls, etc., throughout a port. After extensive interaction with users and stakeholders, we now know that these do in fact constitute excellent applications for which these sensors are extremely well suited (reference Figure 9, Royal Australian Navy's marine terminal fuel pier installation). The range of applications we hadn't fully anticipated, but now know to be substantial, are in the realm of freshwater and inland waterways, particularly at or near petrochemical and industrial facilities. End users in this sector include: refineries, terminals, tank farms, power plants, paper and steel mills, heavy industry/manufacturing, water treatment plants, food oil plants, and more. Figures 5, 6, 7 and 8 exemplify typical installations in these sectors. Basically any facility that stores, processes and/or utilizes large quantities of oil is (or should be) concerned with real time detection. As such these entities and their key personnel are motivated to make use of "best available technologies" (BATs) and "best Management Practices" (BMPs) for early warning and containment of spills.

There is an immediate need at such plants and facilities to protect against spills going undetected and escaping into the environment. In part this need is driven by requirements for 'oil-centric' facilities to update their Spill Prevention Control and Countermeasure (SPCC) plans, as mandated by CFR, and overseen by the US EPA. For example, this type of sensor can be utilized in support of conformance with regulations listed in sections of CFR parts 112.7(a), 112.8(b), and 112.8(c) [4]. Detectors may also be used to augment an entity's strategy to meet their NPDES permit requirements and similar regulatory requirements, both local and international. Additional motivation can be attributed to the fact that spills are costly due to expensive cleanup, mitigation, fines, and bad publicity (there's motivation in not wanting to become tomorrow's headlines!). Thus there is ample justification for utilizing the early warning detection and alarm capabilities an oil spill sensor provides, to prevent or contain a spill before it becomes a disastrous event.

In addition to spill monitoring deployments along coasts and in ports & harbors, or installing spill alarms as safeguards along industrial spillways, a third major application is envisioned for remote spill detection sensors: protection of sensitive wildlife habitats and/or aquaculture/fish farms. In this scenario detector(s) are installed beyond or at the perimeter of a sensitive habitat such as an estuary, wetlands, bird sanctuary, or shellfish bed. If a spill encroaches upon the boundary of a protected area, on an incoming tide for example, the remote spill detector will alert designated personnel for immediate response. This will trigger the appropriate planned contingency response action in time to avert catastrophic damage and casualties to wildlife and natural resources.

In this scenario spill detectors could be incorporated into the areas contingency plan (such as the ACPs that exist for many designated sensitive areas in California), to provide the early warning defense mechanism that is needed, but currently does not exist. As part of a given contingency plan, designated spill responders will receive a spill alert in near real time, allowing them to deploy pre-positioned booms, or implement pre-planned *time-critical* response activities, to protect sensitive habitat such as eelgrass and nesting areas that might otherwise be devastated. Strategic locations for sensor placement can be based on vulnerability analysis or environmental sensitivity index maps. Sensors are also a natural fit and are easily integrated into GIS-based monitoring and response systems, which are of increasing utility for habitat protection, resource monitoring, and contingency planning.

VII. CONCLUSION

The principle of detection upon which this sensor is based is not new science; however, the methodology and application of this technology in this sensor package is new. In meeting our design goals, and having successfully produced a non-contact spill detection system, we feel optimistic and reassured that this mechanism will prove invaluable in each of the applications discussed. And of course our work is not done…

Planned improvements for this system include continued refinement of the optics, increased signal to noise ratio, and increased detection range. Further to these system improvements, we anticipate adapting the current design for additional applications such as those in the offshore (eg. production platform) environment, and in the habitat protection scenario suggested above. Additional applications are sure to arise, including a pending first-time installation on a series of offshore loading buoys, slated to become operational in Autumn 2006.

There has been interest expressed as well in the ability to quantify the concentration of oil detected, or maybe even identify the type of oil, using this sensor. When we set out to develop this sensor, our primary intent was to qualify the presence of oil; Yes or No, Green or Red; and to sound an alarm when trace oil is detected (Yes/Red!). As such the detector is designed to qualify when oil is present. However, having received requests for PPM measurement from several sources, we are working to develop a meaningful correlation to enable quantification output.

Milestones include our having certified these sensors to comply with EPA defined standards, requiring successful completion of the US EPA’s “Standard Test Procedures for Evaluating Leak Detection Methods”. Another significant milestone is our having now successfully supplied customers with more than fifty systems to date. Success with users in real-world applications is always a big step in the progression of developing and introducing new technology products. We now have the assurances of a growing user-base to reference, and market sectors to build upon, as knowledge and acceptance of this new technology spreads.

New product features will evolve and new applications will emerge as feedback from end users and regulators continue to drive our further development of this system. A key component going forward will be to increase awareness of the availability and benefits of this new sensor technology, and to encourage widespread use and adoption of remote spill alarms as a best management practice, and as an integral part of stakeholders’ spill prevention and response strategies. The future is now for utilization of new remote spill detection technology to aid in the prevention and early containment of oil spill pollution.

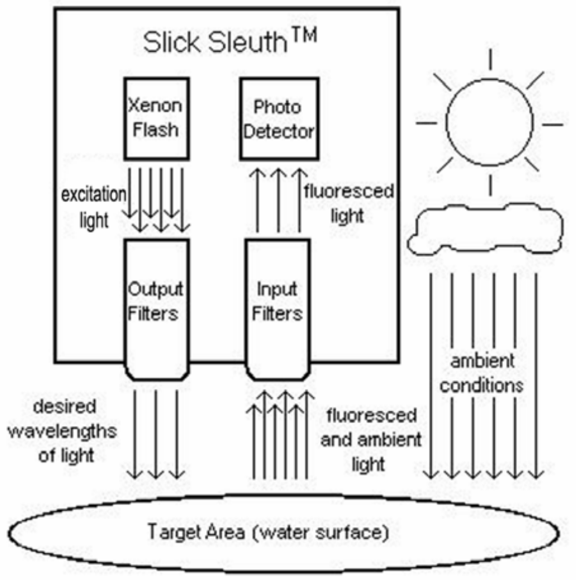

Figure 1. Basic operation of sensor.

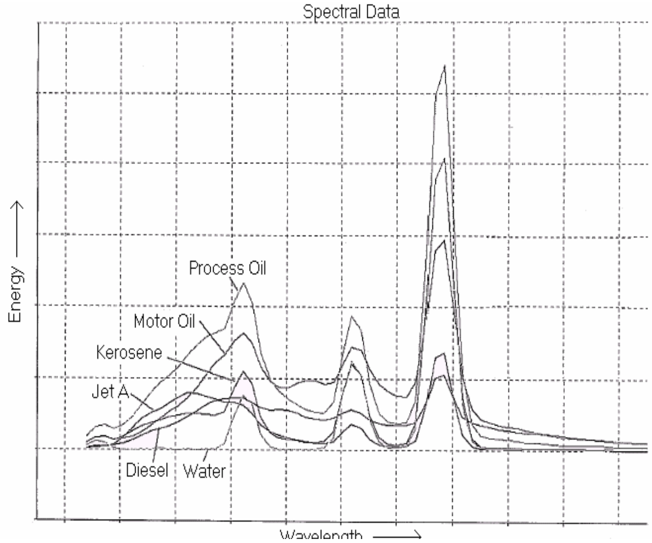

Figure 2. Relative fluorescence of various hydrocarbons

Figure 3. Prototype spill sensor. Installed near fuel pier (background).

Figure 4. Early production unit. DC/Solar power, radio telemetry.

Figure 5. Oil detector operating over stormwater sump. Real time output to nearby control center, and automated shutoff of sump pump.
Photo courtesy Dominion.

Figure 6. One of 5 units deployed at a Shell refinery (Australia) to monitor cooling water outfall channels. *Photo courtesy Shell.*

Figure 7. Unit deployed over deep sump at a GenCo in the USA. Automated control of sump pump discharge. *Photo courtesy Entergy.*

Figure 8. Discharge monitor installed at production facility in Ecuador.
Photo courtesy Occidental.

Figure 9. Slick Sleuth installed on fuel pier and marine terminal. Alarm output monitored using SMS messaging to key personnel. *Photo courtesy RAN.*

REFERENCES CITED

1. Etkin, D.S., “Analysis of Oil Spill Trends in the United States and Worldwide”, in Proceedings of the International Oil Spill Conference, pp. 1291-1300, (2001).

2. Bartman, G. and Fletcher, M., “UV Fluorescence for Monitoring Oil and Grease in Produced Water- Real Data from the Field”, Presented at the 12th Annual Produced Water Seminar, Houston, TX, (January 16, 2002).

3. Brown, C. and Fingas, M., “Review of Oil Spill Remote Sensing”, Presented at SpillCon 2000, Darwin, Australia, (August 16, 2000).

4. United States Federal Register. “Rules and Regulations”. Vol. 67, No. 137. (2002).

5. United States Environmental Protection Agency. “Understanding Oil Spills and Oil Spill Response; Understanding Oil Spill in Freshwater Environments” (ref pg. 28). (1999).