Evaluation of spill response equipment

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ABSTRACT

Associations, Companies, and laboratories annually undertake assessments on pollution response equipment and techniques. These assessments serve the crucial objectives of validating equipment compatibility with end-user specifications, exploring innovations, and addressing gaps in pollution control. The diverse array of tested equipment spans spill surveillance tools (detectors, tracking buoys…), at-sea response mechanisms (recovery chains, dispersion systems, drones…), and shoreline response tools (anchoring, cleanup devices…).

For example, in the framework of the “Evaluation of spill response equipment”, Cedre, which is a French association dedicated to addressing accidental water pollution, identifies and tests new or existing equipment that can fill the gaps or improve anti-pollution response. Engaging in collaboration with Cedre's partners, the selection of devices aligns precisely with their specific needs. Furthermore, equipment manufacturers have the opportunity to enlist Cedre for testing their oil spill response tools or any equipment applicable to oil spill detection or mitigation. Specifically tailored programs for the oil industry encompass comparative testing of various systems leveraging distinct technologies but serving a common purpose: punctual oil detection, identification of pipeline leakages, and multilayer sensors for gravimetric separators…

Three distinct types of tests form the cornerstone of the assessment approach: standardized tests, real-environment implementation tests, and customized tests crafted to address specific requirements. This paper introduces these testing methodologies through three experimental trials: a) standardized oil recovery system test, b) custom-made multilayer detection with probes test, and c) real-environment implementation test for fast current devices.

Conducted under conditions closely mirroring real-life scenarios, these tests empower end-users to make informed selections based on their unique requirements. Simultaneously, equipment manufacturers gain valuable insights into aligning their products with end-users' needs and iteratively enhancing their offerings.

INTRODUCTION

A profound understanding of the capabilities of spill response equipment is indispensable for defining effective response strategies. Initial insights may be derived from equipment data sheets or sales brochures, offering a broad overview of the equipment's applications. However, to ensure optimal performance, it is crucial to consider various parameters that may influence equipment effectiveness, such as pollutant characteristics, environmental factors, and specific technical conditions-information often not readily available (Cabioc'h et al., 2005; IMO, 2002).

To tackle these issues, three distinct test types tailored to different objectives are employed to assess oil spill response equipment: standardized tests, pollutant-free implementation tests in real environments, and custom-made tests designed to address specific needs:

1. Standardized Tests

The objective is to characterize or compare diverse equipment under standardized configurations based on established standards (BSEE, 2015; Cedre,2020; EMSA, 2016). These tests are conducted at the request of manufacturers or end-users, evaluating various products (sorbents, dispersants) or equipment (pumps, skimmers). For example, Cedre performs skimmer performance tests based on the NT T71-500 standard, assessing equipment effectiveness under controlled conditions with different oil types and thicknesses.

2. Implementation Tests

The objective is to simulate antipollution responses to highlight equipment benefits and limitations in specific environments or conditions. These tests are executed in diverse settings (harbors, areas with fast currents or marshes, rivers). For example, Cedre collaborated with partners to conduct trials in the Loire estuary, where currents often exceed 2 knots, to test equipment designed for high-current areas.

3. Custom-Made Tests

The objective is to demonstrate the equipment's capacity to address specific issues or challenges. In this objective, designed protocols and test setups are tailored to customer needs, addressing unique problems or showcasing device effectiveness in specific contexts. Tests can be conducted at Cedre's facilities, partner sites, or customer locations, with or without thirdparty involvement. For example, responding to an end user's request, Cedre conducted custom-made tests on four multilayer probes.

This article delves into three distinct test scenarios recently conducted by Cedre.

METHODS

Standardized test: Oil recovery system

Protocol

The evaluation of oil recovery systems hinges on adherence to the exacting French standard "NF T71-500, Equipment for Abatement of Water Pollution by Oil - Skimmers - Test Methods for Performance Assessment in a Controlled Environment" (AFNOR, 2023). This standard, crafted to ensure rigorous assessment, forms the backbone of Cedre's oil recovery system tests.

Comprehensive Performance Assessment

Cedre's testing regimen comprehensively assesses skimmer performance within a controlled environment, encompassing a spectrum of oil types, including light, heavy, and emulsified heavy oils with varying viscosities. The tests, designed in line with AFNOR standards, provide a robust evaluation of skimmers under diverse oil spill scenarios.

Oil Variants for Thorough Testing

For each test, two kinds of oil are used:

1. Pure Oil: The evaluation employs pure oil, featuring 2 or 3 oil types with distinct viscosities. This meticulous approach ensures that skimmer performance is tested across a range of oil compositions, mirroring real-world conditions.

2. Reverse Emulsions: The testing regimen extends to reverse emulsions, prepared on-site through the precise blending of seawater and oil type IV (see. Table 1). This dynamic testing scenario simulates the challenges posed by emulsified oils during spills.

Table 1. Reference petroleum products (AFNOR, 2023)

Category	Qualification	Viscosity
Category I	Very low viscosity	5 cSt to 10 cSt
Category II	Low viscosity	100 cSt to 300 cSt
Category III	Moderate viscosity	1 000 cSt to 3 000 cSt
Category IV	High viscosity	10 000 cSt to 30 000 cSt
Category V	Very high viscosity	50 000 cSt to 70 000 cSt

Cedre's commitment to precision is exemplified by the meticulous control of viscosity for each oil variant in its laboratory. Rigorous checks and balances ensure that the testing environment accurately mirrors the conditions experienced during actual oil spill events.

Measurement and results

Throughout the testing process, an array of key metrics is meticulously measured to provide a thorough evaluation of oil recovery systems. These metrics include the recovery rate, emulsification tendency, and selectivity, each contributing valuable insights into the system's performance under diverse spill conditions.

1. Recovery Rate Measurement

Throughout the assessment, close attention is given to the skimmer's recovery rate, a key parameter that significantly influences their performance. The recovery rate is calculated based on the collected mass, considering the distinct densities of oil and water. This essential metric provides a quantitative measure of the system's efficiency in retrieving oil from the water medium.

2. Emulsification Tendency Assessment

The propensity of the oil to emulsify, indicating the percentage of water present in the oil, is a critical parameter assessed during testing. This measure offers insights into the system's ability to handle emulsified oils, a common challenge in real-world spill scenarios.

3. Selectivity Analysis

The selectivity of the skimmer is discerned through careful analysis of collected samples. This process involves evaluating the skimmer's ability to selectively recover oil while minimizing water content, a crucial aspect of its overall efficiency. Selectivity, a pivotal aspect of the evaluation, is determined through in-depth analysis within Cedre's cutting-edge laboratory. Each sample undergoes a meticulous examination to ascertain:

- Free Water Quantity: The volume of free water present in the sample.
- Percentage of Water in Oil: This reveals the extent of oil emulsification, a crucial factor in spill response effectiveness.

The selectivity metric is derived by subtracting the change in water content and the quantity of free water from the overall collected volume. This nuanced calculation, illustrated in Figure 1, provides a comprehensive understanding of the system's selectivity performance.

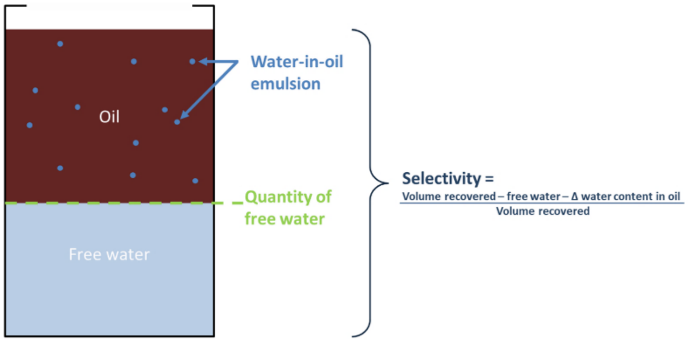

Figure 1. Selectivity measurement

4. Oil attractivity

The creation of a slick movement by the skimmer is observed qualitatively by the operators.

Material: Test Area Configuration

The evaluation unfolds in a carefully designed test area, encompassing specific components to ensure precision and reliability. The key elements of the test area include (Figure 2):

➊ Tested Skimmer. The skimmer under examination, representing the focal point of the assessment.

➋ Controlled Seawater-Filled Area. An expanse with a precisely known surface, pre-filled with seawater, serves as the receptacle into which the skimmer is strategically positioned. The discharged oil is carefully introduced into this area, characterized by a meticulously measured thickness.

➌ Discharge Pipe. A dedicated discharge pipe facilitates the seamless transfer of the recovered oil flow to a sample tank suspended on a precision weighing system.

➍ Weighing System (Sample Tank). A weighing system accompanies the sample tank, ensuring accurate measurement of the collected oil.

➎ Sampling Points. Discrete sampling points are strategically positioned to extract representative samples, contributing to the determination of the skimmer's selectivity.

Figure 2. Standardized tests: Oil recovery system. Test area. Example

Custom-made test: multilayer detection

Protocol

Responding to an end user's request, Cedre conducted custom-made tests on four multilayer probes. In this specialized assessment, dynamic variations in water, emulsion, and oil levels serve as the foundation for a robust protocol. The data generated by the probes, capturing level measurements, are compared to the monitored variations within the test bench (refer to Figure 3, steps 1 to 4). Additionally, the flushing capability undergoes thorough scrutiny (Figure 3, steps 1, 5, and 6).

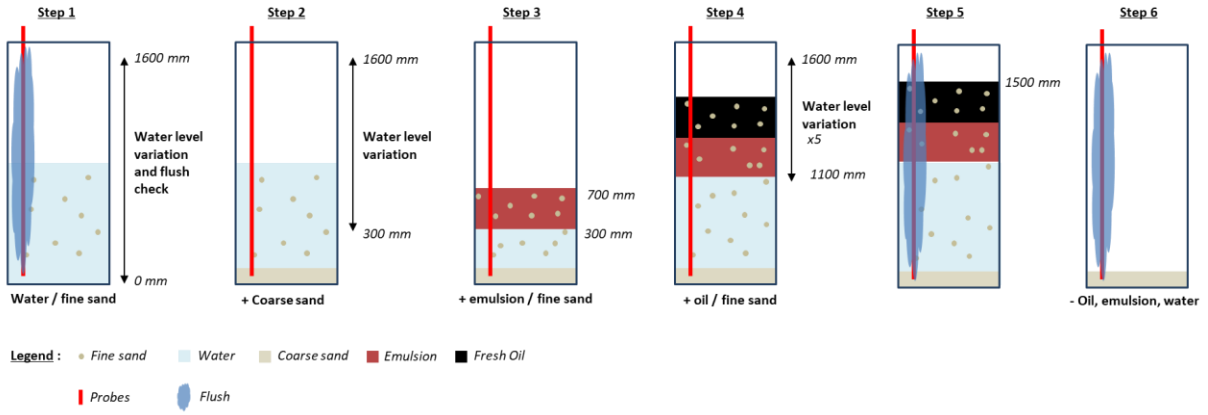

Figure 3. Custom-made tests: multilayer detection. Protocol

To simulate real-world conditions, the test is replicated after subjecting the probe to a substantial wax coating. Subsequently, the probe undergoes a second round of testing post-application of a precise coating of bitumen infused with $CaCO_3$, $BaSO_4$, sand, and iron oxides.

Materials

Equipment

At the behest of the end-user, four probes, each employing distinct technologies, undergo rigorous testing.

Test area

The expansive test hall at Cedre is purposefully configured to accommodate these intricate tests (see Figure 4). Key components of the test area include:

❶ Seawater Storage. Seawater is housed in two dedicated IBC tanks, ensuring a consistent supply to the test bench.

❷ Injection System. A pneumatic diaphragm pump, coupled with an injection pipe, facilitates the controlled injection of seawater into the test bench.

❸ Oil and Emulsion Storage. Dedicated IBC tanks, resting on retention containers, store both oil and its associated emulsion for each trial.

❹ Injection Mechanism. A thermic lobe pump, supported by pipes and an injection pipe, facilitates the precise injection of oil and emulsion into the test bench.

❺ Flushing Skids. Strategically placed outside or on the platform, these skids play a crucial role in the flushing process.

❻ Probe Setup. A crane positioned just above the test bench aids in the meticulous placement of probes.

❼ Monitoring and Recording. Adjacent to the test bench (Cedre's experimentation column), a dedicated table captures and records data emanating from the probes.

❽ Cedre's experimentation column. Placed in a hall in which the environmental parameters can be controlled, the experimentation column is composed of six sides of which three are transparent and features a watertight lid to which an extractor fan for explosive vapours is fitted.

❾ Ex-proof Outlet Fan. An Ex-proof outlet fan, essential for vapor extraction during oil-related tests, ensures a safe testing environment.

This detailed setup, incorporating advanced equipment and stringent protocols, aims to deliver precise insights into multilayer detection technologies, addressing the specific needs and conditions of the end-user.

Figure 4. Custom-made tests: multilayer detection. Test area.

Layers

In the experimental setup, seawater sourced from the Bay of Brest (France) is employed, thoroughly cleansed, and filtered for optimal quality. To enhance the complexity of the test scenario, fine sand is intentionally dispersed within the seawater, maintaining a concentration of 20 mg/L.

The selected oil for our trials aims for a target viscosity of approximately 100 cSt at 15°C. It's essential to note that, given the ambient temperature fluctuates naturally during the tests, the viscosity may exhibit variability from one trial to the next. Furthermore, the chosen oil boasts a flash point exceeding 60°C, ensuring safety throughout the experiments.

For the emulsion component, careful preparation occurs *ex-situ* to guarantee precise control over its properties, including water content, viscosity, specific gravity, and homogeneity. This involves a detailed blending of fresh oil (constituting 50% of the mixture) with seawater (constituting the remaining 50%). The resulting emulsion achieves a final viscosity of approximately 1,500 cSt. This deliberate formulation allows to assess the performance and response of the multilayer detection probes under diverse and controlled conditions, ensuring the robustness and relevance of our experimental outcomes.

Implementation tests: fast-current device

Protocol

The evaluation of the fast-current devices encompasses five distinct phases: Deployment, Transfer on the Water, Maneuverability Assessment, Collection Behavior Assessment, and Retrieval of the Equipment. This part of the paper specifically delves into the intricacies of the "Collection Behavior Assessment" phase.

Within this phase, we examine two dynamic configurations, as illustrated in Figure 5: one involves towing the containment systems using two vessels, while the other employs a single vessel with the second point of traction connected to a paravane.

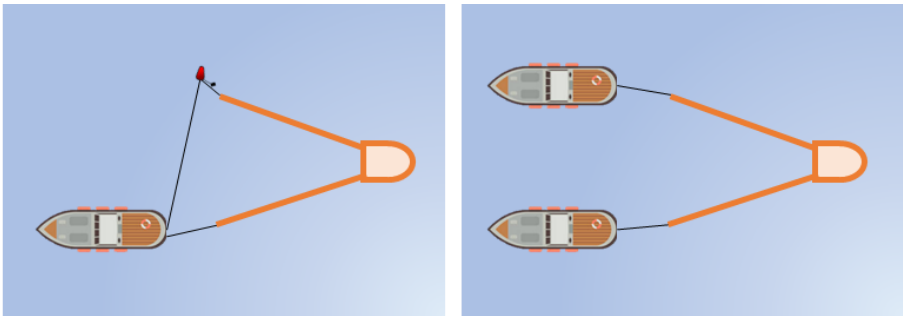

Figure 5. Tests under real conditions: fast-current devices. Configurations tested in dynamics.

For each configuration, a simulated pollution scenario is created and addressed by the fast-current device. The system's speed is measured using a current meter and gradually increased until the containment of the collected pollutant is jeopardized.

Material

Equipment

Six devices undergo testing under these dynamic conditions: Speed Sweep (DESMI), LMOS15 (LAMOR), Current Buster 2 and 4 (NOFI), Oiltrawal NO T 600 (Norlense), and R3S (Elastec).

Test aera

The trial site is situated on the French West Coast, within the Loire estuary. This selection is strategic due to the prevalent currents exceeding 2 knots, especially during the ebb tide (Shom, 2001), and the availability of necessary infrastructure for the trials, such as quays, pontoons, embankments, lifting equipment, and vessels. Additionally, the proximity to essential resources enables seamless collaboration with our partners, including the Saint Nazaire Subdivision of Phares et Balises and the Nantes – Saint Nazaire Port.

Pollutant

Given the impracticality of spilling oil in the Loire estuary, natural compounds are employed to simulate oil (Cedre, 2017a). In this project, popcorn serves as the simulated pollutant. Its buoyant nature allows for an effective visualization of the behavior of a floating product in the tested devices. Importantly, popcorn is biodegradable and is considered to have negligible environmental impact under the stipulated test conditions.

Boats and current measurements

Two boats play a crucial role in the fast-current device test. The first is a buoy tender equipped with two 175-hp Cummins engines and a bow thruster. The second is an aluminum hull boat featuring a 225-hp Volvo Penta inboard engine.

Additionally, a third boat, an aluminum hull vessel with a 115-hp outboard motor, is primarily utilized for observations, pollutant release, and current measurements (see Figure 6). This boat also provides support for the two other vessels during specific operations.

Figure 6. Measurement of surface currents

RESULTS/DISCUSSION

Standardized test: skimmer performance

This section delves into the performance evaluation of two distinct skimmers, shedding light on their efficacy in oil recovery. The skimmers under evaluation are:

1. Mechanical Weir Skimmer, with the following manufacturer's specifications:
    - Flow Rate: 5 to 70 m^3/h
    - Selectivity: 75% to 100%
2. Oleophilic Belt Skimmer, with the following manufacturer's specifications:
    - Flow Rate: Approximately 50 m^3/h
    - Selectivity: Approximately 95%

This comprehensive evaluation framework aims to provide nuanced insights into the comparative performance of the mechanical weir skimmer and the oleophilic belt skimmer, offering valuable data for informed decision-making in spill response strategies.

The subsequent Table 2 delineates the outcomes derived from the assessment of skimmers, namely the oleophilic belt skimmer and the mechanical weir skimmer, subjected to testing at Cedre using three distinct types of oils.

Table 2. Standardized protocol: skimmers performances. Example of results.

	Light oil		**Fresh heavy fuel oil**		**Emulsified heavy fuel oil (60% water)**	
Technology	Mechanical Weir skimmer	Oleophilic belt skimmer	Mechanical Weir skimmer	Oleophilic belt skimmer	Mechanical Weir skimmer	Oleophilic belt skimmer
Viscosity	Category I Very low viscosity		Category III Moderate viscosity		Category IV High viscosity	
Creation of slick movement by operators	/	/	/	Required	Required	Required
Selectivity	99%	65 %	67 %	55%	37 %	65 %
Recovery rate (oil)	≈ 34 m^3/h	≈ 6 m^3/h	≈ 3.6 m^3/h	≈ 9 m^3/h	3.4 m^3/h	9,5 m^3/h

These findings underscore the significance of rigorous testing and reveal variations in performance exhibited by the same skimmer with respect to the collected oil. Beyond technical and environmental aspects, the results suggest that in this case, the mechanical weir skimmer might be more suitable for addressing pollution from lighter products, whereas the oleophilic belt skimmer could be preferred for scenarios involving emulsified products.

Additionally, such tests can shed light on the constraints of pumps in transferring viscous pollutants, emphasizing the potential necessity for incorporating annular water injection (AWI) in certain situations (IMAROS, 2022) (see Table 3).

Table 3. Standardized protocol: skimmer performance with and without AWI. Example of results.

	Fresh VLSFO oil			
Viscosity	Category IV High viscosity			
Technology	Oleophilic drum skimmer with a centrifugal pump. Manufacturer's specifications: - Flow Rate: 20 m³/h - Selectivity: not communicated			
Pump(s) and Additional Equipment	Centrifugal pump	Centrifugal pump + Water annular injection	Centrifugal pump + Volumetric lobe pump	Centrifugal pump + Water annular injection + Volumetric lobe pump
Creation of slick movement by operators	/	/	/	/
Selectivity	98%	72%	95%	89%
Recovery rate (oil)	0.70 m^3/h	2.97 m^3/h	1.96 m^3/h	6.56 m^3/h

In these cases, the AWI system increases significantly the oil recovery flow rate of the recovery device by improving this parameter by a factor of 3 to 4. Selectivity is however slightly degraded due to the water input intrinsic to the system's operation.

Custom-made test: multilayer detection

Custom-made test of multilayer probes permits us to appreciate the human-machine interface, the accuracy of different technologies, and their response in degraded conditions. For example, Table 4 hereafter illustrates a synthesis of the results obtained at step 4 of the protocol (Figure 3).

Table 4. Custom-made tests: multilayer detection. Examples of results.

	Test conditions		**Probes**			
	Level measured	**Deposit**	**Probe 1**	**Probe 2**	**Probe 3**	**Probe 4**
Average gaps for the 5 levels of variation (Figure 3, step 4)	Water level	Without	104 mm	466 mm	22 mm	21 mm
		Wax	199 mm	395 mm	211 mm	101 mm
		Bitumen	95 mm	279 mm	8 mm	67 mm
	Emulsion level	Without	54 mm	170 mm	42 mm	52 mm
		Wax	66 mm	804 mm	69 mm	83 mm
		Bitumen	31 mm	97 mm	13 mm	68 mm
	Oil level	Without	20 mm	9 mm	8 mm	26 mm
		Wax	21 mm	7 mm	7 mm	8 mm
		Bitumen	70 mm	3 mm	78 mm	49 mm
	Upper level	Without	23 mm	10 mm	21 mm	32 mm
		Wax	25 mm	32 mm	35 mm	14 mm
		Bitumen	54 mm	165 mm	219 mm	51 mm

Color code (end user criteria):

- Green: Average gaps < 100 mm
- Orange: 100 mm < Average gaps < 200 mm
- Red: 200 mm < Average gaps

Pollutant-free implementation tests: fast-current device

Fast-current device trials demonstrated the capability to effectively collect and concentrate floating pollutants, even at current speeds exceeding 0.7 knots (speeds generally considered as the minimum required to create a pollutant leak under a boom perpendicular to the current (90 degrees) (US Coast Guard, 2001)). Results are detailed in Table 5 (Cedre, 2014, 2015, 2017b, 2019). These trials not only affirmed the operational feasibility of these systems but also provided valuable insights, allowing for the identification of their strengths and certain limitations. In dynamic mode, the trials revealed that towing the system with a single vessel and a paravane is notably more efficient than using two vessels, mainly due to challenges in coordinating maneuvers between the two vessels. This approach not only simplifies the operation but also allows the second vessel to undertake additional tasks, potentially reducing mobilization time and costs by employing a single vessel instead of two.

Table 5. Tests under real conditions: fast-current devices. Examples of results.

		Fast-current device 1	**Fast-current device 2**	**Fast-current device 3**
Environmental conditions	Chop	30 cm	30 to 40 cm	50 to 70 cm
	Wind	< 10 knots	12 - 15 knots	< 10 knots
Configuration	2 boats	Loss of containment at 3.1 knots	Loss of containment at 3.5 knots	Maximum speed reached: 2.8 knots (no loss of containment)
	1 boat + Paravane	Loss of containment at 3.1 knots	Loss of containment at 3.5 knots	Loss of containment at 3.5 knots

CONCLUSIONS

This paper presents three distinct types of tests conducted by Cedre, offering illustrative examples among the extensive range of potential assessments: a) standardized testing of oil recovery systems, b) custom-made multilayer detection using probes, and c) implementation testing of fast current devices. By subjecting these technologies to comparable conditions closely resembling real-world scenarios, these tests empower end-users to make informed choices in selecting the most suitable equipment for their specific requirements. Concurrently, these assessments allow equipment manufacturers to align their products with end-users' needs and enhance their performance. While equipment data sheets or sales brochures provide an overarching view of the field of application, it is crucial to consider various parameters that may influence performance, such as pollutant specificities, environmental factors, or technical conditions—information typically absent from standard technical data sheets. Cedre offers the flexibility to conduct these tests either at its facilities, utilizing custom-made test benches tailored to the customer's requirements, or in real-world environments through collaborations with Cedre's partners.

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