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Deliverable D4.2: Summary of WP4

The objective of WP 4 is to be able to give recommendations regarding the applicability of different response methods and equipment to the new generation fuel oils. The following tasks were performed:

Task 4.1 Mechanical recovery:
Mechanical oil recovery was tested at test facilities at NCA and Cedre.

- Test of different oil skimmers for mechanical oil recovery under different conditions.
- Comparison of test procedures from different partners: Cedre's and NCA's standardised protocols were be compared and experiences were exchanged.

Task 4.2 Dispersants:
Chemical dispersants were tested at test facilities at Cedre.
Chemical dispersibility of the oils, weathered at the laboratory and the meso-scale, was studied according to IFP and MNS protocols. The results are reported in the deliverable from WP 3.

Task 4.3 In situ burning:
In situ burning was tested at test facilities at Cedre.

Laboratory testing of ignitability of oils: Ignitability and burning efficiency of fresh floating oil slicks were assessed thanks to a device developed at Cedre.

Task 4.4 Shoreline clean-up:
Shoreline clean-up was assessed at test facilities at Cedre and NCA.

- Oil adhesion on hard (rocky shore) substrates was tested at Cedre (the high-pressure cleaning efficiency test device), to determine of oil adhesion on granite tiles. Due to the results also further rock types were tested.
- Simple practical testing of sorbents was carried out in the NCA test facility, following a test procedure developed in a cooperation project led by the the Swedish Coast Guard.

Conclusions from task 4.1 Mechanical recovery

Before testing were performed at the NCA's and Cedre's facilities, the standardised protocols were compared and customized in order for the test results to be comparable.

There was great variation in the properties of the oils tested, as is also shown in the chemical analyses. This leads to different kinds of problems for mechanical recovery. The biggest problems were the poor adhesion to the skimmers and that the oil had "short" properties, so that movement towards the skimmer was poor. Dynamic conditions (skimmer in motion in the slick, or slick moving towards the skimmer) could be considered to recover this kind of products in order to feed the skimmer and avoid the creation of a gap between the skimmers and the oil slick. Oils with a high pour point will be a problem because an oil spill will not necessarily form an oil slick but will occur as individual oil clumps that are difficult to collect and will largely remain solid.

None of the chosen skimmers worked well, but it cannot be excluded that other skimmers on the market may be better suited to these low sulphur fuel oils. It was found that floats, floating elements and the design of the skimmers acted as barriers to the flow of oil. There was also a problem with the hose dimensions being too small to transport oil from skimmer to collection tank. Here, the possibility of water injection should be considered, to reduce the friction between oil and hose. It should also be considered whether the design of the container for the pump is correctly dimensioned for oils with a high pour point. Also, using a volumetric pump instead of a centrifugal pump could enhance recovery rates.

In the event of a spill of low-sulphur oils, an oil analysis will not necessarily tell us which skimmer will work best, but it can provide indications of the problems that can be encountered. Because there is great variation in the low-sulphur oils that were investigated, there should be a flexible toolbox, with many varieties of skimmers for example, so as to be equipped to handle different problems. We recommend further testing with other skimmers and/or modifying the skimmers that have already been tested.

Conclusions from task 4.2 Dispersants:

N.A.

Conclusions from task 4.3 *In situ* burning:

Three VLSFO were tested *for in situ burning*, using a dedicated test bench to assess the possibility of using the *in situ burning* technique, in terms of both efficiency and potential impacts. Following the usual protocol of 10 seconds ignition, burning of the 3 oils was considered not successful. Additional attempts were carried out by increasing the ignition time (not exceeding 10 minutes). Two of the three VLSFO tested by this way caught in fire. The last one burnt only with the addition of a gelly igniter. Once burning was initiated (regardless of technique), it lasted about 10 minutes and was not characterized by a burning efficiency of more than 15%.

Those results suggest that this technique seems difficult to be applied in real conditions considering a spill involving VLSFO.

Conclusions from task 4.4 Shoreline cleanup:
The first conclusion resulting from the trials is that some VLSFO can be absorbed on tiles surface, and to a greater extend to some natural pebbles of different natures. In case of oil spill at sea, this phenomenon could thus be observed, depending on the VLSFO involved and on the rock's nature. This could generate particular difficulties for shoreline cleanup.
From the washing trials, washing efficiency revealed that water temperature first (hot water) and then pressure seems to clean more efficiently the tiles. It should however be noticed that this protocol enables a comparison of the results obtained for various oils and substrates but does not reproduce shoreline clean-up technique as used in the field.
The testing of sorbent booms at the NCA's facility showed that the booms did not absorb the chosen VLSFOs nor the ULSFO.

Further details on the tasks 4.1, 4.3 and 4.4 can be found in the appendices.

List of appendices

Task 4.1 Mechanical Recovery (NCA)
Task 4.1 Mechanical Recovery (CEDRE)
Task 4.3 In-situ burning (CEDRE)
Task 4.4 Shoreline clean-up (CEDRE)

Acknowledgement

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IMAROS

Work Package 4

Task 4.1 Mechanical Recovery

Executive summary

The objective of the Task 4.1 of the IMAROS project was to test the mechanical recovery of two VLSFO (fresh and emulsified) and one ULSFO (fresh and emulsified) collected by the project partners with three different skimmers in order to improve our knowledge on those products and recovery systems.

Tests were performed in an indoor basin at NCA's test facilities. Two VLSFO and one ULSFO were tested: IM-14, IM-15 and IM-16. The three skimmers used are based on different technologies: drum, belt and adhesion bands skimmers. The choice of skimmers was decided by the core project team.

There was great variation in the properties of the oils tested, as is also shown in the chemical analyses. This leads to different kinds of problems for mechanical recovery. The biggest problems were the poor adhesion to the skimmers and that the oil had "short" properties, so that movement towards the skimmer was poor. Oils with a high pour point will be a problem because an oil spill will not necessarily form an oil slick but will occur as individual oil clumps that are difficult to collect and will largely remain solid.

None of the chosen skimmers worked well, but it cannot be excluded that other skimmers on the market may be better suited to these low sulphur fuel oils. It was found that floats, floating elements and the design of the skimmers acted as barriers to the flow of oil. There was also a problem with the hose dimensions being too small to transport oil from skimmer to collection tank. Here, the possibility of water injection should be looked at, to reduce the friction between oil and hose. It should also be considered whether the design of the container for the pump is correctly dimensioned for oils with a high pour point.

In the event of a spillage of low-sulphur oils, an oil analysis will not necessarily tell us which skimmer will work best, but it can provide indications of the problems that can be met. Because there is great variation in the low-sulphur oils that were investigated, there should be a flexible toolbox, with many varieties of skimmers for example, so as to be equipped to handle different problems. We recommend further testing with other skimmers and/or modifying the skimmers that have already been tested.

Contents

1 Introduction

The objective of Work Package 4 is to be able to give recommendations regarding the applicability of different response methods and equipment to the new generation of fuel oils. This report answers task 4.1, which was to test the mechanical recovery of low-sulphur fuel oils under different conditions. The intention of the tests was to gain more knowledge about which recovery methods would work on these types of fuel oil. Three different types of oil skimmers were selected. It was discussed with the project partners that low-sulphur fuel oils, because of their high pour point, probably would have similar properties to heavy fuel oils. For this reason, three skimmers that are intended for the recovery of heavy fuel oil were chosen.

2 Materials and methods

2.1 Test set-up

The National Centre for Testing of Oil Spill Response Equipment at Horten in Norway provides the opportunity to test oil skimmers under controlled and highly realistic conditions. The test centre consists of an indoor saltwater basin with a double bottom. The basin is 30 metres long, 7 metres wide and up to 4 metres deep. It is also possible to create currents and waves in the basin. Figure 1 shows a diagram of the test basin. The tests were performed at water temperatures between 11-16 ^{o}C, and air temperatures between 13-16 ^{o}C.

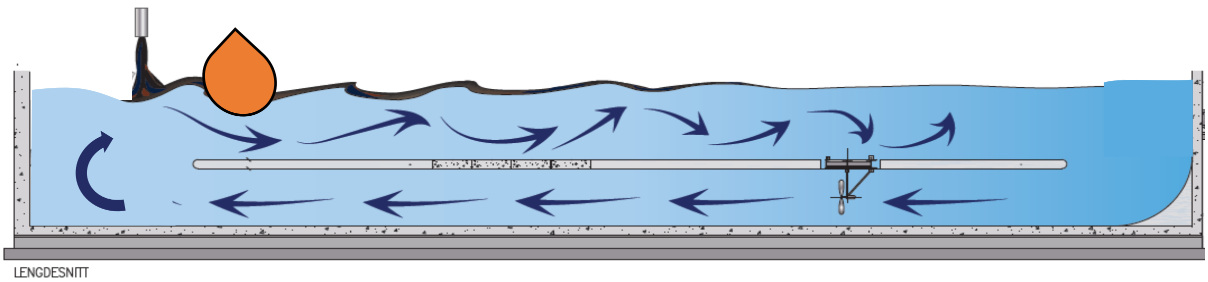

Figure 1: Cross section of the test basin. The blue arrows show how the water is circulated in the basin with the aid of a propeller. The orange object is a wave ball, which can create waves in the water.

The skimmers were tested according to the NCA's "Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment" and the following configuration was used:

Test 1 – Recovery of fresh oil in a small basin

Recovery test where the skimmer lies in a thick layer of oil in a small basin with no current in the water. The basin was made of PVC pipes with a dimension of 4x4 metres and a skirt that went 1 metre down into the water (see Figure 2). About 3 m^3

of oil were filled into the basin, which gave an oil thickness of approximately 19 cm. The skimmer was consequently working in practically fresh oil. The test was performed by finding out the amount of time the skimmer used to recover 500 litres of oil to a collection tank. The skimmer was operated to avoid collecting water, since it is undesirable to create oil emulsion during the test. Each test was performed three times. A deviation of maximum 20% between the three tests was acceptable.

Figure 2: Photograph of the 4×4 metre small basin.

Test 2 – recovery of oil emulsion in a boom with current

Recovery test where the skimmer lies in oil emulsion in a boom with current in the water (see Figure 3). About 2 m^3 of oil emulsion was filled into the boom, which gave an average oil thickness of 10 cm. The test was performed by finding out the amount of time the skimmer took to recover 800 litres of oil emulsion to a collection tank. The skimmer is run for optimum performance in relation to oil thickness, i.e. there is a need for adjustment of the speed during the test as the oil layer becomes thinner. Each test was performed three times with the same oil emulsion. A maximum deviation of 20% between the three tests was acceptable. The oil emulsion was replaced for each new skimmer.

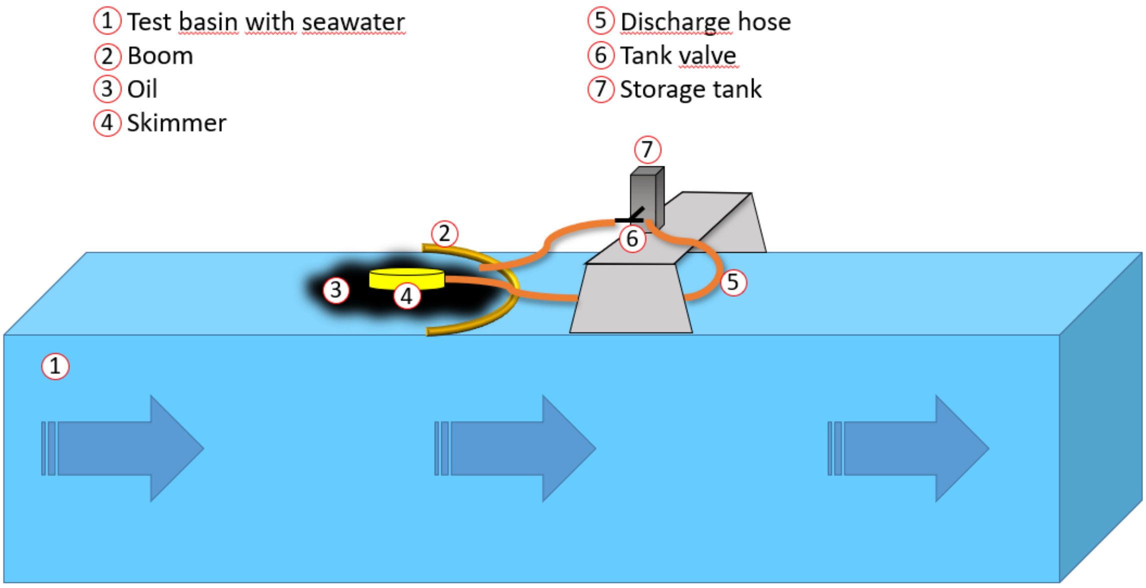

Figure 3: Diagram of the set-up for test 2 with oil emulsion in a boom with current.

After recovery, the oil was left to be decantated in the collection tank for 15 minutes, to separate free water and oil emulsion. The free water was then drained out of the tank and the recovery rate and effectiveness were calculated.

2.2 Calculation of recovery rate and effectiveness

Based on the relationship between the skimmer manufacturer's specified maximum recovery capacity and the highest recovery rate measured in the three repetitions of each test, it was decided that the test results would be presented with the effectiveness stated as follows:

- A recovery rate above 50% of the manufacturer's maximum capacity is rated as *good*
- A recovery rate between 25-50% of the manufacturer's maximum capacity is rated as *reduced*
- A recovery rate between 5-25% of the manufacturer's maximum capacity is rated as *poor*
- A recovery rate below 5% of the manufacturer's maximum capacity is rated as *unsuitable*

2.3 Oil skimmers

The following oil skimmers were tested:

Type of skimmer	Manufacturer's specified maximum capacity
Drum skimmer	Approx. 50 m^3/h
Belt skimmer	Approx. 80 m^3/h
Adhesion band skimmer	Approx. 9 m^3/h

Two additional oil skimmers were tested on one of the oils (VLSFO IM-14) as an extra test, due to vacant capacity. The skimmers used in this additional test were:

Type of skimmer	Manufacturer's specified maximum capacity
Brush skimmer	Approx. 30 m^3/h
Weir skimmer	Approx. 70 m^3/h

More detailed information about the skimmers can be seen in Appendix 1.

2.4 Hoses

For information about which hydraulic hoses and pressure/discharge hoses were used in the tests, see Appendix 1.

2.5 Oil types

The low-sulphur oils tested were:

VLSFO IM-14	Very Low Sulphur Fuel Oil
VLSFO IM-15	Very Low Sulphur Fuel Oil
ULSFO IM-16	Ultra Low Sulphur Fuel Oil

2.6 Making oil emulsion

The oil emulsion was made after test 1 was finished. The fresh oil was taken out of the small basin and pumped over to a mixing tank. 1 m^3 of the chosen test oil was added at a time and the oil was circulated/mixed while an even supply of water was introduced until about 2 m^3 of stable oil emulsion was created with a water content equivalent to 50%. The oil emulsion was pumped into the test basin and drifted into the boom, with a water current of approx. 0.8 knots.

2.7 Sampling and chemical analyses

Samples of each test oil were taken at different stages of the testing. The samples were sent to the independent research institute SINTEF for analysis of water content, viscosity and density, as well as GC/FID for some of the samples. See SINTEF report (2022)[1] for more information about sampling and analysis results.

2.8 Test of absorbent booms

As a collaboration between the Nordic countries, a common test procedure has been developed for testing absorbent booms ("Framtagning av testmetod för utvärdering av sorptionslänsor" by the Swedish Coast Guard (2022)). Absorbent booms made of cotton and polypropylene were tested in a thick layer of fresh oil and in oil emulsion, to see how effectively they collect oil. The booms had a length of 1 metre and a diameter of 12.5 cm. The booms were weighed before and after they had been in the oil. After recovery, the booms were cut open throughout to see whether oil and/or water had penetrated the material.

[1] Faksness, L.-G. & Altin, D. (2022): Physical-chemical properties of low sulphur fuel oils, and chemical characteristics and acute toxicity of their WAFs - IMAROS. SINTEF report 2022:00608.

3 Results

Recovery tests were performed in fresh oil in a small basin and in oil emulsion in a boom with current. The complete results for effectiveness on the different oils for the different skimmers are presented in Table 1.

- Recovery above 50% of the manufacturer's maximum capacity is rated as *good*
- Recovery between 25-50% of the manufacturer's maximum capacity is rated as *reduced*
- Recovery between 5-25% of the manufacturer's maximum capacity is rated as *poor*
- Recovery below 5% of the manufacturer's maximum capacity is rated as *unsuitable*

Table 1: Overview of the results of effectiveness from the tests.

	VLSFO IM-14		VLSFO IM-15		ULSFO IM-16	
	Fresh oil	Emulsion	Fresh oil	Emulsion	Fresh oil	Emulsion
Drum skimmer	poor	reduced	reduced	reduced	unsuitable	unsuitable
Belt skimmer	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
Adhesion band skimmer	poor	reduced	reduced	good	unsuitable	unsuitable
Brush skimmer		poor				
Weir skimmer		unsuitable				

VLSFO IM-14

Tests on VLSFO IM-14 were performed during weeks 48 and 49, 2021. The table below shows the results for the different skimmers from testing in fresh oil and emulsion. The recovery rate presented in the table is the best that was measured of the three repetitions. See Appendix 2 for the extended results and test conditions.

Table 2: Results of testing of VLSFO IM-14.

	Drum skimmer		Belt skimmer		Adhesion band skimmer	
	Fresh oil	Emulsion	Fresh oil	Emulsion	Fresh oil	Emulsion
	poor	reduced	unsuitable	unsuitable	poor	reduced
Recovery rate *m^3/h*	9.6	15.8	1.7	1.3	1.4	2.5
Effectiveness *%*	19%	32%	2.1%	1.6%	16%	28%
Viscosity *cP ($10\ s^{-1}$) 15˚C*	12,333*	16,844	12,333*	15,269	12,333*	17,445
Water content *vol%*	9.1%*	46.6%	9.1%*	47.3%	9.1%*	46.3%

**The figures are from the same oil sample, taken after testing all three skimmers in fresh oil*

3.1.1 General experiences with VLSFO IM-14

It was difficult to get the fresh oil out of the IBC tanks. Heat ($20^{o}C$) and pressure had to be applied to get the oil out.

It was easy to make an oil emulsion that remained stable. It took 2 hours to mix a stable oil emulsion with a water content of approximately 50%. The oil changed from being black to the characteristic “chocolate mousse” appearance.

Oil samples were taken from both fresh oil and oil emulsion that were allowed to stand at room temperature overnight. On the following day it could be observed that the sample of oil emulsion was solid and impossible to pour, while the fresh oil sample was still liquid.

After the oil emulsion was released into the basin and captured in the boom, the oil layer became thicker. When current was introduced to the water, the outer edge of the oil slick began to “roll”, which meant that it was thicker at the start of the slick than further in by the boom. See Figure 4 for an illustration of this phenomenon.

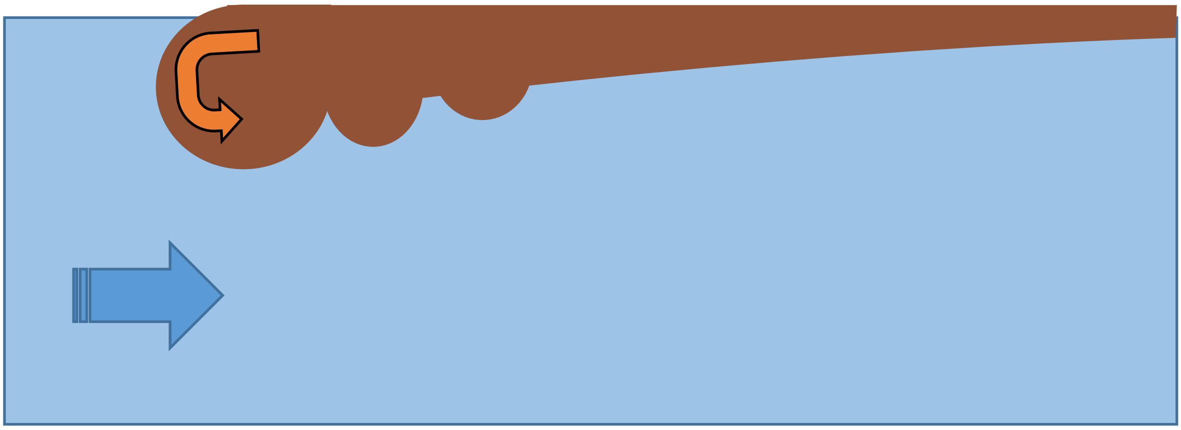

Figure 4: The oil “rolls” at the start of the oil slick. This meant a greater thickness at the outer edge of the oil slick and the least thickness further in by the boom.

3.1.2 Experiences with the skimmers

Both fresh oil and oil emulsion had good adhesion to the drum skimmer. The problem was that a layer of water quickly occurred between the skimmer and the oil slick that prevented further recovery. See Figure 5 for an illustration.

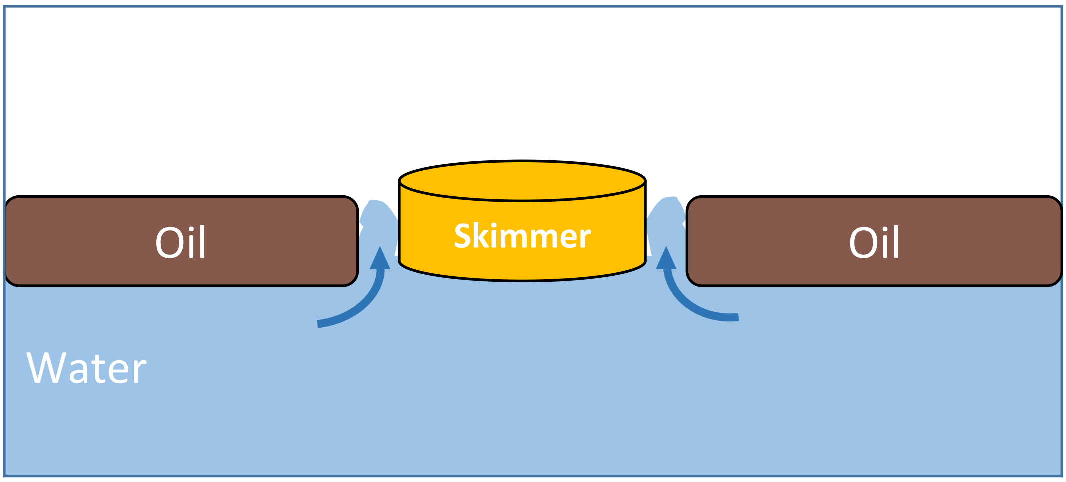

Figure 5: Illustration of the layer of water that occurred between skimmer and oil.

Various methods were tried to remove the water layer so that the drums could reach the oil. The first attempt was to increase the speed of the current so as to push the oil in towards the skimmer, without result. The next attempt was to move the skimmer in the oil slick with the crane so as to help the skimmer collect the oil. It was then observed that the whole oil slick moved around at the same time as the skimmer, without getting rid of the water layer (see Figure 6). It was only when the skimmer pushed the oil slick in towards the boom that the drums got hold of more oil. This was because the oil emulsion had nowhere else to go.

Figure 6: Photograph of the drum skimmer in motion in an attempt to take in oil. As the picture shows, there is still a clear area of water between skimmer and oil.

The belt skimmer had difficulty in pulling the oil up onto the belt. In oil emulsion, the belt managed to get some oil into the container when the skimmer was operated very slowly. As was found with the drum skimmer, a layer of water quickly appeared between skimmer and oil, which prevented further recovery. Here too, increasing the current or moving the skimmer around in the oil slick did not help.

When using the adhesion band skimmer, fresh oil adhered well to the bands. The problem the skimmer had when collecting fresh oil was to pump the oil out of the container because of great resistance in the hoses. The result was that the bands filled the container faster than the pump could empty it. When collecting oil emulsion, the resistance in the hoses was less and the pump worked more easily. This led to a somewhat higher recovery rate, but the problem was that the oil emulsion had poorer adhesion to the bands than the fresh oil. It was observed that the bands pulled the oil emulsion about 50 cm above the surface before the oil emulsion fell off the band (see Figure 7).

Figure 7: Adhesion band skimmer in IM-14 oil emulsion.

3.1.3 Additional testing of two skimmers on IM-14 oil emulsion

Additional testing was performed on IM-14 oil emulsion with two extra oil skimmers. These were a brush skimmer and a weir skimmer. The test results are presented in table 3. The highest recovery rate measured across the three repetitions of each test is presented in the table. See Appendix 2 for the extended results and test conditions.

Table 3: Results of extra testing with brush skimmer and weir skimmer on VLSFO IM-14.

	Brush skimmer		Weir skimmer	
	oil emulsion in small basin	oil emulsion in boom with current	oil emulsion in small basin	oil emulsion in boom with current
Result	poor	poor	unsuitable	unsuitable
Recovery rate *m^3/h*	3	2.2	0	0
Effectiveness %	10%	7.3%	0 %	0 %
Viscosity *cP ($10\ s^{-1}$) 15°C*	16,693	21,297	13,404	19,475
Water content *Vol%*	38%	51%	50%	39%

When using the brush skimmer in oil emulsion, the same problems were experienced as with the earlier test on the oil. Once again, a layer of water formed between skimmer and oil emulsion which prevented further recovery. See Figure 8 for a photograph of the brush skimmer in oil emulsion.

Figure 8: Brush skimmer in IM-14 oil emulsion.

When testing with the weir skimmer, there was no movement of oil emulsion towards the skimmer, making recovery impossible (see Figure 9).

Figure 9: Photograph of weir skimmer in oil emulsion. There was no movement towards the skimmer, only water.

3.2 VLSFO IM-15

Tests on VLSFO IM-15 were performed during weeks 43 and 44, 2021. The table below shows the results for the different skimmers from testing in fresh oil and emulsion. The recovery rate presented in the table is the best that was measured of the three repetitions. See Appendix 2 for the extended results and test conditions.

Table 4: Results of testing of VLSFO IM-15.

	Drum skimmer		Belt skimmer		Adhesion band skimmer	
	Fresh oil	Emulsion	Fresh oil	Emulsion	Fresh oil	Emulsion
Result	reduced	reduced	unsuitable	unsuitable	reduced	good
Recovery rate *m^3/h*	14.5	23.5	0.5	2.5	3.7	5
Effectiveness *%*	29%	47%	0.6%	3%	41%	55%
Viscosity *cP ($10\ s^{-1}$) 15˚C*	5,581*	45,812	5,581*	39,024	5,581*	41,688
Water content *vol%*	2.2%*	48.2%	2.2%*	41.6%	2.2%*	46.7%

**These figures are from the same oil sample, taken after testing all three skimmers in fresh oil*

3.2.1 General experiences with VLSFO IM-15

The fresh oil was free-flowing, so that there was no need to apply neither pressure nor heat to get the oil out of the IBC container.

It was easy to make an oil emulsion that remained stable. It took 4 hours to mix a stable oil emulsion with a water content of approximately 50%. The oil changed from being black to the characteristic "chocolate mousse" appearance.

It was easy to build oil thickness and the oil slick had a thickness of between 5-10 cm. This meant that there was no need for a strong current in the water. The oil emulsion had good flow properties.

Oil samples were taken from both fresh oil and oil emulsion that were placed in a refrigerator overnight. On the following day the sample of oil emulsion was solid and impossible to pour, while the fresh oil sample was still liquid. The fresh oil had a pour point of 0^oC (±3).

3.2.2 Experiences with the skimmers

The fresh oil had poor adhesion to the skimmers. Unlike the fresh oil, the oil emulsion had good adhesion to the drum skimmer. This led to a higher recovery rate. When the drums got hold of the oil emulsion, it was conveyed well to the container on the skimmer (see Figure 10). What limited the skimmer's capacity were problems with supply to the pump.

Figure 10: Photograph of the drum skimmer in IM-15 oil emulsion.

When using the belt skimmer (see Figure 11), the problem was that the fresh oil ran through the holes in the belt. The belt also had problems picking up the oil because of its poor adhesion to the belt. This was true for both fresh oil and oil emulsion. In oil emulsion, the belt managed to convey some oil to the container when the skimmer was operated very slowly and pushed towards the oil slick.

Figure 11: Photograph of the belt skimmer in fresh oil, showing the poor adhesion. The top of the belt has significantly less oil than the bottom, showing that the oil ran through the holes in the belt.

When using the adhesion band skimmer (see Figure 12), it could be observed that both fresh oil and oil emulsion had good adhesion to the bands. The problem with fresh oil was to pump the oil out of the container because of great resistance in the hoses. The bands were run more slowly so as to put less strain on the pump. When collecting oil emulsion, it was possible to run the bands faster because the water in the oil meant that resistance in the hoses was less. This led to a higher recovery rate.

Figure 12: Photograph of the adhesion band skimmer in fresh oil. The oil had good adhesion to the bands.

3.3 ULSFO IM-16

Tests on ULSFO IM-16 were performed during weeks 4 and 5, 2022. The table below shows the results for the different skimmers from testing in fresh oil. See Appendix 2 for the extended results and test conditions.

Table 5: Results of testing of ULSFO IM-16.

	Drum skimmer		Belt skimmer		Adhesion band skimmer	
	Fresh oil	Emulsion	Fresh oil	Emulsion	Fresh oil	Emulsion
Result	unsuitable	-	unsuitable	-	unsuitable	-
Recovery rate *m^3/h*	0	-	0	-	0	-
Effectiveness *%*	0	-	0	-	0	-
Viscosity *cP ($10\ s^{-1}$) 15˚C*	68,539	-	68,539	-	68,539	-
Water content *vol%*	0.6%*	-	0.6%*	-	0.6%*	-

**Difficulties with analysing water content.*

3.3.1 General experiences with IM-16

The oil was solid in the IBC tanks so that it had to be heated to 40ºC before it was possible to pour it out. The oil was poured into the small basin, where it was left alone for three days to lower the temperature of the oil to the basin temperature (12ºC). This led to the oil becoming solid in the small basin.

When the small basin was removed to release the oil slick, the oil slick kept its square shape and did not float outwards or separate (see Figure 13). The oil slick was completely solid and when one corner was pushed down, the whole slick moved and tilted as if it was an ice floe.

Figure 13: The solid oil slick of IM-16 in the boom.

3.3.2 Experiences with the skimmers

When the drum skimmer was lowered into the oil, it remained lying on top and did not sink into the oil. It was therefore impossible to use the skimmer (see Figure 14).

Figure 14: The drum skimmer stays on top of the oil. This skimmer weighs about 400 kg but did not manage to penetrate the oil slick.

Then an attempt was made to use the adhesion band skimmer in the hope that the bands would transfer energy to the oil, but this did not work as the oil was too stiff to stick to the bands. The adhesion band skimmer was run on the oil slick for ten minutes.

There was also an attempt to use the belt skimmer by running the skimmer through the water and in towards the edge of the oil slick. The skimmer did not work because the oil slick was too thick and solid.

It was clear that this test set-up was not suitable for this oil. As it was not possible to do anything with the oil slick, instead an extra attempt was made by heating 300 litres of oil before releasing it directly into the basin with current. This was done to observe how the oil could be expected to behave in the event of a real oil spill.

The oil flowed easily when it ran out of the hose at a temperature of 40 degrees. Immediately after the oil touched the water (12^{o}C) it created free-floating, porous oil clumps. The oil clumps had a maximum diameter of 10 cm and did not stick to each other.

The oil clumps were collected in the boom and an attempt was made to gather them with the drum skimmer. The drums collected some oil, but the scraper on the skimmer could not manage to remove the oil from the drums because of its stiffness. Even so, some oil ended up on the grating over the container, but because the oil clumps could not pass through the grating the pump could not reach the oil.

An attempt was then made to collect the oil with the belt skimmer. The belt got hold of the oil clumps and conveyed them to the container (see Figure 15). The container filled up, but because the oil was in solid clumps the pump could not get hold of it.

Figure 15: Belt skimmer collecting oil clumps of ULSFO IM-16. To get the skimmer to get hold of the clumps, it had to be actively moved towards the oil.

3.4 Absorbent boom test

Tests of absorbent booms were performed on the IM-14, IM-15 and IM-16 oils, both as fresh oil and oil emulsion. The tables below show the overall results of the tests. The booms were weighed after different intervals from 30 minutes up to 3 days. Every time the booms were lifted from the oil to be weighed, they were left hanging for 5 minutes so that any surplus oil could drip off, i.e. the oil that the boom could not hold. The booms weighed 1 kg before the test started.

Table 6: Results for absorbent booms in fresh oil.

	IM-14 (fresh oil)		IM-15 (fresh oil)		IM-16 (fresh oil)	
	cotton	polypropylene	cotton	polypropylene	cotton	polypropylene
start	*1 kg*	*1 kg*	*1 kg*	*1 kg*	*1 kg*	*1 kg*
60 min	*3 kg*	*3 kg*	*3 kg*	*2.5 kg*	*1 kg*	*1 kg*
+ 5 min	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2 kg*	*1 kg*	*1 kg*
2 hours	*3 kg*	*3 kg*	*3 kg*	*3 kg*	*1 kg*	*1 kg*
+ 5 min	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2.5 kg*	*1 kg*	*1 kg*

Table 7: Results for absorbent booms in oil emulsion.

	IM-14 (oil emulsion)		IM-15 (oil emulsion)	
	cotton	polypropylene	cotton	polypropylene
start	*1 kg*	*1 kg*	*1 kg*	*1 kg*
30 min	*2 kg*	*2 kg*	*2 kg*	*2 kg*
+ 5 min	*2 kg*	*2 kg*	*1.9 kg*	*1.8 kg*
2 hours	*2.5 kg*	*2 kg*	*2.5 kg*	*2 kg*
+ 5 min	*2.5 kg*	*2 kg*	*2.5 kg*	*2 kg*
4 hours	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2.5 kg*
+ 5 min	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2.5 kg*
24 hours	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2.5 kg*
+ 5 min	*2.5 kg*	*2.5 kg*	*2.5 kg*	*2.5 kg*
3 days	*2.5 kg*	*2.5 kg*	*5 kg*	*4.25 kg*
+ 5 min	*2.5 kg*	*2.5 kg*	*4.25 kg*	*3.75 kg*

The results show that absorbent booms do not have the ability to absorb IM-14, IM-15 or IM-16 (see Figure 16). The increase in weight of the booms is from the oil that sticks to the outside of the booms, meaning there is some recovery. But cutting though the booms revealed that neither oil nor water had penetrated the boom material (see Figure 17). This was true for both polypropylene and cotton booms.

Figure 16: Absorbent booms in fresh oil.

Figure 17: Cut polypropylene boom showing that neither oil nor water had penetrated the boom. This was also true for the cotton boom.

4 Discussion

IM-14

This oil was problematic to recover for all the chosen skimmers. This could be related to the oil having “short” properties: in other words the oil slick did not float in towards the skimmer during recovery. This is the opposite of a “long” oil, which moves continuously in towards a skimmer during recovery. Even though the oil showed good adhesion to both drums and belt, recovery was limited by the lack of movement of the oil. The design of the skimmers with floats, edges etc. meant that the oil could not move freely in towards the drums or belt. Once a water layer formed between skimmer and oil, this was very difficult to remove. A number of methods were tried to help the skimmers reach the oil. Using a crane to manoeuvre the drum skimmer around in the oil slick is not a natural way to operate the skimmer and gave an unrealistic result for the recovery rate in oil emulsion.

As an additional test, recovery was attempted with a brush skimmer and a weir skimmer in oil emulsion, without any promising results.

We cannot exclude that there may be other skimmer types on the market that are better suited to collecting this oil.

IM-15

It seems that mechanical recovery with skimmers is a suitable measure for this oil. The oil emulsion had good adhesion, even though the oil was “short”. For recovery of fresh oil, the adhesion band skimmer proved to be the most effective, while for oil emulsion, the drum skimmer also worked well. There are also other skimmers on the market that would probably work well on this oil, but these have not been tested in this project.

IM-16

This oil was extremely difficult to collect because the oil was completely solid. None of the chosen skimmers managed to collect the oil, either as a stiff oil slick or as smaller oil clumps. The skimmers have been designed to collect viscous fluids, so this challenges the working principles of most skimmers. It is not known whether the pumps in the chosen skimmers would have been able to pump out the oil because the design of the skimmer/container meant that the oil could not reach the pump. A possible solution for collecting free-floating oil clumps is to use an excavator bucket or a belt skimmer where the oil goes directly from the belt and down into a collection tank, but this has not been tested in this project.

5 Conclusion

There was great variation in the properties of the oils tested, as is also shown in the chemical analyses. This leads to different kinds of problems for mechanical recovery. The biggest problems were the poor adhesion to the skimmers and that the oil had "short" properties, so that movement towards the skimmer was poor. Oils with a high pour point will be a problem because an oil spill will not necessarily form an oil slick but will occur as individual oil clumps that are difficult to collect and will largely remain solid.

None of the chosen skimmers worked well, but it cannot be excluded that other skimmers on the market may be better suited to these low sulphur fuel oils. It was found that floats, floating elements and the design of the skimmers acted as barriers to the flow of oil. There was also a problem with the hose dimensions being too small to transport oil from skimmer to collection tank. Here, the possibility of water injection should be looked at, to reduce the friction between oil and hose. It should also be considered whether the design of the container for the pump is correctly dimensioned for oils with a high pour point.

In the event of a spillage of low-sulphur oils, an oil analysis will not necessarily tell us which skimmer will work best, but it can provide indications of the problems that can be met. Because there is great variation in the low-sulphur oils that were investigated, there should be a flexible toolbox, with many varieties of skimmers for example, so as to be equipped to handle different problems. We recommend further testing with other skimmers and/or modifying the skimmers that have already been tested.

Whether mechanical recovery with skimmers is a suitable measure is also dependent on external factors. Problems caused by the pour point especially increase with cold temperatures, so further testing should also be performed at lower temperatures.

Appendix 1

Hydraulic hoses

Hoses with different dimensions that are adapted to thematic couplings of type 7500 (3/4), 5000 (1/2) and 3800 (1/4) were used. Length of the hoses is approx. 15 meters. This was used for all the skimmers that were tested.

Power pack

The NCA's test facilities own fixed unit was used for running pumps and skimmers. The unit has a power of 90 kW, with variable pump.

Pressure/discharge hoses

The individual skimmer's original hose package was used:

Skimmer	Hoses
Drum skimmer	Discharge hose: 4'' 15 meters
Belt skimmer	Discharge hose: 4'' 15 meters
Adhesion band skimmer	Discharge spiro hose: 2'' 15 meters Pressure spiro hose: 2'' 15 meters
Brush skimmer	Discharge hose: 4'' 15 meters
Weir skimmer	Discharge hose: 2,5'' 15 meters

Appendix 2: test results

IM-15: DRUM SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date	25.10.2021
Oil	VLSFO IM-15			
Skimmer	Drum skimmer			
Oil temperature	17˚C			
Air temperature	15.5˚C			
Water temperature	15.8˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	3000 L	3000 L	3000 L	
Oil thickness	18 cm	18 cm	18 cm	
Volume of oil collected	480 L	450 L	490 L	
Volume of free water collected	0 L	0 L	0 L	
Time elapsed	04:45	02:10	02:02	
Oil uptake rate	6 m^3/h	12.5 m^3/h	14.5 m^3/h	
Oil sample	V1 (before run 1)	-	-	
Deviation from procedure				

Purpose	Test 2 - oil emulsion in boom with current		Date	28.10.2021
Oil	VLSFO IM-15			
Skimmer	Drum skimmer			
Oil temperature	19˚C			
Air temperature	15.7˚C			
Water temperature	15.7˚C			
Salinity	1.03˚C			
	Run 1	Run 2	Run 3	
Current	0.5 kn	0.5 kn	0.5 kn	
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L	
Oil thickness	10 cm	10 cm	10 cm	
Volume of oil collected	691 L	674 L	690 L	
Volume of free water collected	109 L	126 L	110 L	
Time elapsed	02:52	02:33	01:46	
Oil uptake rate	14.5 m^3/h	15.8 m^3/h	23.5 m^3/h	
Oil sample	V17 (before run 1)	-	V22 (after run 3)	
Deviation from procedure				

IM-15: BELT SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date	26.10.2021
Oil	VLSFO IM-15			
Skimmer	Belt skimmer			
Oil temperature	16.4˚C			
Air temperature	15.4˚C			
Water temperature	15.8˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	3000 L	3000 L	-	
Oil thickness	18 cm	18 cm	-	
Volume of oil collected	63 L	63 L	-	
Volume of free water collected	0 L	0 L	-	
Time elapsed	08:27	08:23	-	
Oil recovery rate	0.5 m^3/h	0.5 m^3/h	-	
Oil sample	-	-	-	
Deviation from procedure	Did not recover the intended amount of oil due to poor recovery	Did not recover the intended amount of oil due to poor recovery	did not complete the third run due to the poor recovery	

Purpose	Test 2 (oil emulsion in boom with current)		Date	28.10.2021
Oil	VLSFO IM-15			
Skimmer	Belt skimmer			
Oil temperature	18˚C			
Air temperature	15.8˚C			
Water temperature	15.6˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.5 kn	0.5 kn	0.5 kn	
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L	
Oil thickness	10 cm	10 cm	11 cm	
Volume of oil collected	760 L	700 L	665 L	
Volume of free water collected	40 L	100 L	35 L	
Time elapsed	21:16	16:57	16:40	
Oil uptake rate	2.1 m^3/h	2.5 m^3/h	2.4 m^3/h	
Oil sample	V11 (before run 1)		V16 (after run 3)	
Deviation from procedure				

IM-15: ADHESION BAND SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin	Date	26.10.2021
Oil	VLSFO IM-15		
Skimmer	Adhesion band skimmer		
Oil temperature	16.4˚C		
Air temperature	15.4˚C		
Water temperature	15.8˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Total volume of oil in basin	3000 L	3000 L	3000 L
Oil thickness	18 cm	18 cm	18 cm
Volume of oil collected	504 L	504 L	504 L
Volume of free water collected	0 L	0 L	0 L
Time elapsed	08:38	08:37	08:12
Oil uptake rate	3.5 m^3/h	3.5 m^3/h	3.7 m^3/h
Oil sample			V4 (after completion)
Deviation from procedure			

Purpose	Test 2 (oil emulsion in boom with current)	Date	28.10.2021
Oil	VLSFO IM-15		
Skimmer	Adhesion band skimmer		
Oil temperature	17 ˚C		
Air temperature	15,4 ˚C		
Water temperature	15 ˚C		
Salinity	1,03		
	Run 1	Run 2	Run 3
Current	0.5 kn	0.5 kn	0.5 kn
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L
Oil thickness	5-10 cm	5-10 cm	5-10 cm
Volume of oil collected	750 L	716 L	741 L
Volume of free water collected	50 L	84 L	59 L
Time elapsed	09:00	14:06	12:19
Oil uptake rate	5 m^3/h	3 m^3/h	3.6 m^3/h
Oil sample	V5 (before run 1)		V10 (after run 3)
Deviation from procedure			

IM-14: DRUM SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date: 29.11.2021
Oil	VLSFO IM-14		
Skimmer	Drum skimmer		
Oil temperature	14,4 ˚C		
Air temperature	14 ˚C		
Water temperature	14 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Total volume of oil in basin	3000 L	3000 L	3000 L
Oil thickness	18 cm	18 cm	18 cm
Volume of oil collected	328 L	412 L	512 L
Volume of free water collected	34 L	0 L	34 L
Time elapsed	02:43	03:00	03:00
Oil uptake rate	6.7 m^3/h	8.2 m^3/h	9.6 m^3/h
Oil sample	S1 (before run 1)	-	-
Deviation from procedure			

Purpose	Test 2 - oil emulsion in boom with current		Date: 01.12.2021
Oil	VLSFO IM-14		
Skimmer	Drum skimmer		
Oil temperature	15 ˚C		
Air temperature	13 ˚C		
Water temperature	14 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Current	0.5 kn	0.5 kn	0.5 kn
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L
Oil thickness	5-10 cm	5-10 cm	5-10 cm
Volume of oil collected	216 L	475 L	758 L
Volume of free water collected	84 L	25 L	42 L
Time elapsed	2:28	2:48	2:53
Oil uptake rate	5.2 m^3/h	10.2 m^3/h	15.8 m^3/h
Oil sample	S17 (before run 1)	-	S22 (after run 3)
Deviation from procedure			

IM-14: BELT SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date 29.11.2021
Oil	VLSFO IM-14		
Skimmer	Belt skimmer		
Oil temperature	15 ˚C		
Air temperature	15 ˚C		
Water temperature	14 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Total volume of oil in basin	3000 L	3000 L	3000 L
Oil thickness	18 cm	18 cm	18 cm
Skimmer (speed?)			
Volume of oil collected	76 L	63 L	84 L
Volume of free water collected	25 L	0 L	0 L
Time elapsed	03:00	03:00	03:00
Oil uptake rate	1 m^3/h	1.3 m^3/h	1.7 m^3/h
Oil sample	-	-	-
Deviation from procedure			

Purpose	Test 2 (oil emulsion in boom with current)		Date 01.12.2021
Oil	VLSFO IM-14		
Skimmer	Belt skimmer		
Oil temperature	16 ˚C		
Air temperature	15.5 ˚C		
Water temperature	14.5 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Current	0.5 kn	0.5 kn	0.5 kn
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L
Oil thickness	5-10 cm	5-10 cm	5-10 cm
Volume of oil collected	157 L	275 L	275 L
Volume of free water collected	143 L	25 L	25 L
Time elapsed	15:25	12:46	12:48
Oil uptake rate	0.6 m^3/h	1.3 m^3/h	1.3 m^3/h
Oil sample	S11 (before run 1)	-	S16 (after run 3)
Deviation from procedure			

IM-14: ADHESION BAND SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date	29.11.2021
Oil	VLSFO IM-14			
Skimmer	Adhesion band skimmer			
Oil temperature	14.3 ˚C			
Air temperature	14 ˚C			
Water temperature	14 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	3000 L	3000 L	3000 L	
Oil thickness	18 cm	18 cm	18 cm	
Volume of oil collected	500 L	143 L	168 L	
Volume of free water collected	0 L	0 L	0 L	
Time elapsed	22:17	06:10	07:00	
Oil uptake rate	1.3 m^3/h	1.4 m^3/h	1.4 m^3/h	
Oil sample			S4 (after completion)	
Deviation from procedure				

Purpose	Test 2 (oil emulsion in boom with current)		Date	01.12.2021
Oil	VLSFO IM-14			
Skimmer	Adhesion band skimmer			
Oil temperature	16.5 ˚C			
Air temperature	14.5 ˚C			
Water temperature	14 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.5 kn	0.5 kn	0.5 kn	
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L	
Oil thickness	5-10 cm	5-10 cm	5-10 cm	
Volume of oil collected	275 L	280 L	284 L	
Volume of free water collected	25 L	20 L	16 L	
Time elapsed	07:00	07:08	06:41	
Oil uptake rate	2.4 m^3/h	2.4 m^3/h	2.5 m^3/h	
Oil sample	S5 (before run 1)		S10 (after run 3)	
Deviation from procedure				

1.

IM-14: BRUSH SKIMMER

Purpose	Test 1 – oil emulsion in enclosed basin		Date	23.02.2022
Oil	VLSFO IM-14			
Skimmer	Brush skimmer			
Oil temperature	18 ˚C			
Air temperature	13 ˚C			
Water temperature	13 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	2000 L	2000 L	2000 L	
Oil thickness	14 cm	14 cm	14 cm	
Volume of oil collected	160 L	180 L	100 L	
Volume of free water collected	340 L	320 L	400 L	
Time elapsed	03:35	03:36	02:56	
Oil uptake rate	2.7 m^3/h	3 m^3/h	2 m^3/h	
Oil sample	SS5 (before run 1)		SS6 (after run 3)	
Deviation from procedure				

Purpose	Test 2 (oil emulsion in boom with current)		Date	22.02.2022
Oil	VLSFO IM-14			
Skimmer	Brush skimmer			
Oil temperature	17 ˚C			
Air temperature	14 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.7 kn			
Total volume of oil emulsion in basin	2000 L			
Oil thickness	5-10 cm			
Volume of oil collected	109 L			
Volume of free water collected	613 L			
Time elapsed	03:02			
Oil uptake rate	2.2 m^3/h			
Oil sample	SS1+SS2 (before + after run 1)			
Deviation from procedure		Did not complete due to poor recovery rate	Did not complete due to poor recovery rate	

IM-14: WEIR SKIMMER

Purpose	Test 1 – oil emulsion in enclosed basin		Date	23.02.2022
Oil	VLSFO IM-14			
Skimmer	Weir skimmer			
Oil temperature	18 ˚C			
Air temperature	13 ˚C			
Water temperature	13 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	2000 L			
Oil thickness	14 cm			
Volume of oil collected	-			
Volume of free water collected	-			
Time elapsed	-			
Oil uptake rate	0 m^3/h			
Oil sample	SS4 (before run 1)			
Deviation from procedure	No recovery – no inflow of oil into the skimmer	Did not complete due to no recovery	Did not complete due to no recovery	

Purpose	Test 2 (oil emulsion in boom with current)		Date	22.02.2022
Oil	VLSFO IM-14			
Skimmer	Weir skimmer			
Oil temperature	17 ˚C			
Air temperature	14 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.7 kn			
Total volume of oil emulsion in basin	2000 L			
Oil thickness	5-10 cm			
Volume of oil collected	-			
Volume of free water collected	-			
Time elapsed	-			
Oil uptake rate	0 m^3/h			
Oil sample	SS3 (before run 1)			
Deviation from procedure		Did not complete due to poor recovery rate	Did not complete due to poor recovery rate	

IM-16: DRUM SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date	26.01.2022
Oil	VLSFO IM-16			
Skimmer	Drum skimmer			
Oil temperature	13 ˚C			
Air temperature	12 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	3000 L	3000 L	3000 L	
Oil thickness	18 cm	18 cm	18 cm	
Volume of oil collected				
Volume of free water collected				
Time elapsed				
Oil uptake rate				
Oil sample				
Deviation from procedure	No recovery possible	No recovery possible	No recovery possible	

Purpose	Test 2 (fresh oil in boom with current)		Date	01.02.2022
Oil	VLSFO IM-16			
Skimmer	Drum skimmer			
Oil temperature	15 ˚C			
Air temperature	12 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.5 kn	0.5 kn	0.5 kn	
Total volume of oil in basin	300 L	300 L	300 L	
Oil thickness	-	-	-	
Volume of oil collected				
Volume of free water collected				
Time elapsed				
Oil uptake rate				
Oil sample	ULSFO1			
Deviation from procedure	Alternative testing of the oil – 300 L fresh oil into boom. Se report for further explanation.			

IM-16: BELT SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date	26.01.2022
Oil	VLSFO IM-16			
Skimmer	Belt skimmer			
Oil temperature	13 ˚C			
Air temperature	12 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Total volume of oil in basin	3000 L	3000 L	3000 L	
Oil thickness	18 cm	18 cm	18 cm	
Volume of oil collected				
Volume of free water collected				
Time elapsed				
Oil uptake rate				
Oil sample				
Deviation from procedure	No recovery possible	No recovery possible	No recovery possible	

Purpose	Test 2 (fresh oil in boom with current)		Date	01.02.2022
Oil	VLSFO IM-16			
Skimmer	Belt skimmer			
Oil temperature	15 ˚C			
Air temperature	12 ˚C			
Water temperature	12 ˚C			
Salinity	1.03			
	Run 1	Run 2	Run 3	
Current	0.5 kn	0.5 kn	0.5 kn	
Total volume of oil in basin	300 L	300 L	300 L	
Oil thickness	-	-	-	
Volume of oil collected				
Volume of free water collected				
Time elapsed				
Oil uptake rate				
Oil sample	ULSFO1			
Deviation from procedure	Alternative testing of the oil – 300 L fresh oil into boom. Se report for further explanation.			

IM-16: ADHESION BAND SKIMMER

Purpose	Test 1 - fresh oil in enclosed basin		Date 26.01.2022
Oil	VLSFO IM-16		
Skimmer	Adhesion band skimmer		
Oil temperature	13 ˚C		
Air temperature	12 ˚C		
Water temperature	12 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Total volume of oil in basin	3000 L	3000 L	3000 L
Oil thickness	18 cm	18 cm	18 cm
Volume of oil collected			
Volume of free water collected			
Time elapsed			
Oil uptake rate			
Oil sample			
Deviation from procedure	No recovery possible	No recovery possible	No recovery possible

Purpose	Test 2 (fresh oil in boom with current)		Date 01.02.2022
Oil	VLSFO IM-16		
Skimmer	Adhesion band skimmer		
Oil temperature	15 ˚C		
Air temperature	12 ˚C		
Water temperature	12 ˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Current	0.5 kn	0.5 kn	0.5 kn
Total volume of oil in basin	300 L	300 L	300 L
Oil thickness	-	-	-
Volume of oil collected			
Volume of free water collected			
Time elapsed			
Oil uptake rate			
Oil sample	ULSFO1		
Deviation from procedure	Alternative testing of the oil – 300 L fresh oil into boom. Se report for further explanation.		

WP4

Deliverable D4.2

Task 4.1: Mechanical recovery

FINAL REPORT

Co-funded by the European Union

EXECUTIVE SUMMARY

The objective of the Task 4.1 of the IMAROS project was to test the mechanical recovery of two VLSFO (fresh and emulsified) collected by the project partners with two different skimmers in order to improve our knowledge on those products and recovery systems. Tests were performed in an external basin in Cedre’s facilities, at ambient temperature (between 7°C and 12°C, representative of the weather conditions encountered in the European waters).

Two VLSFO were tested: IM-14 and IM-15. IM-14 is characterized by a high pour point (+30°C) while IM-15 is much more fluid, with a pour point of +3°C. The two skimmers used are based on different technologies: oleophilic drum and oleophilic brush belt skimmers. They were chosen because they were already part of the French stockpiles (and so easily available) and also present in some project partners’ national stockpiles.

Tests were carried out in the configuration recommended by the manufacturer (skimmer + pump + hydraulic unit). Considering the oleophilic drum skimmer, an annular water injection was coupled to the pump in order to help the pump transferring the oil.

No significant difference was observed between the two skimmers on their capacity to attract the slick. Considering IM-14, the oil did not flow naturally towards the skimmers (the skimmers dug a hole in the part of the slick that was in direct contact with the skimmers), contrary to IM-15. For IM-14, an assistance was required to feed the skimmers.

In terms of recovery flow rate, except for the emulsified IM-14 oil, in optimal test condition (with annular water injection and oil setting in motion with paddles if necessary), belt and drum skimmers had similar recovery flow rate (between 2 and 3.5 m^3/h, with less than 0.5 m^3/h difference for similar tests). Overall, the recovery rate remained higher on fresh hydrocarbons which are less viscous. In function of the oil nature, the pump could be a limiting factor for the oil recovery, even if the oleophilic drums or the oleophilic brush belts were efficient.

In terms of selectivity, in optimal test condition (with annular water injection and oil setting in motion with paddles if necessary), no obvious difference between the two tested oils was observed. Selectivity ranged between 58% and 95% for all the conditions tested on IM-14 and between 52% and 99% for all the conditions tested on IM-15. It appeared that the oleophilic brush belt skimmer tended to be more selective than the oleophilic drum skimmer, for the two oils tested (between 10 and 40 % more selectivity). The use of annular water injection in order to help the pump of the oleophilic drum skimmer to transfer tested oils may partially explain this difference because of the water brought into the flow rate by this annular water injection equipment.

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Content

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1 Introduction

Each spill entails a series of questions concerning the fate and behavior of the oil involved, and consequently about the oil spill response techniques to be used. Indeed, because oil is a liquid consisting of a complex mixture of hydrocarbons and a number of other molecules, the behavior and the aspect of the spilled oil can change depending on its composition, environmental conditions and weathering.

In order to prepare the response in the event of an accidental oil spill into the aquatic environment, and to limit its consequences, it is necessary to test the response equipment that can be deployed and build up the anti-pollution stocks of the parties involved in the response with regard to these aspects: the oil recovery equipment must be adapted to the oil spill.

The objective of the Task 4.1 of the IMAROS project was to test the mechanical recovery of two VLSFO (fresh and emulsified) collected by the project partners with two different skimmers in order to improve our knowledge on those products and recovery systems. Tests were performed in an external basin in Cedre's facilities, at ambient temperature (between 7°C and 12°C, representative of the weather conditions encountered in the European waters).

2 Materials and methods

2.1 Oils

Two VLSFO were tested: IM-14 and IM-15.

IM-14 is characterized by a high pour point (+30°C) while IM-15 is much more fluid, with a pour point of +3°C.

2.2 Skimmers

The two skimmers used are based on different technologies: oleophilic drum and oleophilic brush belt skimmers. They were chosen because they were already part of the French stockpiles (and so easily available) and also present in some project partners' national stockpiles.

2.2.1 Oleophilic drum skimmer

This skimmer is made of two oleophilic drums. The model tested uses the innovative "grooved drum" technology developed by the manufacturer. The drum skimmer was configured with the recommended centrifugal screw pump and hydraulic unit. The discharge hose diameter is 3 inches.

The centrifugal screw pump performances, announced by the manufacturer, are 40 m^3/h at zero discharge pressure or 13.5 m^3/h with a discharge pressure of 2.8 bars. The drums are driven by a hydraulic motor, accepting a maximum hydraulic flow of 19 L/min for a maximum pressure of 175 bars (manufacturer's data).

The maximum oil recovery rate announced by the manufacturer for this skimmer model is 20 m^3/h.

2.2.2 Oleophilic brush belt skimmer

This skimmer is made of an oleophilic stiff-brush conveyor belt. It is equipped with an integrated volumetric screw pump. The discharge hose diameter is 4 inches. During the tests carried out at Cedre, the skimmer was configured in association with the integrated oil transfer pump and recommended hydraulic unit. The skimmer has a water suction propeller forcing oil to the brush conveyor system.

According to the skimmer data sheet, it has an oil recovery rate of 30 m^3/hr.

2.3 Standards and references

The test method used to test skimmers is described in the French standard AFNOR NF T 71-500 (Oil spill response equipment - Skimmers - Performance test methods in controlled environment).

2.4 Test areas

The test area consisted of (see *Figure 1*):

- ❶: Spill area: a skimmer was positioned in the middle of a 16 m² area in which the oil was spilled. There is no current in this area. Tests are then performed in "static" mode;
- ❷: Hydraulic unit: an hydraulic unit supplying the pump and the skimmer was installed near the spill area;
- ❸: Discharge pipe: a 10 m long pipe was used to redirect the flow to the discharge tank (❹). The diameter of this hose was modified to match with the discharge port diameter of each tested pump;
- ❹: Discharge tank: a 1.8 m^3 tank allowing the recovery and quantification by weighing the product collected by the skimmer and transferred by the pump. The weighing measurements were performed using the Tractel® Dynafor™ Expert LLX2 dynamometer;
- ❺: Sampling beakers used to collect the product in order to determine *a posteriori* the selectivity of the process (see protocol § 2.5).

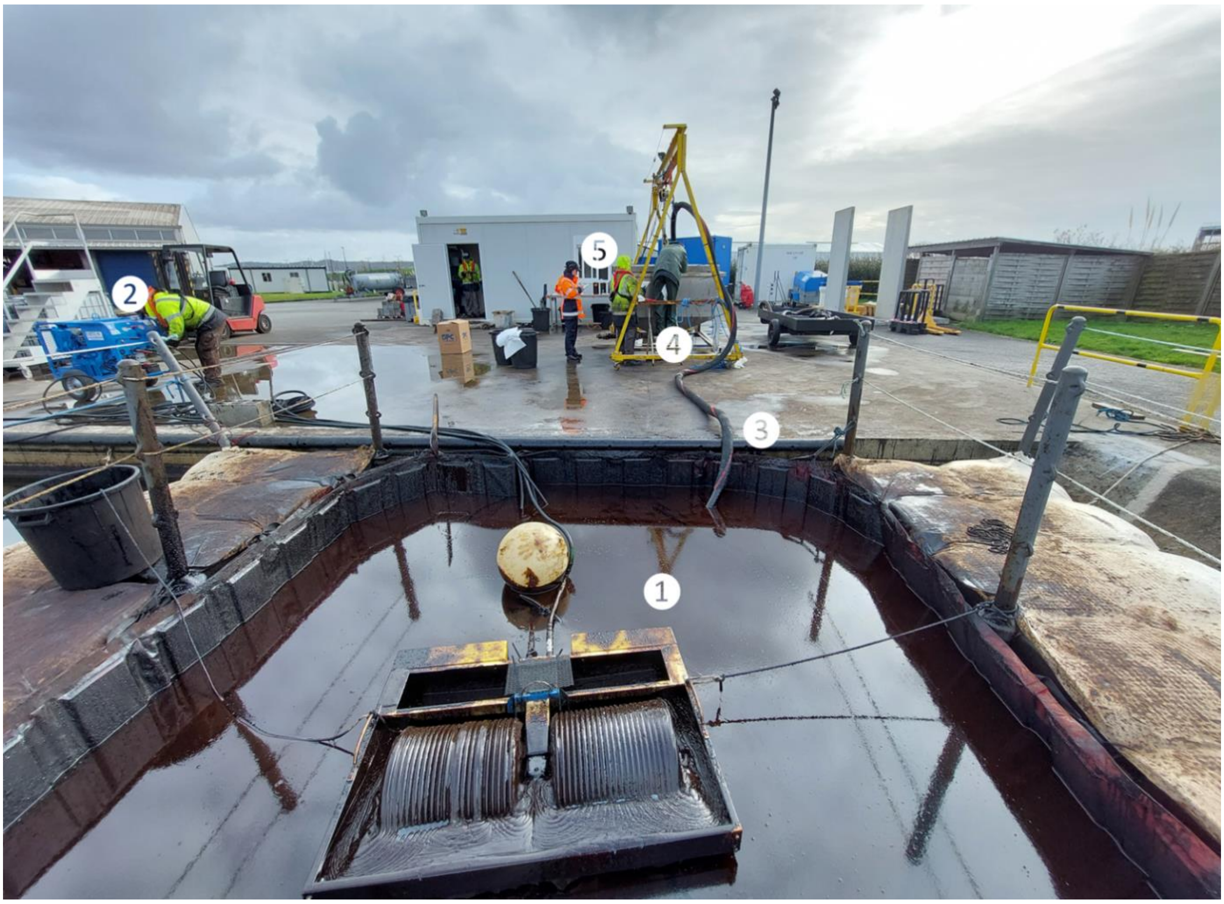

Figure 1 *Test areas*

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2.5 Test protocol

Test grid

Tests were carried out in order to determine the influence of the oils and emulsions on the performance of the device (in particular on the selectivity, the water content and the rate of collection of the hydrocarbon). The provisional test grid is presented on *Figure 2*.
Given the nature of the oils, it was decided to start the trials with the sample IM-15, more fluid and looking less challenging than IM-14.

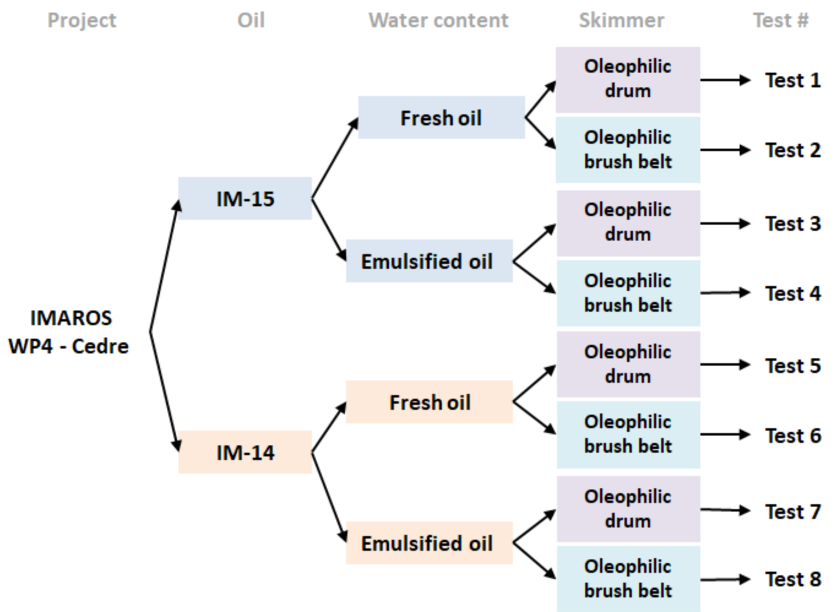


Figure 2 *Provisional tests grid*

Test protocol

A. <u>Tests preparation</u>
   - A.a. Measurement of the water temperature (spill area);
   - A.b. Measurement of the oil density and viscosity at the temperature measured in A.a;
   - A.c. Discharge of the oil;
   - A.d. Installation of the skimmer;
   - A.e. Launching of the hydraulic unit to initiate the test (activation of the recovery);
   - A.f. Waiting a homogeneous discharge (water + hydrocarbons).

B. <u>Start of the performance measurements</u>
   The time step of each of the actions performed during step B must be recorded in order to determine the recovery rate and time associated with each sample.
   - B.a. Flow measurements: continuous measurements (1 second time step);

B.b. Selectivity and water content measurements: sampling at the outlet of the discharge pipe (at T_0, then define the time step according to the recovery flow rate).

C. <u>End of test</u>

C.a. Shut down the hydraulic unit;

C.b. Reading of the results.

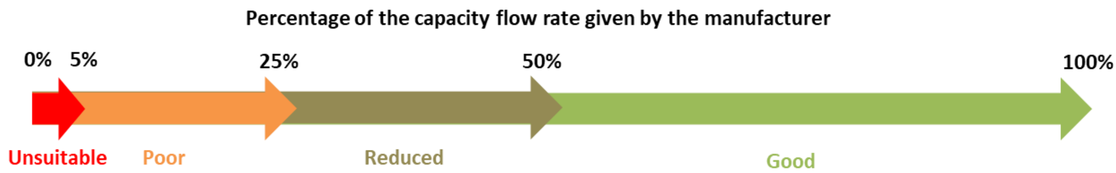
Reading of the results

Three parameters were measured / observed to estimate the performance of a skimmer: the motion of the oil slick, the selectivity and the oil recovery rate. These parameters can be influenced by the thickness of the slick and the viscosity of the collected oil. Their influence on the selectivity and the recovery rate were therefore studied according to the test grid presented in *Figure 2*.

The **motion of the slick** is observed qualitatively by the operators (setting in motion or splitting of the slick by the skimmer).

The **recovery rate** is measured according to the volume recovered and the selectivity, then qualified as:

- "Good", when the uptake is over 50% of the capacity flow rate given by the manufacturer,
- "Reduced", when the uptake is between 25% and 50% of the capacity flow rate given by the manufacturer,
- "Poor" , when the uptake is between 5% and 25% of the capacity flow rate given by the manufacturer,
- "Unsuitable", when the uptake is below 5% of the capacity flow rate given by the manufacturer.



The **determination of the selectivity** was carried out after 20 minutes of decantation (in accordance with the NF T71-500) from the samples taken at the outlet of the discharge pipe, by taking into account two parameters:

- **The quantity of free water** in each sample in order to determine the percentage of oil (emulsified or not) recovered;
- **The percentage of water in the oil,** which corresponds to the emulsification of the oil through the quantification of the variation of the water content between the inlet and outlet of the recovery system.

The final selectivity corresponds to the volume collected minus the quantity of free water and the variation of the water content in the oil (see *Figure 3*).

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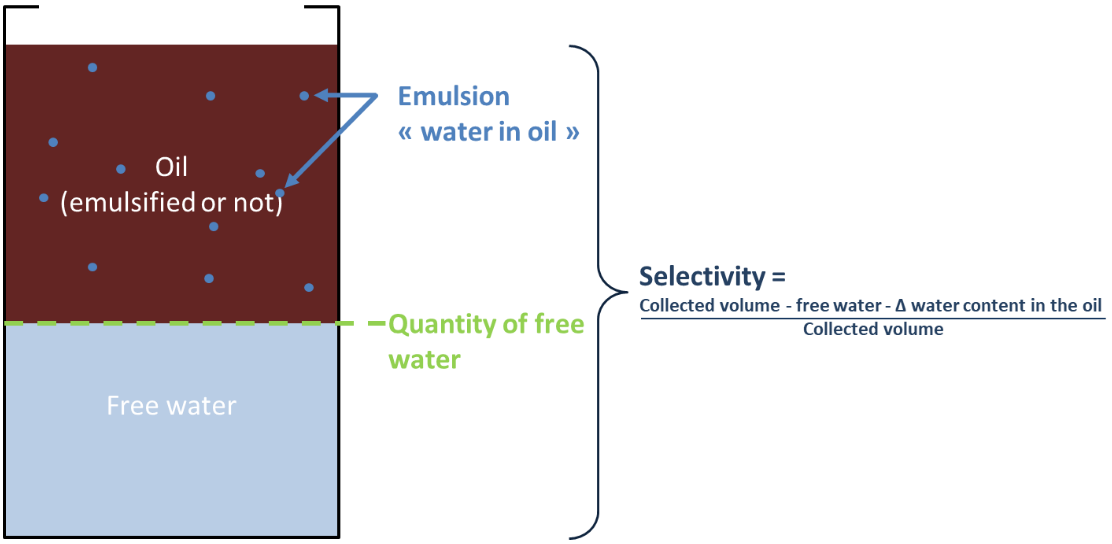

Figure 3 *Selectivity measurement*

2.6 Test conditions and final tests grids

Tests were carried out in the configuration recommended by the manufacturer (skimmer + pump + hydraulic unit). Nevertheless, when the flow rate was too low (less than 1 m^3/h), additional equipment (water injection and/or pump) was added and/or the slick was set in motion by the operators.

Thus, as it appeared during the first test that the pump associated with the drum skimmer was a limiting factor for recovery (the drums were very efficient but the pump couldn't transfer all the collected oil), different configurations have been tested:

- Test 1.1: drum skimmer associated with the recommended pump;
- Test 1.2: drum skimmer associated with the recommended pump connected with a water annular injection and with an additional volumetric lobe pump;
- Test 1.3: drum skimmer associated with the recommended pump and the volumetric lobe pump;
- Test 1.4: drum skimmer associated with the recommended pump connected with a water annular injection.

The configuration retained for all tests was the skimmer associated with the manufacturer recommended pump, coupled with an annular injection (Test 1.4 configuration)**.**

In the framework of the test campaign, a single test was initially planned for each condition. However, considering the trial with the emulsified IM-14 sample and the belt skimmer (trial #8), it appeared that the skimmer tended to create a "hole" in the slick by collecting only the product directly in contact with it. A second test was thus performed with the setting in movement of the slick by the operators (with paddle) in order to push the oil toward the drums.

It was then decided to assist the skimmers in collecting the oil by moving the slick towards the skimmer when they "dug" a hole in the slick.

The final tests girds is presented in Figure 4 and test conditions are synthetized in Table 1.

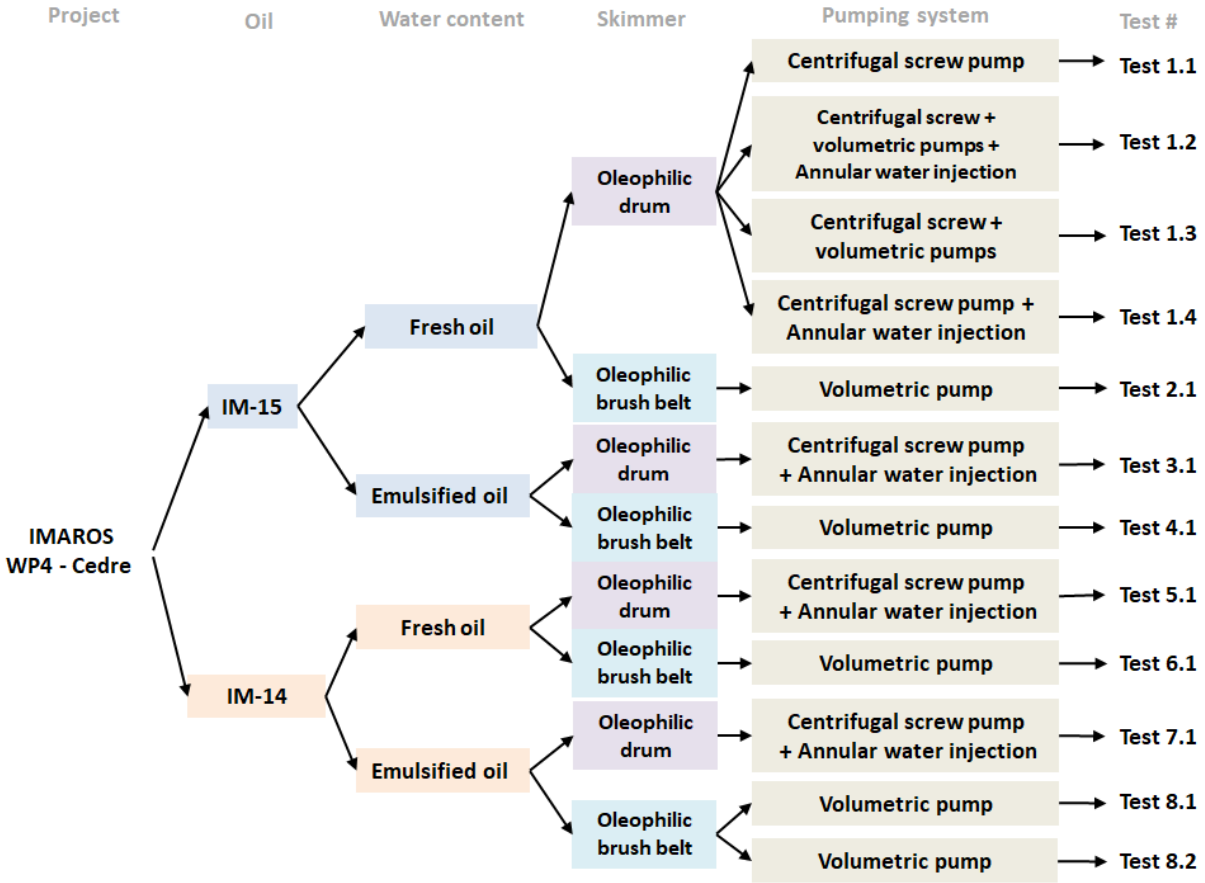

Figure 4 *Final tests gird*

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Table 1 *Test conditions*

Tests		1.1	1.2	1.3	1.4	2.1	3.1	4.1	5.1	6.1	7.1	8.1	8.2
Slick characteristics	Oil	Fresh IM-15					IM-15 emulsified		Fresh IM-14		IM-14 Emulsified		
	Water content	/				/	57%	48%	/	/	55%	50%	
	Visosity (in cSt) ($10.s^{-1}$)	9 144 at 8°C				7 145 at 11.3°C	68 198 at 7.5°C	28 677 at 11°C	26 768 at 8.9°C	33 625 at 8,3°C	42 022 at 7°C	35 149 at 7.7°C	
	Oil layer	7.5 cm (homogenous)					7.5 cm (homogenous)		7.5 cm (not homogenous because HC freezes in contact with cold water)		6.8 cm (homogenous)	7.5 cm (homogenous)	
Recovery system	Skimmer	Oleophilic drum				Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic brush belt
	Pump	Centrifugal				Volumetric	Centrifugal	Volumetric	Centrifugal	Volumetric	Centrifugal	Volumetric	Volumetric
	Discharge hose diameter	3 inches				4 inches	3 inches	4 inches	3 inches	4 inches	3 inches	4 inches	
	Additional equipment	/	+Annular water injection + volumetric lobe pump	+ volumetric pump	+Annular water injection	/	+Annular water injection	/	+Annular water injection	/	+Annular water injection	/	/
Motion of the slick		/				Assist (paddle) at the end of the test (thin layer)	Assist (paddle) at the end of the test (thin layer)	Assist (paddle) at the end of the test (thin layer)	Assist (paddle)	Assist (paddle)	Assist (paddle)	/	Assist (paddle)

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3 Results

3.1 Detailed results of each trial

Fresh IM-15

A) Oleophilic drum skimmer

A single test was initially planned with the fresh IM-15 oil and the drum skimmer, using the centrifugal pump supplied with the skimmer. However, it appeared during the first test (1.1) that the pump was a limiting factor for recovery (the drums recovered more oil than the pump could transfer). Four trials were thus performed in order to test different configurations:

- Test 1.1: drum skimmer associated with the centrifugal pump;
- Test 1.2: drum skimmer associated with the centrifugal pump connected with an water annular injection and with a volumetric lobe pump;
- Test 1.3: drum skimmer associated with the centrifugal pump and a volumetric pump;
- Test 1.4: drum skimmer associated with the centrifugal pump connected with a prototype of annular injection.

The metal grid protecting the pump against marine litter, which created a flow restriction, was removed.

These tests were performed at 8°C, which induced an oil viscosity of 9 177 cSt ($10.s^{-1}$).

Motion of the slick

It appears that drums were very efficient and that the oil flowed naturally towards the skimmer without need to push the slick.

Selectivity

Selectivity ranged between 72% and 98% (test 1.1 around 98%, test 1.2 around 86%, test 1.5 around 95% and test 1.4 around 72%).

As expected tests **with the annular injection** (1.2 and 1.4) have a **lower selectivity** than the test without annular injection, probably due to the volume of water brought in by this system.

Oil recovery rate

As seen before, for all tests with the oleophilic drum skimmer the metal grid protecting pump against marine litter, which created a flow restriction, was removed.

In the test 1.1 the skimmer recovered more oil than the pump could transfer: in this configuration the recovery rate was qualified as “poor” (0.7 m^3/h i.e. 4% of the maximum skimmer’s recovery rate). This is why other configurations were tested.

The more efficient tests in terms of recovery rate were:

- Test 1.2, with the annular injection and the volumetric pump, which was qualified as "reduced" (≈ 6.5 m^3/h, i.e. ≈33% of the maximum skimmer's recovery rate), followed by,
- Test 1.4, with the annular injection, which is qualified as "poor" (≈ 3 m^3/h, i.e. ≈ 15% of the maximum skimmer's recovery rate).

As expected, tests **with the water annular injection** (1.2 and 1.4) have an **upper flow rate** than the test without water annular injection.

Figure 5 *Test 1.1*

Figure 6 *Test 1.2*

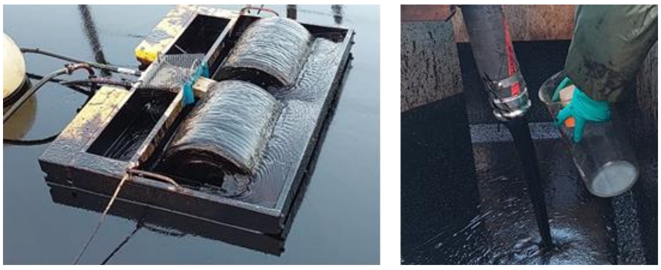

Figure 7 *Test 1.4*

B) Oleophilic brush belt skimmer

A single test was performed, using the pump supplied with the skimmer. The skimmer and pump were efficient but the propeller disseminates the oil in the basin under the boom.

This test was performed at 11.3°C, which induced an oil viscosity of 7 145 cSt (10.s^{-1}).
The metal grid protecting pump against marine litter did not create any flow restriction and was then kept in its place.

Motion of the slick

The oil flowed naturally to the skimmer without the need to push the slick, except at the end of the test (≈ T_0+10min), when the oil turned into small patches of oil instead of a thin continuous layer.

Selectivity

In term of selectivity, the average selectivity was around 94%.

Oil recovery rate

In terms of recovery rate, the average flow rate was around 3.4 m^3/h.

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IM-15 Emulsified

A) Oleophilic drum skimmer

A single test was performed with the emulsified IM-15 oil using the pump supplied with the skimmer and the water injection. The drums were very efficient. The metal grid protecting pump against marine litter, which created a flow restriction, was removed.

This test was performed at 7.5°C, which induced an emulsion viscosity of 68 198 cSt (10.s^{-1}).

Motion of the slick

It appears that the skimmer was effective and the oil flowed naturally to the skimmer without the need to push the slick, except at the end of the test, when the oil was only in small amounts and created patches of oil instead of a thin continuous layer.

Selectivity

In term of selectivity, the average selectivity was around 58% (with the water annular injection).

Oil recovery rate

As for the test with fresh IM-15 oil, the skimmer recovered more oil than the pump could transfer: the centrifugal pump showed difficulties and worked thanks to annular water injection addition.

The average flow rate was around 2.22 m^3/h (with the annular water injection).

B) Oleophilic brush belt skimmer

A single test was performed with the emulsified IM-15 oil and the oleophilic brush belt skimmer, using the pump supplied with the skimmer. The skimmer and pump were efficient but the propeller disseminates the oil in the basin even if the rotation speed of the skimmer was reduced compared to fresh recovery in order not to make a hole into the slick.

This test was performed at 11°C, which induced an emulsion viscosity of 28 677 cSt (10.s^{-1}).

The metal grid protecting pump against marine litter, did not create any flow restriction and was then kept in its place.

Motion of the slick

It appears that the skimmer was effective and the oil flowed naturally to the skimmer without the need to push the slick, except at the end of the test, when the oil was only in small amounts and created patches of oil instead of a thin continuous layer.

Selectivity

In term of selectivity, the average selectivity was around 95%.

Oil recovery rate

In terms of recovery rate, the average flow rate was around 2.5 m^3/h.

Fresh IM-14

A) Oleophilic drum skimmer

A single test was performed with the fresh IM-14 oil using the pump supplied with the skimmer and the water injection. The metal grid protecting pump against marine litter, which created a flow restriction, was removed.

This test was performed at 8.9°C, which induced an emulsion viscosity of 26 768 cSt ($10.s^{-1}$).

Motion of the slick

The product in contact with the skimmer was collected but the skimmer tended to create a "hole" in the slick by collecting only the product that was directly in contact with it: the slick did not naturally flow back towards the skimmer and the skimmer did not present a sufficient attraction.

In order to collect the oil, the skimmer must be artificially fed (by paddles during the test).

Selectivity

In term of selectivity, the average selectivity is around 85% (with the skimmer artificially fed and the water annular injection).

Figure 8 *Fresh IM-14 oil recovered with the drum skimmer*

Oil recovery rate

As for the test with fresh IM-15 oil, the skimmer recovered more oil than the pump could transfer: the centrifugal pump showed difficulties and worked thanks to the annular water injection (see Figure 8).

The average flow rate was around 2.5 m^3/h (with the skimmer artificially fed and the annular water injection).

B) Oleophilic brush belt skimmer

A single test was performed with the fresh IM-14 oil and the oleophilic brush belt skimmer, using the pump supplied with the skimmer.

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This test was performed at 8.3°C, which induced an emulsion viscosity of 33 625 cSt ($10.s^{-1}$).

The metal grid protecting pump against marine litter did not create any flow restriction and was then kept in its place.

Motion of the slick

It appears that the skimmer was efficient but the it tended to create a "hole" in the slick by collecting only the product that was directly in contact with it: as the slick has a frozen appearance, it did not naturally flow back towards the skimmer and the skimmer did not present a sufficient attraction in spite of the presence of a propeller.

In order to collect the oil, the skimmer must be artificially fed.

Figure 9 *"Hole" in the fresh IM-14 oil slick created by the belt skimmer*

Selectivity

In term of selectivity, the average selectivity was around 94% (with the skimmer artificially fed).

Oil recovery rate

The average flow rate was around 2.2 m^3/h (with the skimmer artificially fed).

Emulsified IM-14

A) Drum skimmer

A single test was performed with the emulsified IM-14 oil and the drum skimmer, using the pump supplied with the skimmer and the water injection. The metal grid protecting pump against marine litter, which created a flow restriction, was removed.

This test was performed at 7°C, which induced an emulsion viscosity of 42 022 cSt ($10.s^{-1}$).

Motion of the slick

The product in contact of the skimmer was collected but the drum tended to create a "hole" in the slick by collecting only the product that was directly in contact with it: the slick did not naturally flow back towards the skimmer and the skimmer did not present a sufficient attraction.

In order to collect the oil, the skimmer must be artificially fed.

Selectivity

In term of selectivity, the average selectivity was around 52% (with the skimmer artificially fed and the annular injection).

Oil recovery rate

As for the test with fresh IM-15 oil, the skimmer recovered more oil than the pump could transfer: the centrifugal pump showed difficulties and worked thanks to the water injection (prototype) (see Figure 10).

The average flow rate was around 0.5 m^3/h (with the skimmer artificially fed and the annular injection).

Figure 10 *Emulsified IM-14 oil recovered with the drum skimmer, with and without water annular injection*

B) Oleophilic brush belt skimmer

In the framework of the test campaign, a single test was initially planned with the emulsified IM-14 oil and the belt skimmer. However, as it appeared that the skimmer tended to create a "hole" in the slick by collecting only the product directly in contact with it. A second test was thus performed with the setting in movement of the slick by the operators (with paddle) Thus tow trials have been performed in order to test different configurations:

- Test 8.1: belt skimmer associate with the volumetric pump;
- Test 8.2: belt skimmer associate with the volumetric pump with the slick setting in movement by the operators.

This test was performed at 7.7°C, which induced an emulsion viscosity of 35 149 cSt ($10.s^{-1}$).

The metal grid protecting pump against marine litter did not create any flow restriction and was then kept in place.

Motion of the slick

In the 8.1 test, the product in contact of the skimmer was collected but the skimmer tends to create a "hole" in the slick by collecting only the product that is directly in contact with it:

the slick does not naturally flow back towards the skimmer and the skimmer does not present a sufficient attraction in spite of the presence of a propeller.

In order to collect the oil, a second test will be performed with the artificial fed of the skimmer.

Selectivity

In term of selectivity, the whole of the tests are up to 75% of selectivity (test 8.1 around 79% and test 8.2 around 99%).

As expected test **without the slick setting in movement by the operators** had a **lower selectivity** than the test with.

Oil recovery rate

In term of oil recovery flow rate test 8.1 was around 0.2 m^3/h and test 8.2 around 5 m^3/h.

As expected test **without the slick setting in movement by the operators** had a **lower flow rate** than the test with.

3.2 General comments

3.2.1 Oil aspects

3.2.1.1 IM-15

The fresh IM-15 appeared very sticky compared to the same emulsified oil, which was easier to recover. The emulsion was prepared ex-situ in order to control its water content and homogeneity. It was made in a specially designed mixing tank by a continuous addition of water to the oil. It took approximately 4 hours to form each emulsion.

3.2.1.2 IM-14

The fresh and emulsified IM-14 oil appeared less sticky compared to the fresh IM-15 but the emulsion looked more elastic. The emulsion was prepared ex-situ in order to control its water content and homogeneity. It was made in a specially designed mixing tank by a continuous addition of water to the oil. It took approximately 4 hours to form each emulsion. The emulsions were not easy to form, the pre-heating of the oil was necessary to obtain a stable and homogeneous emulsion.

Oils characteristics are presented in *Table 2*. Due to rheological properties of the oils, viscosities are given at two different shear rates, 10 s^{-1} and 100 s^{-1}

Table 2 *Fresh and emulsified oils characteristics*

	Water content	Temperature (°C)	Density	Viscosity ($10 s^{-1}$, in cSt)	Viscosity ($100 s^{-1}$, in cSt)	Slick layer	Note
Fresh IM-15	0 %	8.5	0.954	9 144	9 009	Homogeneous thickness layer in the test area (7.5 cm)	Very sticky and dark blackish color (see Figure 11)
		11.3	/	7 145	6 426		
Emulsified IM-15	57 %	7.5	/	68 198	15 685	Homogeneous thickness layer in the test area (7.5 cm)	Less sticky with a brown color (see Figure 11)
	48 %	11		28 677	12 654		
Fresh IM-14	0 %	8	0.944	26 768	14 044	Not homogeneous (frozen) = average thickness 7.5 cm	Dark blackish colored slick frozen in contact with the cold water (see Figure 12)
		8.3	/	33 625	14 734		
Emulsified IM-14	55 %	7	/	42 022	1 379	Homogeneous thickness layer in the test area (7.5 cm)	Brown colored slick more or less homogenous. Appears elastic (see Figure 12)
	50 %	7.7		35 149	666		

/ : Not measured

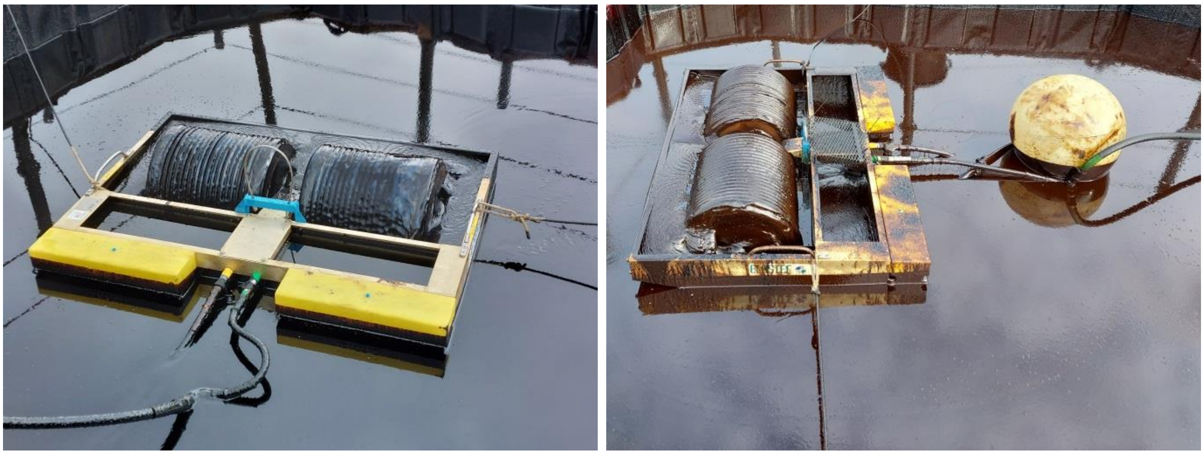

Figure 11 *Fresh (on the left) and emulsified at 57% of water (on the right) IM-15 oil*

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Figure 12 *Non-homogeneous slick of fresh IM-14 oil frozen in contact with cold water (on the left) and homogenous slick of emulsified IM-14 oil (on the right)*

3.2.2 Oil recovery

Motion of the slick

No significant difference was observed between the two skimmers on their capacity to attract the slick:

- Considering IM-15:
  - for thick layers, the oil flowed naturally towards both skimmers.
  - for thin oil thickness, assistance was required in order to feed the skimmer with oil (use of paddles) for the emulsified oil with the two skimmers and for the fresh oil with the oleophilic brush belt skimmer.

  With the oleophilic brush belt skimmer, **the propeller tended to disseminate oil in the basin**.

- Considering IM-14:
  - both skimmers dug a hole in the part of the slick that was in direct contact with the skimmer. Assistance was required in order to feed skimmers with oil (use of paddles). **The oil did not flow naturally toward skimmers.** This could be due to **its high pour point** which, at the test temperature, induces the oil freezing.

Under equal conditions (meteorological and oceanic conditions, recovery system and recovery conditions), **slick movement, selectivity and recovery flow rate were influenced by the oil properties**.

Selectivity

In optimal test condition (with annular water injection and oil setting in motion with paddles if necessary), **no obvious difference between the two tested oils was observed.** Selectivity ranged between 58% and 95% for all the conditions tested on IM-14 and between 52% and 99% for all the conditions tested on IM-15.

It appeared that the oleophilic brush belt skimmer tended to be more selective than the oleophilic drum skimmer, for the two oils tested (between 10 and 40 % more selectivity). The use of annular water injection in order to help the pump of the oleophilic drum skimmer to transfer tested oils may partially explain this difference because of the water brought into the flow rate by this annular water injection equipment.

Recovery flow rate

Except for the emulsified IM-14 oil, in optimal test condition (with annular water injection and oil setting in motion with paddles if necessary), **belt and drum skimmers had similar recovery flow rate** (between 2 and 3.5 m^3/h, with less than 0.5 m^3/h difference for similar tests). Overall, the recovery rate remained higher on fresh hydrocarbons which are less viscous.

In function of the oil nature, the **pump could be a limiting factor for the oil recovery**, even if the oleophilic drums or the oleophilic brush belts were efficient.

In the framework of the tests, the oleophilic drum skimmer associated with the centrifugal screw pump (supplied with the skimmer), which are a proven technologies, couldn't transfer tested oils. Indeed, it appeared that the pump was a limiting factor for recovery (the drums recovered more oil than the pump could transfer). This problem was solved by adding a second pump in series and/or adding an annular water injection system. This issue didn't not appear with the oleophilic brush belt skimmer and its associated volumetric pump.

In addition, this difficulty in transferring the pollutant was probably increased by the smaller discharge diameter (3 inches) of the oleophilic drum skimmer compared to the oleophilic brush skimmer (4 inches).

During the tests at Cedre ,a length of 10 m was used for both discharges hoses. It is probable that, in the reality of oil spill response operations, greater length of discharge hoses are used, thus increasing this difficulty in transferring the pollutant for smaller discharge diameter.The details of each test are available in **Erreur ! Source du renvoi introuvable.**1.

Other observation

During the cleaning operation of the facility following the trials with IM-15 oil, it appeared that the underwater propeller associated with the belt skimmer had disseminated oil in the basin, under the boom used to create the test area.

Operators recovered it with landing net as the oleophilic sorbents seems to be inefficient to recover this oil after it has been broken in small drops by the propeller and weathered during one day on the surface.

3.3 Summary of test conditions and results

Table 3 hereafter summarizes the tests conditions and the results. A color code has been defined. Selectivity threshold were internally decided thanks to observation during the trials. Flow rate threshold are detailed in section 2.5.

Keys:

Selectivity (s)
100 % > s ≥ 80 %
80 % > s ≥ 50 %
50 % > s > 0%

Flow rate
Good
Reduced
Poor
Unsuitable

Test assessment
Validated
Validated with reserve
Not validated under test conditions

Text:

1) The recovery rate is too low to consider this solution in operational conditions.
2) This configuration can be considered as a backup solution but is not optimal from an operational point of view (double pump needed).
3) This configuration can be considered as a backup solution but is not optimal from an operational point of view (annular injection added).
4) From an operational point of view, this solution seems to be the most adapted to the recovery tests of the IM-15 with the tested drum skimmer.
5) This configuration can be considered to recover the largest part of the slick before a finer recovery.
6) This configuration can be considered in a dynamic recovery situation (recovery in an area with stream for example).

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Table 3 *Summary of test conditions and results*

	Tests	1.1	1.2	1.3	1.4	2.1	3.1	4.1	5.1	6.1	7.1	8.1	8.2
Slick characteristics	Oil	Fresh IM-15					Emulsified IM-15		Fresh IM-14		Emulsified IM-14		
	Water content	/				/	57%	48%	/	/	55%	50%	
	Visosity (in cSt) ($10.s^{-1}$)	9 144 at 8°C				7 145 at 11.3°C	68 198 at 7.5°C	28 677 at 11°C	26 768 at 8.9°C	33 625 at 8,3°C	42 022 at 7°C	35 149 at 7.7°C	
	Oil layer	7.5 cm (homogenous)					7.5 cm (homogenous)		7.5 cm (not homogenous because HC freezes on contact with cold water)		6.8 cm (homogenous)	7.5 cm (homogenous)	
Recovery system	Skimmer	Oleophilic drum				Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic drum	Oleophilic brush belt	Oleophilic brush belt
	Pump	Centrifugal				Volumetric	Centrifugal	Volumetric	Centrifugal	Volumetric	Centrifugal	Volumetric	Volumetric
	Discharge hose diameter	3 inches				4 inches	3 inches	4 inches	3 inches	4 inches	3 inches	4 inches	
	Additional equipment	/	+Water annular injection + volumetric lobe pump	+ AL75 pump	+ Water annular injection	/	+ Water annular injection	/	+ Water annular injection	/	+ Water annular injection	/	/
Results	Does oil slick stay in direct contact of the skimmer during the test?	The oil flows naturally towards the skimmer. **<u>No paddles</u>**				The oil flows naturally toward the skimmer, except at the end of the test (thin layer). **<u>No paddles at the begging</u>**	The oil flows naturally toward the skimmer, except at the end of the test. **<u>No paddles at the begging</u>**	The oil flows naturally toward the skimmer, except at the end of the test. **<u>No paddles at the begging</u>**	The skimmer "digs" a hole into the part of the slick in direct contact. **<u>Need to push the slick with paddles</u>**	The skimmer "digs" a hole into the part of the slick in direct contact. **<u>Need to push the slick with paddles</u>**	The skimmer "digs" a hole into the part of the slick in direct contact. **<u>Need to push the slick with paddles</u>**	The skimmer "digs" a hole into the part of the slick in direct contact. **<u>No paddle</u>**	The skimmer "digs" a hole into the part of the slick in direct contact. **<u>Need to push the slick with paddles</u>**
	Selectivity	98%	89%	95%	72%	94%	58%	95%	85%	94%	52%	79%	99%
	Oil recovery flow rate	Unsuitable: 0.70 m^3/h	Reduced: 6.56 m^3/h	Poor: 1.96 m^3/h	Poor: 2.97 m^3/h	Poor: 3.41 m^3/h	Poor: 2.22 m^3/h	Poor: 2.51 m^3/h	Poor: 2.48 m^3/h	Poor: 2.17 m^3/h	Unsuitable: 0.5 m^3/h	Unsuitable: 0.21 m^3/h	Poor: 4.96 m^3/h
	Test assessment	1)	2) and 3)	2)	3) and 4)	5)	2) and 5)	5)	2) and 6)	6)	1)	1)	6)

Conclusion

The objective of the Task 4.1 of the IMAROS project was to test the mechanical recovery of two VLSFO (fresh and emulsified) collected by the project partners with two different skimmers (oleophilic drum skimmer and oleophilic brush belt skimmer) in order to improve our knowledge on those products and recovery systems. Tests were carried out in Cedre's testing facilities and laboratory. Tests were performed in an external basin in Cedre's facilities, at ambient temperature (between 7°C and 12°C, representative weather conditions encountered in the European waters).

Table 4 summarizes the main conclusion of the tests.

Table 4 *Main conclusion obtained after recovery trials of the two VLSFO IM-14 and IM-15*

<table>
<tr><th colspan="2"></th><th>IM-15
Fresh</th><th>IM-15
Emulsified</th><th>IM-14
Fresh</th><th>IM-14
Emulsified</th></tr>
<tr><td colspan="2">Motion of the slick</td><td colspan="2">Oil flows naturally to the skimmers</td><td colspan="2">Need dynamic conditions (skimmer in motion on the slick or skimmer feed)</td></tr>
<tr><td rowspan="2">Recovery</td><td>Oleophilic drum skimmer</td><td>Efficient</td><td>Efficient</td><td>Can be appropriate in dynamic conditions</td><td>Can be appropriate in dynamic conditions</td></tr>
<tr><td>Oleophilic brush Belt skimmer</td><td>Efficient</td><td>Efficient</td><td>Can be appropriate in dynamic conditions</td><td>Can be appropriate in dynamic conditions</td></tr>
<tr><td rowspan="2">Transfer</td><td>Centrifugal pump</td><td colspan="4">Need water annular injection</td></tr>
<tr><td>Volumetric pump</td><td colspan="4">Can be appropriate</td></tr>
<tr><td colspan="2">Selectivity</td><td colspan="4">Between 52 % and 99 % : No difference between the oils
Oleophilic brush belt skimmer more selective</td></tr>
</table>

Considering the two VLSFO tested, the following observation could be formulated:

- With the oleophilic drum skimmer used, a volumetric pump instead of the centrifugal one could enhance recovery rates;
- A discharge hose diameter of 4" instead of 3" would reduce frictions, especially for longer discharge hoses;
- Water annular injection option could be interesting if the pump has difficulty in transferring such oils ;
- Dynamic conditions (skimmer in motion in the slick, or slick moving towards the skimmer) could be considered to recover this kind of products in order to feed the skimmer and avoid the creation of a gap between the skimmers and the oil slick.

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WP4

DELIVERABLE D4.2

TASK 4.3: *IN SITU* BURNING

FINAL REPORT

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1 Material and Methods

Cedre has developed a test dedicated to assess the possibility of using the *in situ* burning technique, in terms of both efficiency and potential impacts. The device recreates the conditions of ignition of an oil slick (*Figure 1*).

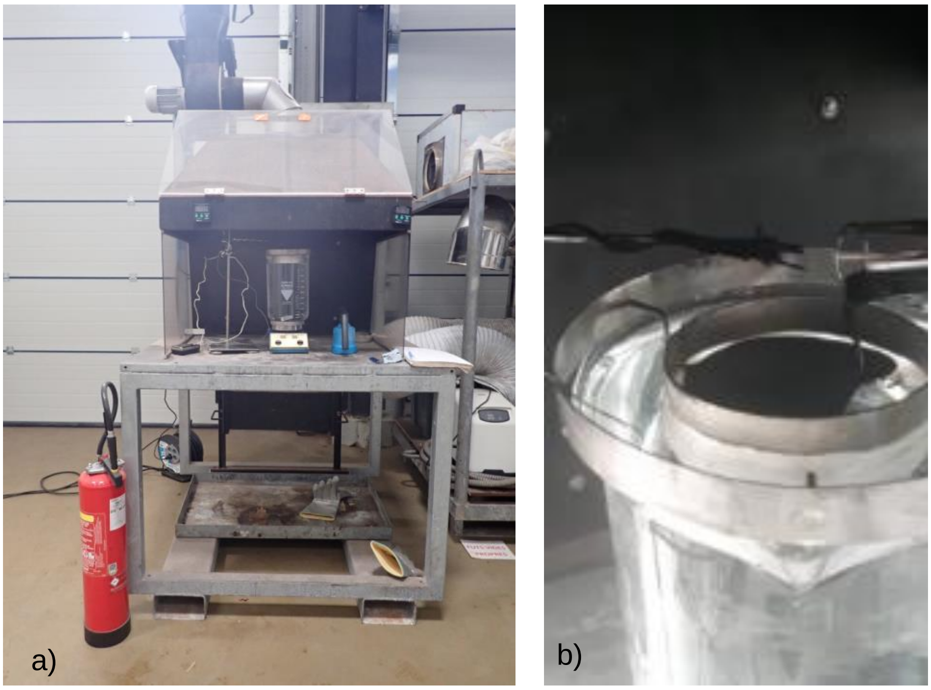

Figure 1 *a) General view of the test bench and b) zoom on the 100 mL oil poured at the water surface, in the glass beaker*

The principle of these tests is to assess the oils ignitibility and to determine the efficiency of the technique. These determinations are completed by viscosity and density measurements of the burning residues.

In the frame of the EU co-funded IMAROS project, three VLSFO were tested (IM-5, IM-14, IM-15). For each of them, triplicates were performed. Around 100 grams of oil were placed in Cedre's burning cell and ignited. Oils were previously placed in the oven at 50°C overnight and mixed before addition to the cell. After addition to the cell, a waiting time was observed to allow the product spreading and equilibrating at room temperature. A reference oil (the same HFO as the one tested in the task 4.4) was tested in one replicate.

The flame was maintained for 10 seconds. The flammability of the oil was visually checked. Burning is considered successful if the oil burns for few minutes (generally around 10 minutes according to this protocol).

Burning residues were extracted by using dichloromethane, ultrasonic bath and after drying on sodium sulphate. Burning efficiency (in %) was calculated as the difference of oil masses (before and after burning) divided by the mass of oil before burning.

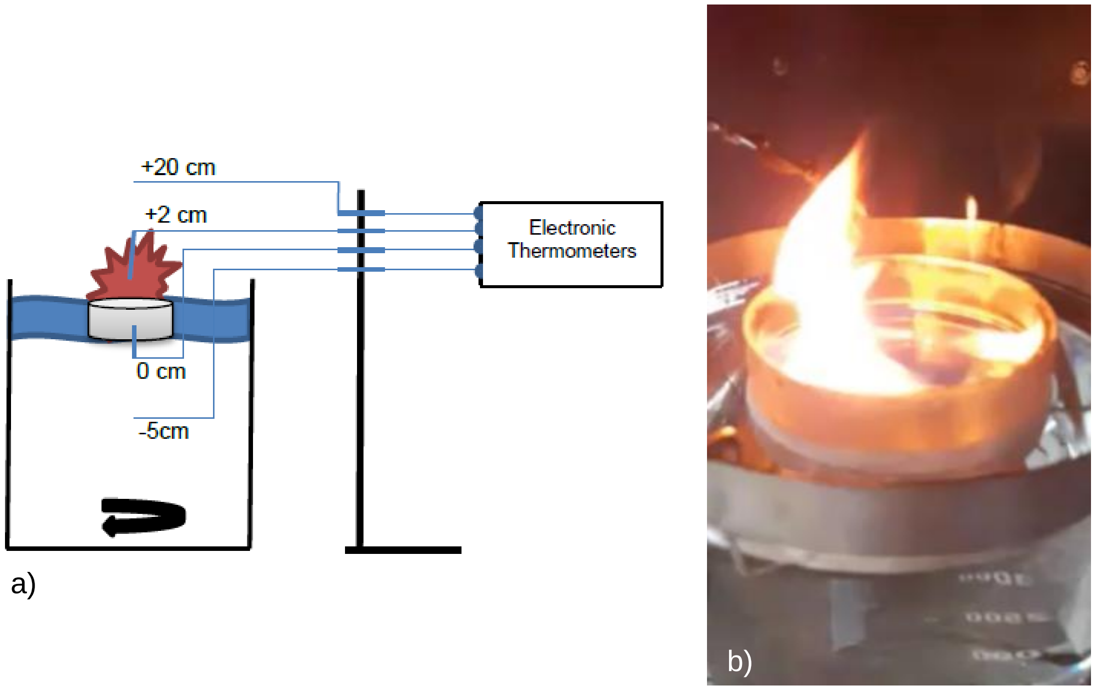

Figure 2 *a) Scheme of the burning cell, b) example of oil burning (IM-5)*

If no flammability was notified, two other attempts of 10 seconds each were performed. Burning is considered non successful if the oil does not catch fire after those attempts. If the burning efficiency is significant, a quantification of the Polycyclic Aromatic Hydrocarbons is performed in the water column in order to provide an assessment of the potential environmental effects due to this technique during real operations (comparison of the concentrations measured during the tests and without burning). Characterization of the residues in terms of viscosity and density is also performed.

In the frame of this project, additional tests were carried out in case of unsuccessful burnings. Oils were exposed to a flame on a continuous way, for a maximum duration of 10 minutes. At the end of those 10 minutes, if no burning was still observed, igniter was added. Gelly igniter was prepared by mixing 1.3 g of igniter powder to 16 g of diesel, 4g of gasoline. A first addition of ~6% (in relation to the amount of oil, i.e. approx.. 1g) of gelly igniter was performed and if no burning was observed, more ignitor was added (~ 3g in total).

2 Results

Table 1 presents the results obtained during this campaign trial. Except for one of the IM-15 replicate, no burning was observed following the usual protocol of ignition of 10 seconds for the three oils tested. For IM-5 and IM-15, the continuous flame allowed initiating the burning within 1 minute. Once burning was initiated, those two oils burnt for ~10 minutes. However, burning efficiencies were low for both oils (~15% for IM-5 and ~10% for IM-15). Residues were characterized in terms of viscosity and density for those two samples. Results, which were compared to the fresh oil values, are summarised in *Table 2*. Residues logically exhibited higher density and viscosity values than the fresh oils. Considering IM-14, even with 10 minutes of continuous flame, the oil did not catch fire. Gelly igniter was needed to initiate burning of this VLSFO and the burning efficiency calculated using this technique was low (10 %). This result was similar to the one observed for the reference HFO that demonstrated an even lower burning efficiency (3 %). It should be noted that, in order to reduce the volume of dichloromethane and given the poor burning ability of IM-14 and of the HFO, the determination of burning efficiency for those two oils was determined by weighting of the recovered residue on a beforehand tared sorbent.

Given the difficulty encountered to initiate burning on those VLSFO and the low burning efficiencies calculated, the quantification of PAH in the water column was not performed.

Table 1 *Ignition and burning times, burning efficiency (in %) and comments on the burnings on the triplicates of oil*

	IM-5			**IM-15**		
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**
Ignition 10 seconds 1	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition
Ignition 10 seconds 2	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	2 seconds burning	2 seconds burning	2 seconds burning
Ignition 10 seconds 3	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	5 seconds burning	**10 min 20 seconds**	11 seconds burning
Ignition time 1	45 seconds	40 seconds	25 seconds	5 seconds	-	10 seconds
Burning time 1	**10 min**	10 seconds	7 seconds	25 seconds	-	2 seconds
Ignition time 2	-	1 minute 20 seconds	16 seconds	35 seconds	-	5 seconds
Burning time 2	-	**10 min**	**8 min 33 seconds**	5 seconds	-	5 seconds
Ignition time 3	-	-	-	15 seconds	-	10 seconds
Burning time 3	-	-	-	**9 min 20 seconds**	-	**9 min 06 seconds**
Burning with igniter (~ 1 g)	-	-	-	**-**	-	**-**
Burning with igniter (~ 3 g)	-	-	-	**-**	-	**-**
Observations	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams and sparks during burning. Flams covers the entire surface of the slick.
Burning efficiency (%)	**18,9**	**13,1**	**13,3**	**9,8**	**9,3**	**12,0**

Table 2 (cont.) *Ignition and burning times, burning efficiency (in %) and comments on the burnings on the triplicates of oil*

	IM-14			HFO
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**
Ignition 10 seconds 1	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition
Ignition 10 seconds 2	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition
Ignition 10 seconds 3	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition	Unsuccessful ignition
Ignition time 1 Burning time 1 Ignition time 2 Burning time 2 Ignition time 3 Burning time 3	10 minutes ignition unsuccessful	10 minutes ignition unsuccessful	10 minutes ignition unsuccessful	10 minutes ignition unsuccessful
Burning with igniter (~ 1 g)	-	-	Burning during 6 min	-
Burning with igniter (~ 3 g)	-	Burning during 12 min	Burning during 5 min	Burning during 3 min
Observations	-	Flams and sparks during burning. Flams covers the entire surface of the slick.	Flams at the ignitor, The oil does not burn. No sparks,	Flams and sparks during burning. Flams covers the entire surface of the slick.
Burning efficiency (%)	**-**	**-**	**9,6**	**3,0**

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Table 2 *Comparison of viscosity (in mPa.s, shear rate 10 and 100 s^{-1}) and density, at 15°C, between the fresh oils and the burning residues*

	IM-5	IM-15
Residue Viscosity @ 10s^{-1} (15°C) (mPa.s)	2 485	39 538
Residue Viscosity @ 10s^{-1} (15°C) (mPa.s)	1 206	18 103
Residue Density (15°C)	0.941	0.998
Fresh oil viscosity @ 10 s^{-1} (15°C) (mPa.s)	*398*	*4 305*
Fresh oil viscosity @ 100 s^{-1} (15°C) (mPa.s)	*507*	*4 137*
Fresh oil Density (15°C)	*0.911*	*0.951*

3 Conclusion

Three VLSFO were tested *for in situ burning*, using a dedicated test bench to assess the possibility of using the *in situ burning* technique, in terms of both efficiency and potential impacts.

Following the usual protocol of 10 seconds iginition, burning of the 3 oils was considered not successful. Additional attempts were carried out by increasing the ignition time (not exceeding 10 minutes). Two of the three VLSFO tested by this way caught in fire. The last one burnt only with the addition of a gelly igniter.

Once burning was initiated (regardless of technique), it lasted about 10 minutes and was not characterized by a burning efficiency of more than 15%.

Those results suggest that this technique seems difficult to be applied in real conditions considering a spill involving VLSFO.

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WP4

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TASK 4.4: SHORELINE IMPACT CLEANUP

FINAL REPORT

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1 Material and Methods

The oil adhesion on the shoreline was assessed at the pilot scale using a device developed at Cedre, the washing robot.

1.1 The washing robot

The equipment (*Figure 1*) is composed of the following main parts:

- a stainless steel frame with an internal volume of about 300 litres;
- a trolley with the washing nozzle;
- a support frame for the polluted hard surfaces;
- two electric screw jacks allowing horizontal and vertical movements of the trolley;
- a high pressure water washer (as can be found in most of oil spill response stockpiles);
- a programmable control driving the two electric screw jacks;
- a water supply with temperature regulation.

The equipment ensures consistent washing conditions for all the successive tests (spraying width, speed and distance). The hard surfaces (granite tiles) are thus washed exactly in the same way, allowing comparative tests.

Figure 1 *The washing robot*

1.2 Hard Substrates and oil addition

The rocky shoreline was simulated by using granite tiles (Quartzite Astera Gris), dimensions 15 x 15 x 2 cm. The surface of the tiles was not smoothed down in order to recreate a substrate as natural as possible (*Figure 2*).

Figure 2 *Granite tiles used in this experiment*

It was decided to work on fresh oils and not on weathered (emulsified) ones, because, even if emulsified oil reaches the coastline, when deposited the emulsion will break and only the layer of oil will remain on the shore. Prior to the beginning of the experiment, the three VLSFO (IM-5, IM-14 and IM-15) were placed in the oven overnight at 50°C. Those tests thus simulate the possible exposure conditions of liquid oil with the shoreline. A heavy fuel oil was used as a comparative and reference oil.
Around 3 grams of VLSFO and of the comparative heavy fuel oil were added at the surface of the tiles and spread with the finger in order to recover the totality of the surface (*Figure 3*). After oiling, tiles were let for drying in a horizontal position for 6 days.

Figure 3 *Example of tile after oil addition and after spreading with the finger*

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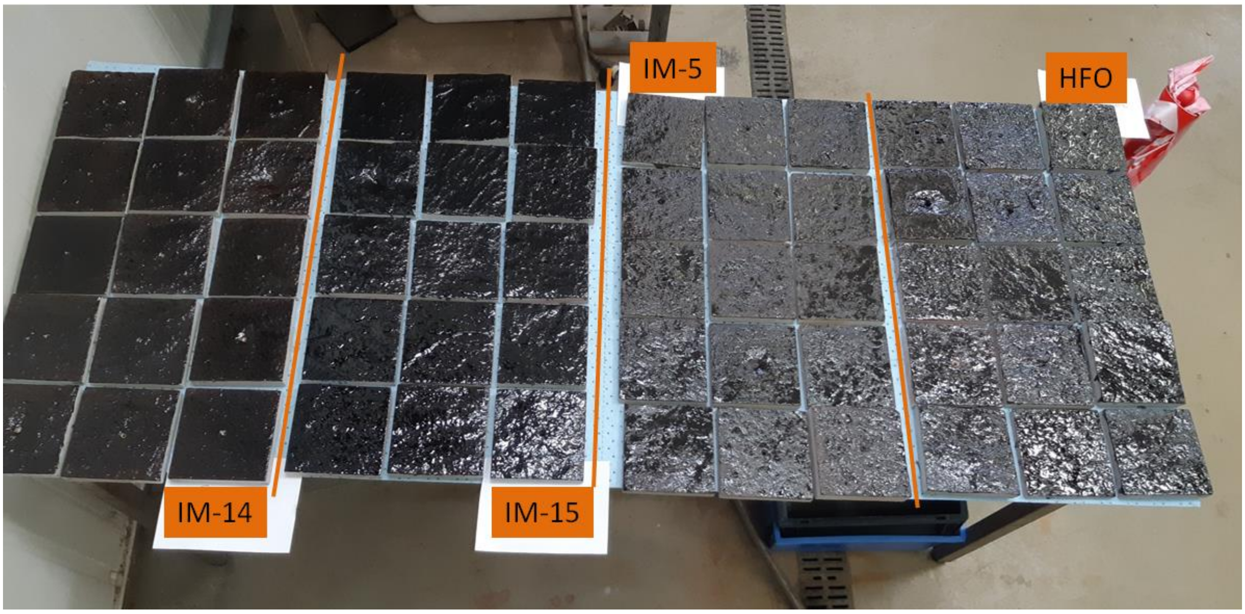

Figure 4 *General view of the polluted tiles after oil spreading*

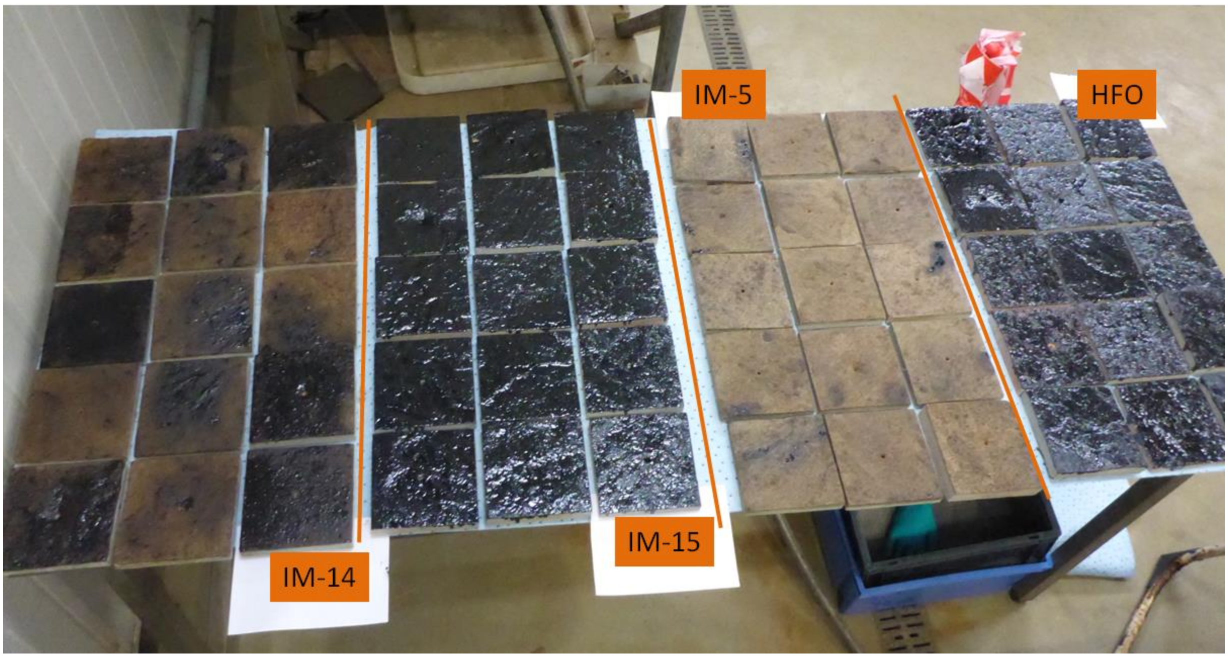

Figure 5 *General view of the polluted tiles after 6 days of drying*

Tiles were then placed in the washing robot for cleaning process using tap water (*Figure 6*). Two conditions of temperature and pressure were studied: ambient temperature (~15°C) and 50°C, 50 bars and 100 bars, leading to four washing experimental conditions: 15°C/50 bars, 15°C/100 bars, 50°C/50 bars and 50°C/100 bars. Control tiles represented polluted tiles not passed through the washing robot process. Triplicates were carried out for each condition,

leading to a total of 15 tiles for each oil. To ensure precise and repeatable washing conditions, tiles were washed 3 by 3 (triplicate of each conditions each time).
This protocol enables a comparison of the results obtained but does not reproduce shoreline clean-up technique as used in the field. In this study, only one water jet is used.

Figure 6 *Installation of tiles in the washing robot*

1.3 Quantification of oil remaining on tiles after cleaning

After cleaning process, the remaining oil was extracted by immerging the tiles (polluted face facing the crystilliser) in dichloromethane (pestipur quality), in an ultrasonic bath for 10 minutes in order to remove the totality of the oil adsorbed on the tiles surface, and, after drying on sodium sulphate (activated at 400°C overnight), diluted to appropriate concentrations (*Figure 7*). The absorbance, and then the concentration, was measured at 580 nm by using a UV/Vis spectrophotometer.

Extracted oil from those tiles allowed the calculation of the cleaning efficiency. This rate corresponds to the amount of oil extracted after the washing robot cleaning step divided by the amount of oil extracted from the control tiles. For each condition of washing, tests were performed in triplicates.

Figure 7 *Oil extraction in dichloromethane and drying over sodium sulphate*

2 Results

2.1 Oil penetration/absorption

As can be seen by comparing *Figures 4* and *5*, after the drying time (before washing), it appeared that IM-5 and, to a lesser extent, IM-14, penetrated into the tiles, leaving an almost oil free surface for IM-5.

A view of the edge tiles allows the observation of this phenomenon for the two samples IM-5 and IM-14 (*Figure 8*), compared to the IM-15 sample and to the HFO.

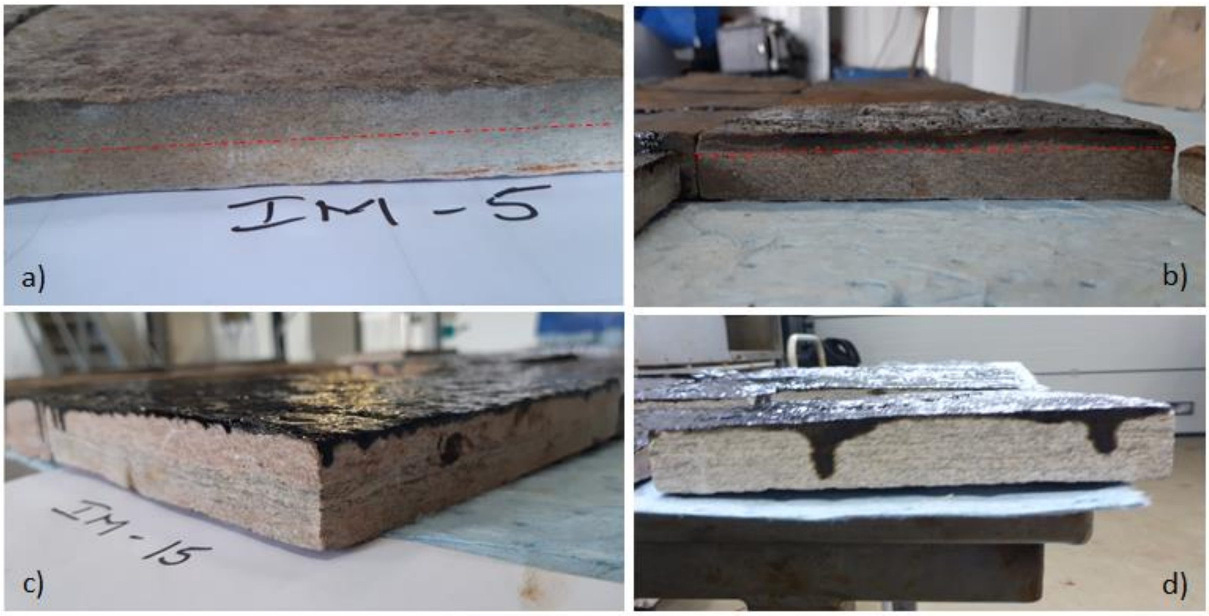

Figure 8 *Oil penetration a) IM-5, b) IM-14, c) IM-15, d) HFO*

Following this observation, few tiles of each VLSFO and of HFO were polluted with oil poured at ambient temperature to see if heated oil could induce this absorption. No washing was performed with the washing robot, the goal was only to study if the same phenomenon was observed for IM-5 and IM-14. *Figures 9* and *10* exhibit the evolution of the tiles aspect 1) immediately and 2) 24h after spreading (*Figure 9*), and after 6 days drying (*Figure 10*). Oil penetration was observed in the same way as in the first set of trials. The oil temperature cannot thus explain the observed phenomenon. Oil was extracted from those tiles to compare these values with the amounts recovered from the control tiles of the main experiment.

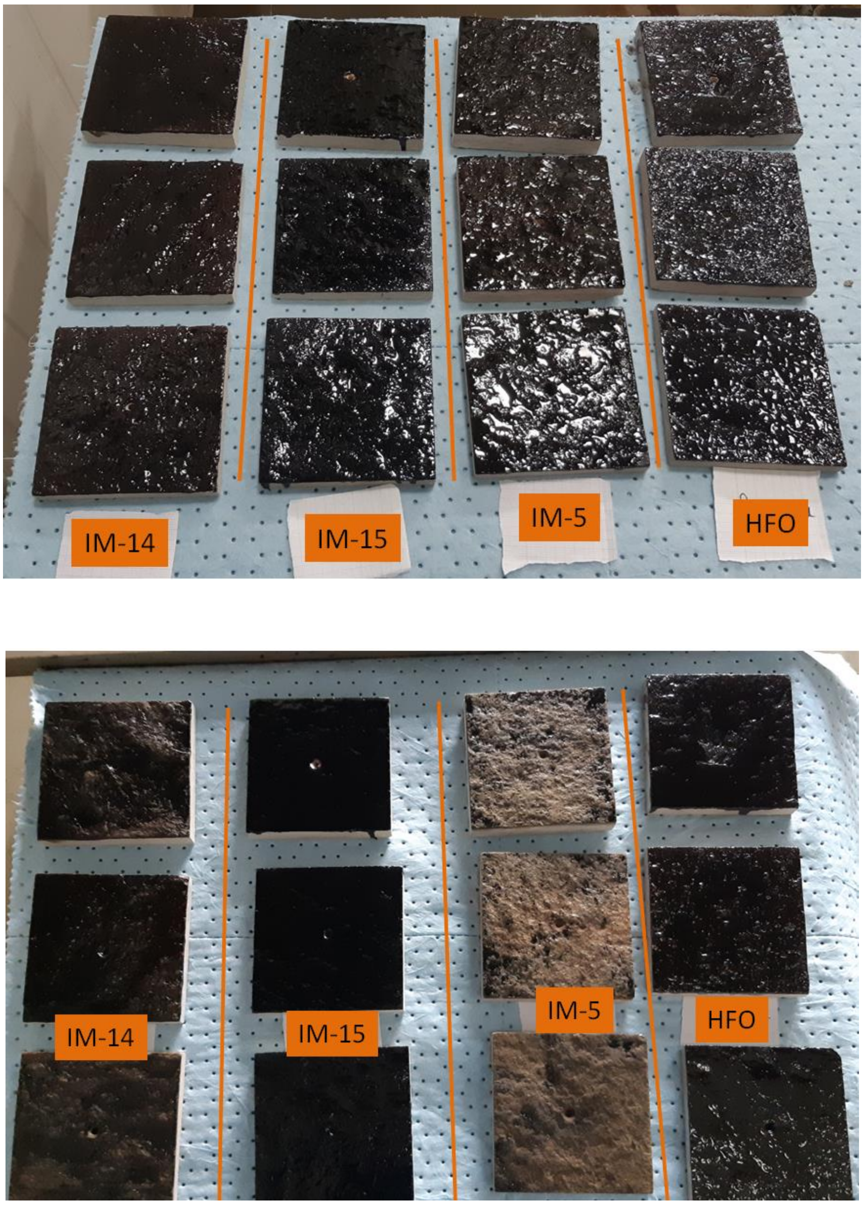

Figure 9 *Visual aspect of the tiles after addition of oil poured at ambient temperature (top: immediately after spreading, bottom: 24h after spreading)*

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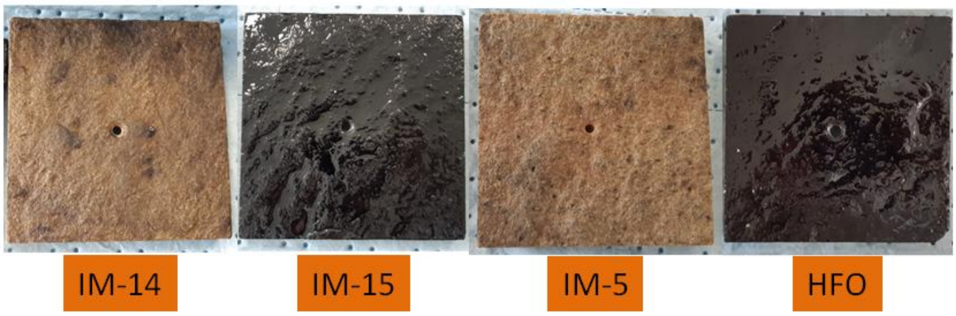

Figure 10 *Visual aspect of the tiles after addition of oil poured at ambient temperature and 6 days drying*

Table 1 presents the amount of oil (in grams) recovered after extraction on the control tiles (*i.e.* without washing phase). Results confirm that IM-5 and IM-14 are absorbed in the tiles and that the oil could not be completely recovered by extraction with dichloromethane (0.36 ± 0.07 g recovered for IM-5 and 0.74 ± 0.55 g recovered for IM-14, compared to ~2.40 g recovered for IM-15 and HFO). Results also confirm that this absorption is observed whatever the oil temperature when poured on the tiles (0.36 ± 0.07 g recovered for IM-5 poured heated compared to 0.25 ± 0.04 g recovered when poured at ambient temperature; 0.74 ± 0.55 g recovered for IM-14 poured heated compared to 0.74 ± 0.90 g recovered when poured at ambient temperature).

Table 1 *Amount of oil recovered (in g) on the control tiles (without washing process) after extraction, with oils poured heated or not on the tiles*

	Oil spreading "hot"	Oil spreading at ambient temperature
HFO	2.40 ± 0.24	2.49 ± 0.10
IM-5	0.36 ± 0.07	0.25 ± 0.04
IM-14	0.74 ± 0.55	0.74 ± 0.90
IM-15	2.43 ± 0.13	2.48 ± 0.10

Finally, for IM-5 and IM-14, 3 tiles were recovered with oil at ambient temperature but no drying was performed. Tiles were processed for oil extraction immediately after oil spreading, *Table 2* presents the amount of oil recovered from the tiles.

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Table 2 *Amount of oil recovered (in g) on the tiles immediately after spreading (without drying time), compared to tiles having experienced 6 days frying time*

	Amount of oil recovered after drying time (in g)	Amount of oil recovered without drying time (in g)
IM-5	0.25 ± 0.04	3.16 ± 0.22
IM-14	0.74 ± 0.90	2.93 ± 0.18

Results show that without drying time, the totality of the oil poured on the tiles surface could be recovered.

With time, IM-5 and IM-14 are thus absorbed on the tiles surface, up to around respectively 92% and 75%.

This additional experiment allowed the determination of a "control absorbed" (i.e. with 6 days drying) and a "control not absorbed" (i.e. immediate oil extraction) that are used hereafter for the washing efficiency calculation.

2.2 Washing efficiency

Table 3 and *Figure 11* present the results of the washing efficiency for the 3 VLSFO and for the reference oil (HFO). Those results take into account the oil "lost" by absorption, explaining the low efficiency calculated for IM-5 and IM-14.

Considering the reference oil (HFO), the water temperature (i.e. hot water) is the main parameter leading to an efficient washing (from nearly 0% at 15°C to 50-60% at 50°C) (*Figure 11*). Even with high pressure added to high temperature, still around 40 % of oil remains on the tiles surface.

Considering IM-15, which exhibits the same behavior as the reference oil (no absorption), the same conclusion as for the HFO can be raised but with lower washing efficiency calculated: hot water (50°C) is required to observe a washing efficiency of ~20-30 %.

Considering IM-5 and IM-14, most of the oil disappeared/was absorbed from the tiles surface before washing. On the remaining oil on the tiles surface, no special trend was observed between the different washing conditions for IM-5, with washing efficiencies around 5 %.

Finally, a combined effect of high pressure and high temperature seems to lead to the best washing efficiencies (~15 %) with IM-15.

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Table 3 *Washing efficiency (in %) for the 3 VLSFO tested (IM-5, IM-14 and IM-15) and the comparative oil (heavy fuel oil), for the 4 experimental conditions tested.*

	washing conditions	replicate	mass of oil extracted from the control tiles (g)	mass of oil extracted after washing (g)	mass of oil removed thanks to washing (g)	Washing efficiency (%)	Average (%)	Standard deviation (%)
HFO	Control	1		-		-	-	-
		2	2,40 ± 0,24	-		-	-	-
		3		-		-	-	-
	15°C - 50 bars	1	-	2,77	0	0	0,0	0,0
		2	-	2,48	0	0		
		3	-	2,75	0	0		
	15°C - 100 bars	1	-	2,66	0	0	1,5	2,7
		2	-	2,59	0	0		
		3	-	2,29	0,11	4,6		
	50°C - 50 bars	1	-	1,49	0,91	38,1	55,6	15,2
		2	-	0,89	1,51	63,1		
		3	-	0,83	1,57	65,6		
	50°C - 100 bars	1	-	1,26	1,14	47,5	60,7	11,5
		2	-	0,77	1,63	68,0		
		3	-	0,80	1,60	66,7		
IM-5	Control absorbed	1		-		-	-	-
		2	0,36 ± 0,07	-		-	-	-
		3		-		-	-	-
	Control not absorbed	1		-		-	-	-
		2	3,16 ± 0,22	-		-	-	-
		3		-		-	-	-
	15°C - 50 bars	1	-	0,19	0,16	5,2	4,8	0,4
		2	-	0,22	0,14	4,5		
		3	-	0,21	0,15	4,7		
	15°C - 100 bars	1	-	0,17	0,18	5,8	6,0	1,5
		2	-	0,21	0,15	4,6		
		3	-	0,12	0,24	7,6		
	50°C - 50 bars	1	-	0,13	0,23	7,2	5,3	1,6
		2	-	0,21	0,15	4,7		
		3	-	0,23	0,13	4,1		
	50°C - 100 bars	1	-	0,18	0,18	5,6	6,1	0,9
		2	-	0,13	0,23	7,2		
		3	-	0,18	0,18	5,7		
IM-14	Control absorbed	1		-		-	-	-
		2	0,74 ± 0,55	-		-	-	-
		3		-		-	-	-
	Control not absorbed	1		-		-	-	-
		2	2,93 ± 0,18	-		-	-	-
		3		-		-	-	-
	15°C - 50 bars	1	-	0,51	0,23	7,9	2,6	4,6
		2	-	1,03	0	0		
		3	-	0,90	0	0		
	15°C - 100 bars	1	-	0,52	0,23	7,7	8,6	1,0
		2	-	0,50	0,24	8,3		
		3	-	0,46	0,28	9,7		
	50°C - 50 bars	1	-	0,43	0,31	10,6	11,9	1,2
		2	-	0,38	0,37	12,5		
		3	-	0,37	0,37	12,7		
	50°C - 100 bars	1	-	0,28	0,46	15,7	15,7	1,6
		2	-	0,33	0,41	14,1		
		3	-	0,23	0,51	17,4		
IM-15	Control	1		-		-	-	-
		2	2,43 ± 0,13	-		-	-	-
		3		-		-	-	-
	15°C - 50 bars	1	-	2,39	0,04	1,8	2,4	2,7
		2	-	2,49	0	0,0		
		3	-	2,30	0,13	5,3		
	15°C - 100 bars	1	-	2,47	0	0,0	0,8	1,3
		2	-	2,38	0,06	2,3		
		3	-	2,70	0	0,0		
	50°C - 50 bars	1	-	2,13	0,30	12,4	21,8	8,6
		2	-	1,85	0,58	23,8		
		3	-	1,72	0,71	29,3		
	50°C - 100 bars	1	-	1,44	0,99	40,9	32,8	19,6
		2	-	2,17	0,26	10,5		
		3	-	1,29	1,15	47,1		

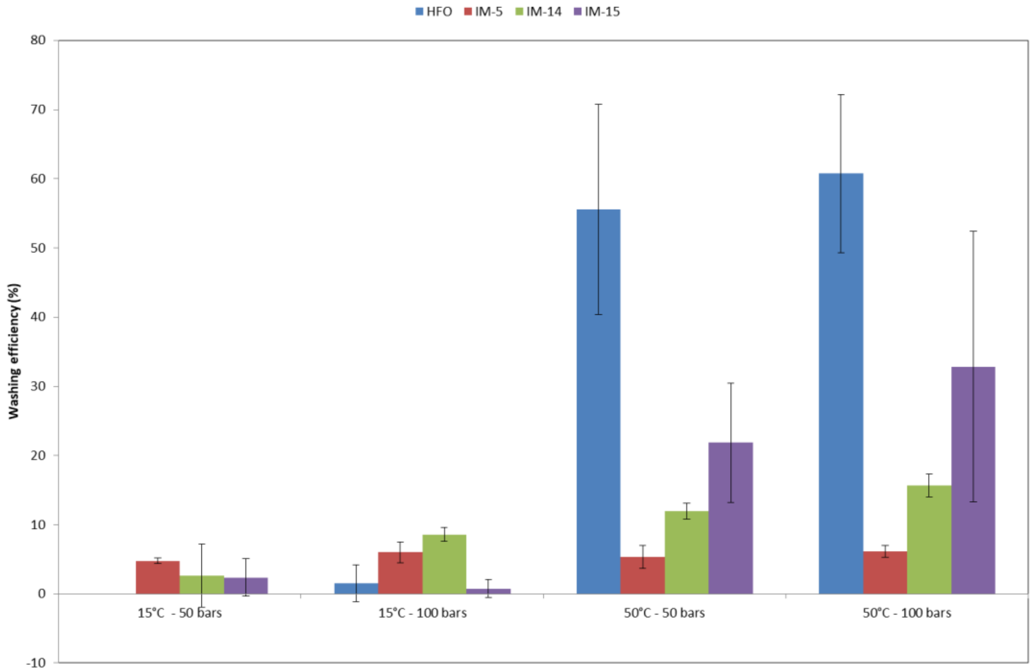

Figure 11 *Washing efficiency of the IM-5, IM-14 and IM-15 VSLFO and the reference oil (HFO)*

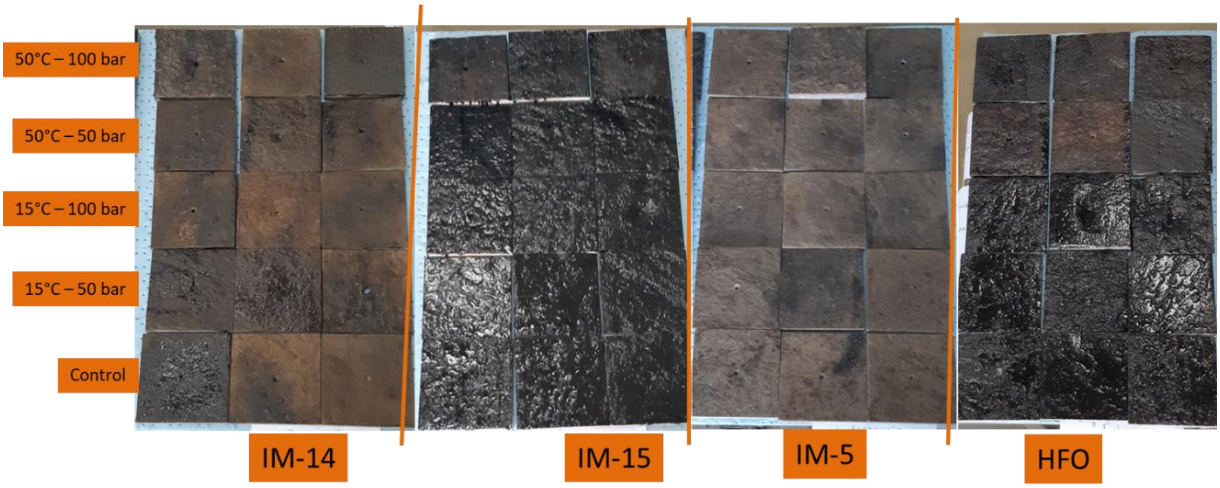

Figure 12 *Visual aspect of the tiles after washing process*

2.3 Additional experiments

At the end of the matrix tests, it was decided to carry out some additional experiments in order to better understand the penetration phenomenon observed with IM-5 and, to a lesser extend, IM-14.

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Two visual tests were performed:

- Oils (IM-5 and IM-14) were added on granite, concrete and marble tiles (in triplicate for each substrate). The tiles were let for drying six days and a visual observation of a potential penetration was performed. When absorption was observed, tiles were then covered with seawater and dispersant (50% vol. / oil) was added on some of them 30 min before water addition in order to study any oil release.

- The same oils (as well as the same reference HFO as used in the washing experiment) were added on natural pebbles collected on the shoreline. A visual observation of a potential penetration was performed and the pebbles were broken after different days of contact with the oil (T+3 days, T+7 days and T+14 days) in order to observe the potential presence of absorbed oil.

2.3.1 Results from the granite, concrete and marble tiles trials

Tiles appearance is visualized on pictures *Figures 13* and *Figure 14*. Oil absorption on granite tiles after 6 days drying is confirmed. No absorption was visible on the three concrete tiles polluted (*Figure 14*). Considering the marble tiles, two tiles polluted with IM-5 and one polluted with IM-14 exhibited absorption. Those results show that different rocks could be impacted by this absorption process. Considering the concrete tiles used, man-made structures (concrete) may not be affected by this phenomenon.

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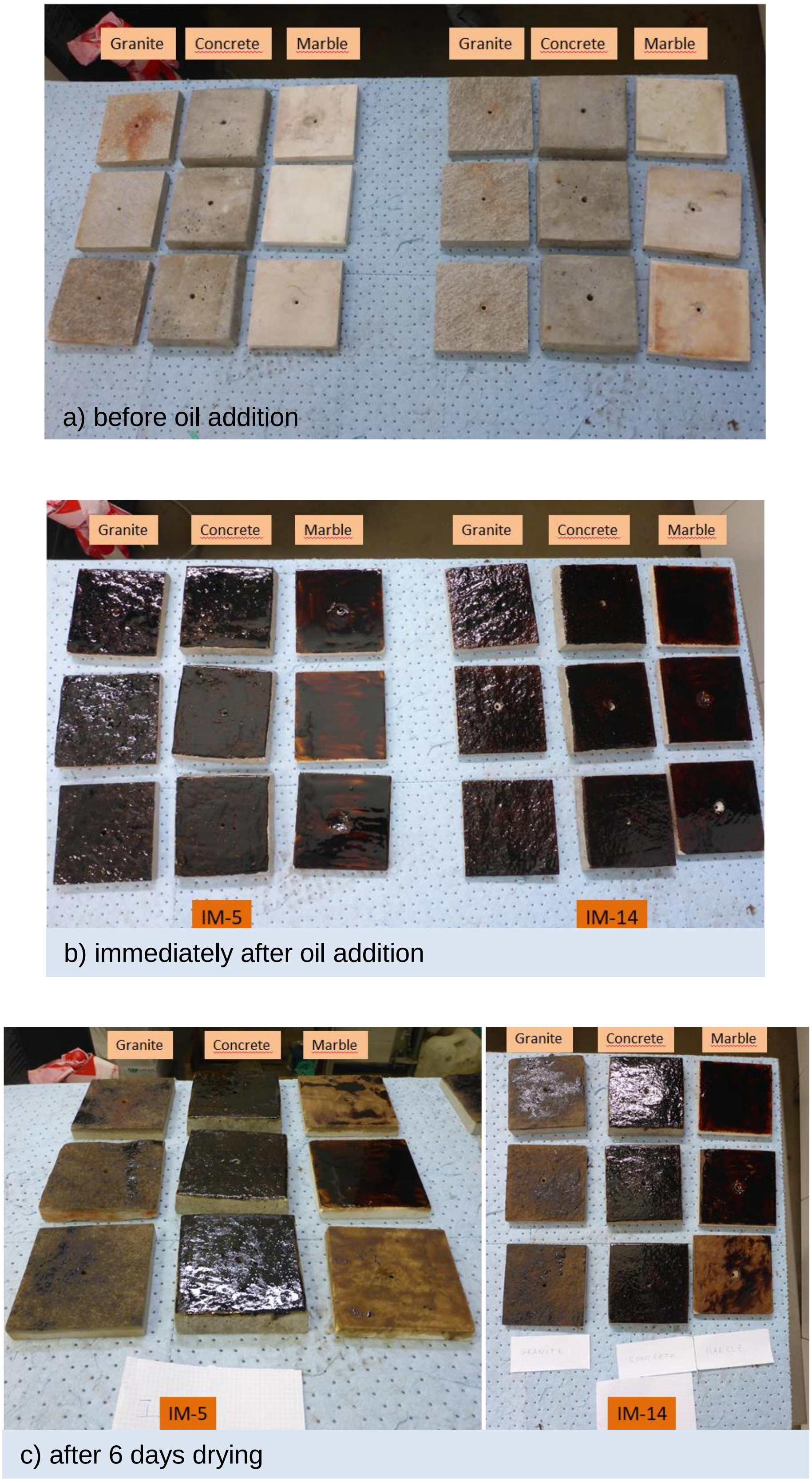


Figure 13 *Oil addition on granite, concrete and marble tiles.*

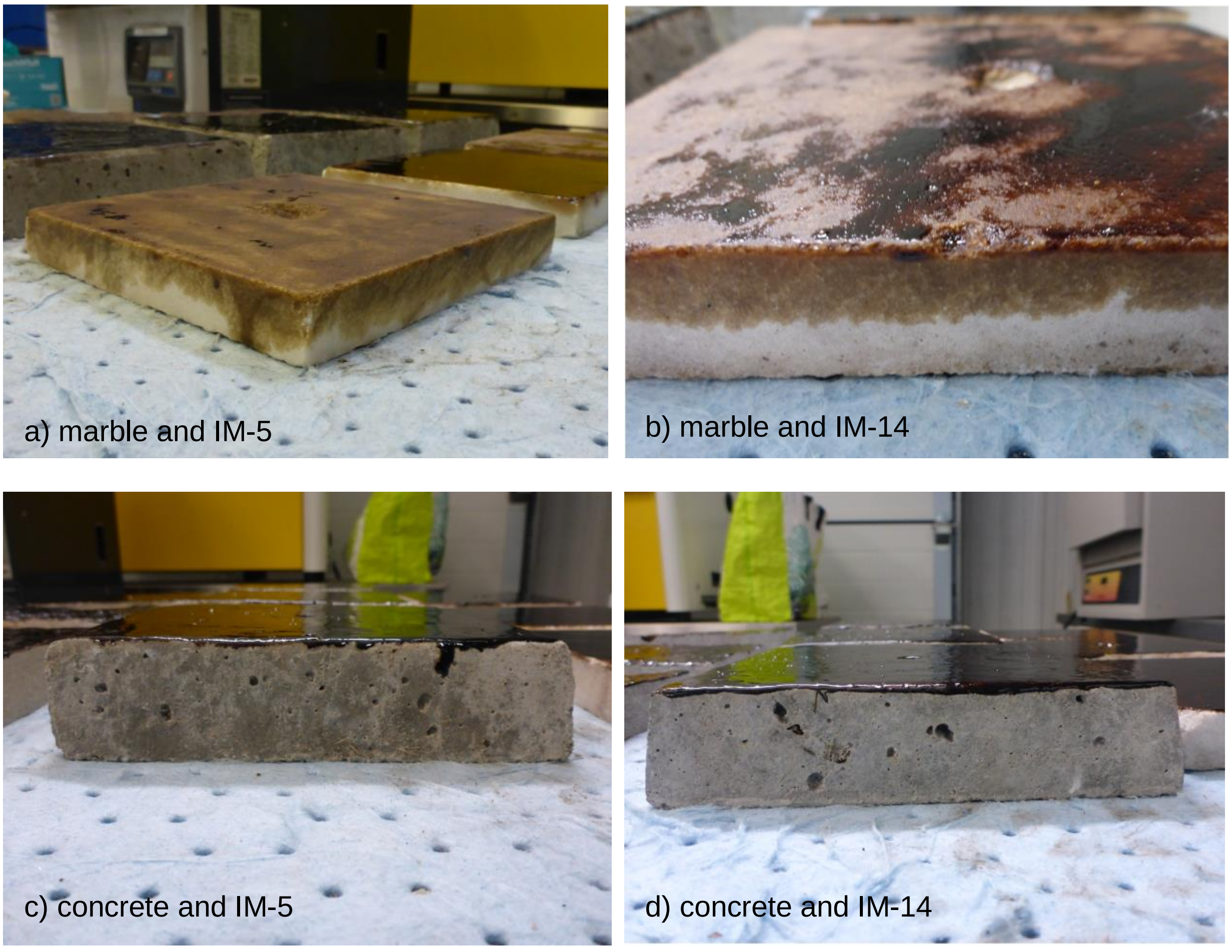
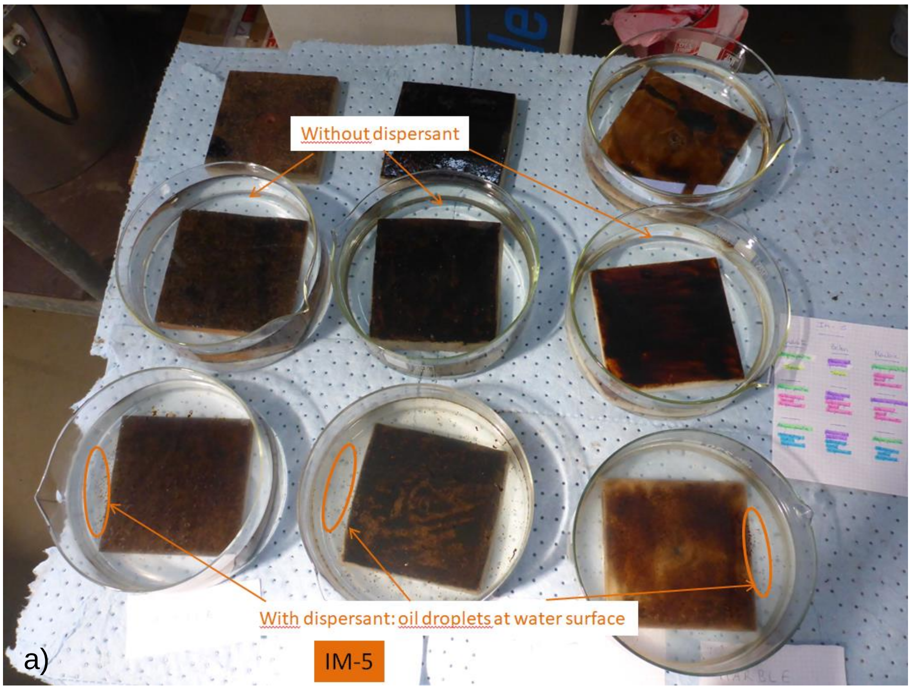


Figure 14 *View of the edge tiles for the test involving a), b), c) and d)*

Tiles exhibiting penetration were immerged in seawater; no special observation was noticed (*Figure 15*). Only sheens were visible on water surface. Finally, the addition of dispersants on the tiles surface 30 minutes before immersion leads to some oil release at the water surface. Nevertheless, this oil is more probably coming from remaining oil on the surface rather than release of absorbed oil.

The tiles were let in the water for several days but no change was noticed over time.



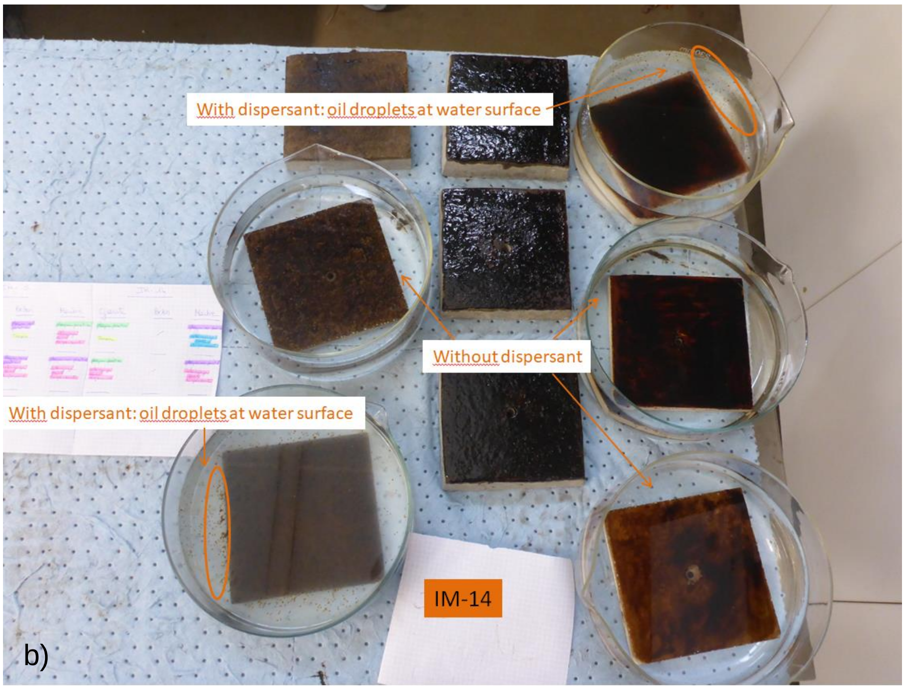
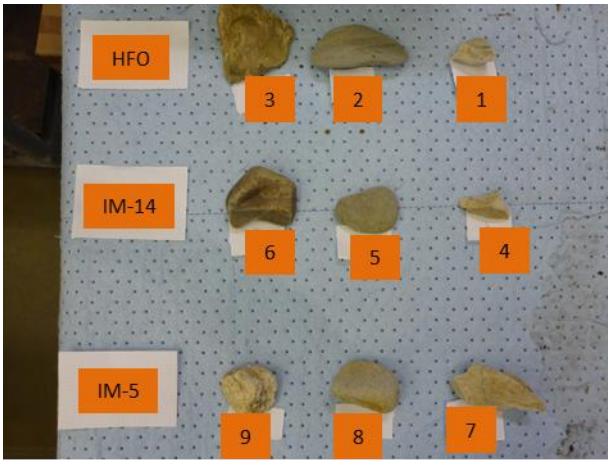


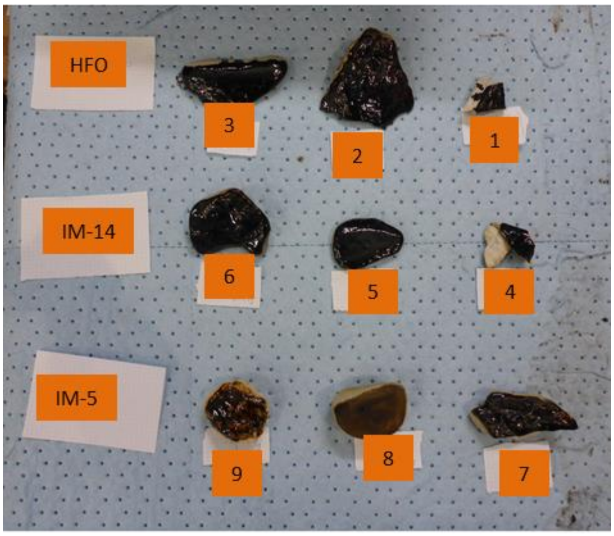
Figure 15 *Effect of tiles immersion in seawater on potential oil release (a) IM-5 and b) IM-14), with and without dispersant addition*

2.3.2 Results from the natural pebbles trials

Pictures from the pebbles before and after oil addition are presented on *Figure 16*. Oil was only added on one face of the pebbles.



a) before oil addition



b) after oil addition

Figure 16 *pictures of the natural pebbles*

<u>Results T+3 days</u>

Three days after oil addition, the aspect of some pebbles had changed. Pebbles polluted with IM-5 (pebbles 7, 8 and 9) looked drier. Absorption was visible on pebble 7. To a lesser extend, this observation could be raised for pebble 4 polluted with IM-14. No change was observed for pebbles covered with the reference oil (HFO; pebbles 1, 2 and 3).

Pebbles 1, 4 and 7 were broken in order to visualize the oil penetration (*Figure 17*). Those three pebbles come from the same initial rock (cut in pieces).

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a) pebble 1 with HFO

b) pebble 4 with IM-14

c) pebble 7 with IM-5

Figure 17 *Inside view of pebbles after 3 days of contact with the oils*

A clear penetration is observed for the pebble 7 and, to a lesser extent, for the pebble 4.

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<u>Results T+7 days</u>

Pebbles 2, 5 and 8 were broken in order to visualize the oil penetration (*Figure 18*).

a) pebble 2 with HFO

b) pebble 5 with IM-14

c) pebble 8 with IM-5

Figure 18 *Inside view of pebbles after 7 days of contact with the oils*

No clear oil penetration was observed for those pebbles, leading to the conclusion that not all the rocks absorb the VLSFO.

Pebbles 1, 4 and 7 (coming from the same initial rock) seem more porous than the pebbles 2, 5 or 8.

Results T+14 days

Pebbles 3, 6 and 9 were broken in order to visualize the oil penetration (*Figure 19*).

a) pebble 3 with HFO

b) pebble 6 with IM-14

c) pebble 9 with IM-5

Figure 19 *Inside view of pebbles after 14 days of contact with the oils*

Penetration was only observed on one part of the pebble 6 (IM-14).
Penetration seems thus more related to the oil and the rock natures than to the contact time between them.

3 Conclusion

The first conclusion resulting from those trials is that some VLSFO can be absorbed on tiles surface, and to a greater extend to some natural pebbles of different natures. In case of oil spill at sea, this phenomenon could thus be observed, depending on the VLSFO involved and on the rocks nature. This could generate particular difficulties for shoreline cleanup.

From the washing trials, washing efficiency revealed that water temperature first (hot water) and pressure then, seem to clean more efficiently the tiles. It should however be noticed that this protocol enables a comparison of the results obtained for various oils and substrates but does not reproduce shoreline clean-up technique as used in the field. In this study, only one water jet is used.

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