International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 02 | Feb 2020 www.irjet.net p-ISSN: 2395-0072

REMOVAL OF OIL SPILLAGE IN MARINE ENVIRONMENT USING GROOVED TYPE CYLINDRICAL SKIMMING PROCESS

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Abstract - *An oil skimmer is a device that separates oil or particles floating on a liquid surface. Oil skimmers are not oil-water separator devices. They are used for oil spill remediation, as a part of oily water treatment systems, removing oil from machine tool coolant and removing oil from aqueous parts washers. The use of skimmers in industrial applications is often required to remove oils, grease and fats prior to further treatment for environmental discharge compliance. By removing the top layer of oils, water stagnation, smell and unsightly surface scum can be reduced. Placed before an oily water treatment system an oil skimmer may give greater overall oil separation efficiency for improved discharge wastewater quality. There are many other methods of removing oil spillage. Oil spillage can be removed by incorporating chemicals, but they have a disadvantage that the chemicals may cause danger to the ecosystem. Another method is the incorporation of Bacteria (Pseudomonas). In this method the bacteria decompose oil and oil recovery becomes impossible. The main advantage of using a skimmer is that the spilled oil can be recovered and can be reused. Generally, the common types of skimmers used are Disk type, Belt type, Rope type, Brush type, Weir type, Drum type. Of these types of skimmers disk type skimmers are most widely used, while drum skimmers are used rarely. The main reason is due to the weight of the drum and inefficiency of adsorbing oil effectively. In this report design modifications in a drum type skimmer which may increase oil adsorbing are discussed.*

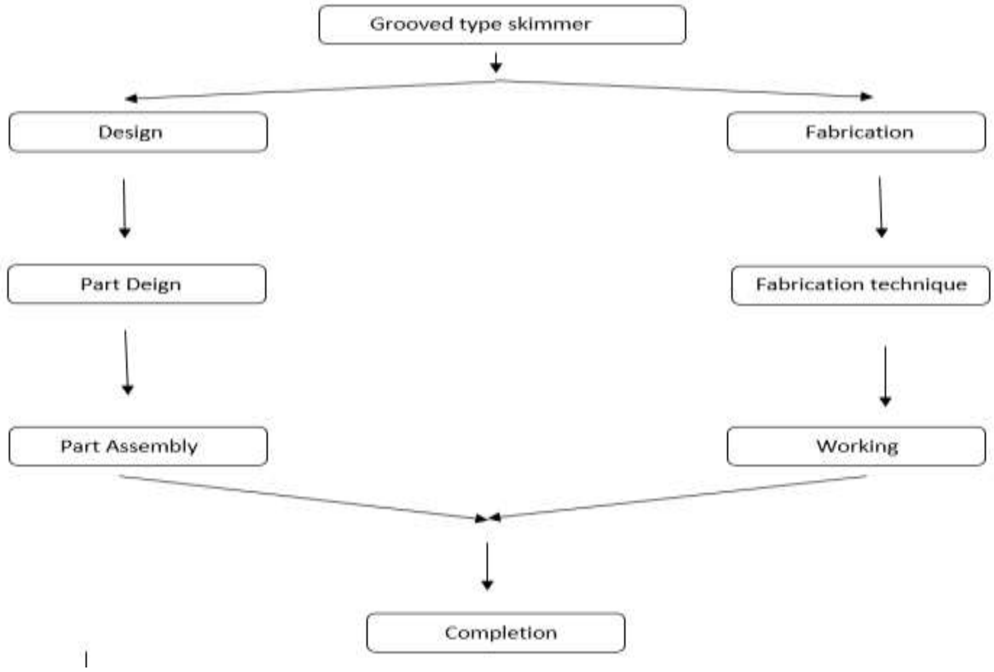
***Key Words*: Recovery surface, Environment Friendly, Recovery Rate, Oil Spillage, Surface skimming, Electric Motor, Grooves.**

1. INTRODUCTION

Oleophilic skimmers are the most used type of mechanical oil spill response equipment. They operate on the principle of oil adhesion to a rotating surface. The rotating surface lifts oil out of the water to an oil removal device (e.g., scraper, roller, etc.), which then transfers it into a collector. When employed on a large scale, mechanical recovery may be very time-consuming and expensive due to its low recovery rates. Recovery rates of adhesion skimmers range between 0.2m3/h for diesel oil and 50m3/h for heavy crude. A more efficient recovery device can thus reduce the time and cost of the clean-up and prevent significant environmental damage. Various shapes of the recovery unit, such as a mop, belt, brush, disc, and drum, have been developed to increase skimmer efficiency. The low recovery rates of the smooth drum, belt, and disk skimmers can be explained by their relatively small surface area. Only a limited amount of oil adheres to the recovery surface in every rotation, requiring a large number of skimmers and longer operation time to increase the overall recovery efficiency. Although these skimmers allow more oil to adhere to the recovery surface, not all the adhered oil can be removed from the bristles by the scraper, especially when recovering lighter oils.

A novel pattern has been developed for the recovery surface that can significantly increase the recovery efficiency of an oil skimmer. This pattern is composed of a series of U-shaped grooves in the direction of rotation of the recovery unit. The scraper can be machined to almost perfectly match the recovery surface. Thus, close to 100% of the adhered oil can be removed and transferred into the oil collector in every rotation. This pattern maximizes the surface area of a drum, belt, or disc skimmer. Depending on the angle and depth of the channels, the surface area can be increased several-fold for the same width of recovery surface. Thus, the overall volume of recovered oil is much higher for a grooved surface than for a smooth one. The total area inside the grooves is independent of the groove angle. The number of grooves per unit width of the recovery surface is inversely proportional to the groove angle; thus, the total groove area is constant for any given groove depth. It must be noted though, that during the recovery process, oil may not occupy the entire area available inside the groove.

2. METHODOLOGY:



3. PRINCIPLE OF OPERATION

The reason that oil floats on water is the main principle involved in skimmer. The reason that oil floats on water is as follows

3.1 Specific Gravity

Most Hydro Carbons have lower Specific Gravity than water. Without agitation oil separates from water and floats to the surface. These oils are known as LNALP'S, Light Non-Aqueous Phase Liquid. Oils (and other components) that sink in water having higher Specific Gravity are known as DNALP'S (Dense Non-Aqueous Phase Liquid).

3.2 Surface Tension and Affinity

Oil bonds more tightly to itself and other materials than to water. This affinity, and difference in surface tension between oil and water, causes oil to adhere to a skimming medium

The oil spill recovery process is composed of two equally important goals. The first one is to remove oil from the water surface and the second one is to remove oil adhered to the recovery surface and transfer it into to a collector. The recovery efficiency depends on the achievement of both of these goals. In case of a smooth surface (e.g. smooth drum, disk or belt), the amount of oil recovered from the water surface is relatively low, but close to 100% of it can be removed by a cleaning blade.

In the case of a brush surface, the recovery of oil from the water surface is high on the first pass, but a significant amount of oil remains on the surface, reducing the overall recovery rate. The characteristics of an adhesion skimmer surface pattern and materials that can significantly increase oil recovery efficiency can be summarized as follows:

It should have the maximum surface area possible for a given width of the recovery surface;

• The formation of oil menisci is highly desirable, since this allows a thicker layer of oil to be recovered from the water, and it slows oil drainage back into the oil spill;

• The cleaning blade should be able to remove close to 100% of the oil adhered to the recovery surface;

• The surface pattern and materials should be tailorable to the oil properties of a particular region (e.g. Alaskan crudes);

• The recovery surface pattern and materials should take into consideration the changes in oil properties that occur as the oil weathers, and in colder climates.

The materials used as the contact surface have been selected based on their ability to adhere to oil, their durability and relatively low swelling, and feasibility of implementation in existing skimmers

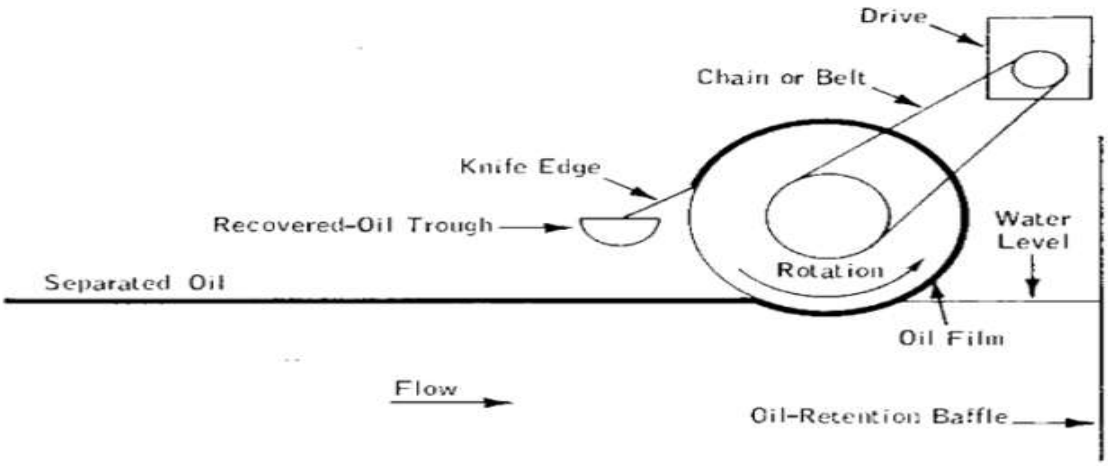


Fig 1: Basic schematic of a Skimming process

3. DESIGN PARAMETERS

There are various parameters which govern the performance of skimmers. They are mainly based on environmental conditions and external agents like wind, waves and temperature.

3.1Parameters governing the working of a Skimmer

3.1.1 Recovery rate

Rate at which skimmer recovers pure oil from an oily environment

3.1.2 Recovery efficiency

Relation between recovered oil and recovered fluids (oil / water mixture)

3.1.3 Throughput efficiency

Relation between recovered oil and encountered oil.

3.1.4 Performance in Waves

This is the parameter which influences the efficiency of the skimmer in actual working conditions as waves on surface of water cause disturbances in skimming.

3.1.5 Construction

Skimmer construction must be tough, rugged and simple in construction so as to withstand strong currents and winds.

3.1.6 Maintenance

Maintenance of skimmer also is important in the design of skimmer, so as to increase the life time of the equipment.

4. SELECTION OF MATERIAL

The main objective in the fabrication of machine is the proper selection of material for the different parts of the skimmer. It is important to have a clear effect of the manufacturing process and heat treatment on the properties of material. The choice of material for engineering purposes depends upon the following factors:

1) Availability of the material.

2) Suitability of materials for the working condition in service.

3) The cost of materials.

4) Physical and chemical properties of materials.

5) Mechanical property of material.

The mechanical properties of the metals are associated with the ability of material to oppose mechanical forces and load.

Based on the above constraints it was found that Polypropylene material was most suitable for skimming. The main reason is that polypropylene material is Hydrophobic and oleophilic that is it adsorbs oil and not water. This property is vital for a skimmer and hence this material was chosen as the drum material.

Table -1: Table depicting the types of skimmer

	Skimmer	Recovery rate	Oils	Sea state	Debris	Ancillaries
Oleophilic	Disc	Dependent on number and size of discs. Tests show grooved discs can be highly effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	Rope mop	Dependent on number and velocity of ropes. Generally low throughput.	Most effective in medium oils although can be effective in heavy oil.	Very little or no entrained water. Can operate in choppy waters.	Able to tolerate significant debris, ice and other obstructions.	Small units have built in power supply and storage. Larger units require separate ancillaries.
Oleophilic	Drum	Dependent on number and size of drums. Tests show grooved drums are more effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	Brush	Throughput dependent on number and velocity of brushes. Generally mid-range.	Different brush sizes for light, medium and heavy oils.	Relatively little free or entrained water collected. Some designs can operate in choppy waters, others would be swamped in waves.	Effective in small debris but can be clogged by large debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	Belt	Low to mid-range.	Most effective in medium to heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris but can be clogged by large debris.	Can deliver oil directly to storage at the top of the belt. Ancillaries required to discharge from a vessel to shore.
Non-Oleophilic	Vacuum/ suction	Dependent upon vacuum pump. Generally low to mid range.	Most effective in light to medium oils.	Used in calm waters. Small waves will result in collection of excessive water. Addition of a weir more selective.	Can be clogged by debris.	Vacuum trucks and trailers are generally self-contained with necessary power supply, pump and storage.
Non-Oleophilic	Weir	Dependent upon pump capacity, oil type etc. Can be significant.	Effective in light to heavy oils. Very heavy oils may not flow to the weir.	Can be highly selective in calm water with little entrained oil. Can be easily swamped with increase in entrained water.	Can be clogged by debris although some pumps can cope with small debris.	Separate power pack, hydraulic and discharge hoses, pump and storage. Some skimmers have built-in pumps.
Non-Oleophilic	Belt	Low to medium.	Most effective in heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris. Clogged by large debris.	As for oleophilic belt skimmer.
Non-Oleophilic	Drum	Mid range.	Effective with heavy oils.	Can be highly selective in calm water with little entrained oil. However, can be swamped in waves.	As for weir skimmer.	As for weir skimmer.

5. DESIGN

5.1 Detailed View of the setup with Parts

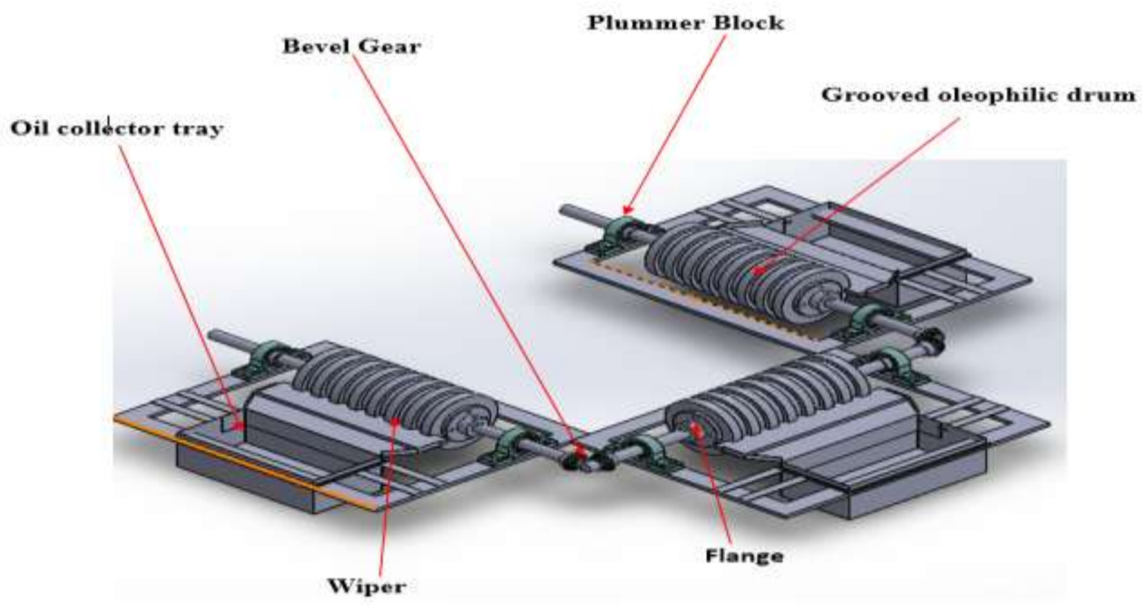


Fig2: Complete proposed assembly-CAD model

5.3 Major Sub-Assemblies of the setup:

5.3.1 Driving Unit:

1.Hydraulic Torque Motor or Hydro Motor

5.3.2 Skimming Unit

1.Poly Propylene Drum with Groove

2.Wiper

3.Oil Collection tank

5.3.3 Floating Unit

1.Syntactic Foam

These are the three main subassemblies that constitute the grooved type skimmer.

6. CALCULATION

6.1 SUPPORTING SHAFT:

The shaft from the Plummer block is assumed as a cantilever beam and the design calculation for safety is calculated.

The deflection equation for a cantilever beam is given by the following equation,

$$Deflection = \frac{Pl^3}{3EI}$$

Where $I = \frac{\pi d^4}{64}$

The moment of inertia of a soild circular rod is given by the equation,

$$I = \frac{\pi \times 0.025^4}{64}$$

$I = 1.9174 \times 10^{-8} m^4$

$$Deflection = \frac{75 \times 0.1^3}{3 \times 201 \times 10^9 \times 1.9174 \times 10^{-8}}$$

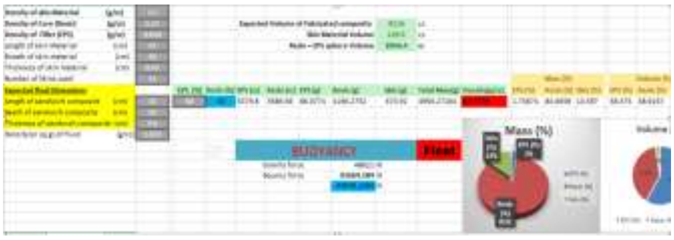
$Deflection = 3.88 \times 10^{-7} m$

It is seen that the deflection is very negligible and hence design is safe.

6.2 Float Calculations

6.2.1 Float 1a – (13 skins and 32cm length)

This type has 13 skins and is smaller than float 1b. The specifications are,



6.2.2 Float 1b – (16 skins and 32cm Length)

This Type is larger than the previous float with 16 skins and heavier. The specifications are,

Float 1 has 13 layers of syntactic foam. The withstanding capacity is as follows,

Withstanding Capacity: 2�.9+4.4=18.2kg

6.2.3 Float 2a – (13 skins and 30cm length)

This float is smaller with 13 skins and 30cm length. The specifications are

6.2.4 Float 2b – (16 skins and 30cm length)

This type has 16 layers of skin and is 30 cm in length. This type is intermediate in size between Floats1b and 2a. The specifications of this type of float are as follows,

Float 2 had about 16 layers of syntactic foam. Its withstanding capacity is as follows,

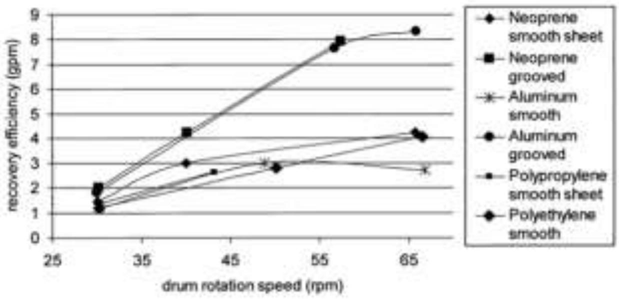
Withstanding Capacity: 2×8.6+5.3=22.5kg

From the two float calculations the ideal float was Float 2b as it met the required depth of immersion for a skimmer. For a skimmer about 1/4 th of the skimmer must be immersed on the top surface of the liquid so that other parts of the skimmer is not wetted by water or oil.

7. ANALYSIS

7.1 Material Selection and analysis

The graph below shows the variation of recovery efficiency for various drum rotation speeds



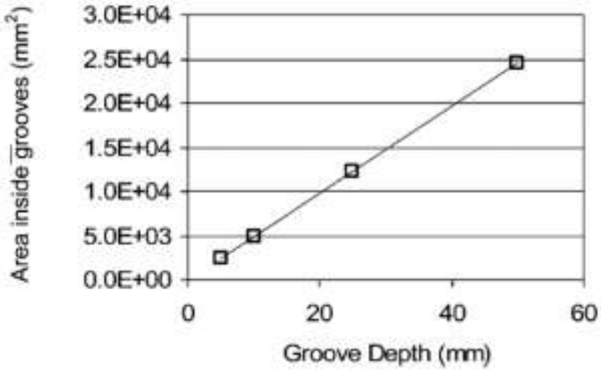
***Graph 1**: Graph showing the variation of recovery efficiency with drum speed*

From the above Graph it can be seen the different types of materials suitable for skimmer material. All the material mentioned in the graph has the properties that they are both hydrophobic and oleophilic. The graph clearly depicts that grooved type skimmers perform better than their ordinary smooth type skimmers. There is far more superior material other than polypropylene like Boron Nitride Nano sheets. They can very well be used as a skimmer material; however, their fabrication is difficult compared to other materials hence they are used only for specific applications. A notable observation made was that as drum rotation speed was increased above a certain value more water was collected along with oil. Several experimentations revealed that ideal speed of rotation of 50rpm was to be maintained for skimming operation.

7.2 Effect of Operational and Design Parameters in Performance

7.2.1 Effect of groove depth on area inside grooves:

The effect of groove depth on area between grooves is plotted in the graph below. The groove depth on x-axis and area between grooves in y-axis

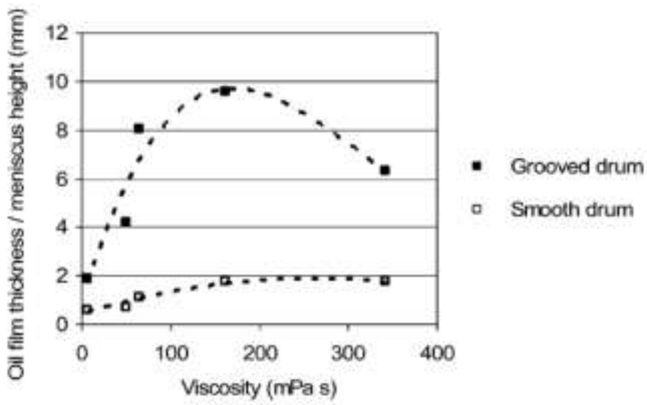


***Graph 2**: Graph showing relation between groove depth and Area between grooves*

The graph shows the variation of area with groove depth. It can be inferred that the area inside the grooves increases as depth of the groove increases. The depth of the groove can't be increased up to a certain value as increasing further would drastically affect the wiper configuration. Thus an optimal value of groove depth must be made such that wiper configuration is not affected.

7.3 Effect of viscosity on oil thickness:

The graph below depicts the relation between viscosity and oil film thickness



***Graph 3**: Graph showing relation between Viscosity and oil film thickness*

The graph shows the variation of viscosity with oil film thickness. It can be seen that temperature drastically affects the effect of viscosity thereby reducing the oil film thickness. Thus, oil recovered from the surface would be less. In cold climate recovery of oil viscosity increases thus enabling more oil to be collected within a short period of time.

8. TESTING

8.1 Test Protocol:

The testing was done with the fabricated setup shown below,

***Fig3**: Final Fabricated setup of the skimmer*

The test protocol carried out included the following testing methods:

a) The polypropylene drum was installed into the skimmer frame. The skimmer assembly was then secured in the center of the test tank. The test tank had already been filled with water.

b) A known volume of test oil was added to the test tank. This established an oil slick of known thickness. Slick thickness was controlled at a predetermined level throughout a given test. As the oil skimmer recovered oil from the test tank, additional oil was pumped from the oil reservoir at approximately the same rate. In this way, real-time control of the slick thickness was controlled to within ± 20%. After a given test run, an accounting of oil volume recovered and oil volume distributed provided data for a mass balance and a final check of the real-time data.

c) Varying the speed of the skimmer drum controlled the encounter rate of the oleophilic surface with the oil front. The speed of rotation of the oil skimmer drum was controlled using the handle provided with the shaft. Three rotational speeds (30, 40 and 70 rpm) were used for most of the tests. The first two speeds represented the regular operational conditions of a drum skimmer, with minimal free water skimming. The 70 rpm speed represented the maximum rotational speed that was achieved by this particular skimmer. At this speed, more oil was collected, but more free water was entrained by the skimmer, particularly for thinner oil slicks (10 mm). A higher rotational speed also emulsified oil to a greater extent.

d) At the end of each test run, the total amount of fluids (oil and water) in the recovery tank was measured. The water was taken out from the bottom of the tank for several minutes until no more free water was evident, and a volume of the remaining oil or oil emulsion was measured again. This data, along with recovery time, were used to establish the amount of recovered oil and recovery rates.

g) Other parameters and data that were documented were the initial oil and water temperature, oil and water surface temperatures during the test, and ambient weather conditions. Photo and video documentation were maintained

9. FUTURE SCOPE

The Grooved type cylindrical skimmers in current state is mostly fabricated using mechanical components and mechanisms. However, there are a considerable option to integrate automation and IOT. Sensors can be used to detect oil slick thickness and the skimmer rotation speed can be adjusted according to it. Also, Image processing techniques can be used to identify the oil density by analyzing the color intensity. Also, instead of hydraulic torque motor electric motors can be used which still reduces the weight of the overall setup.

10. CONCLUSIONS

The oil spill recovery tests with oleophilic drum skimmer showed that:

- Drum rotational speed had a significant effect on the recovery rates. For the particular skimmer and a dram type tested, 40 rpm appeared to be a nearly optimal rotational speed in most of cases. Beyond 40 rpm, the dram started to entrain significant amounts of free water. It has to be noted, however, that free water was the only limiting factor. If a response team is not concerned with free water in the recovered product, the maximum rotational speed should be used to recover more oil.

- Recovery rates are significantly influenced by the viscosity of oil. For thicker oil slicks, recovery rate increases with viscosity. For thinner oil slicks, recovery rate appears to decrease with viscosity, within the range of observed viscosities.

Apart from this other outcomes were inferred as follows

- The merits of recovery options at sea and nearshore should be assessed against prevailing conditions at sea like wind, atmospheric temperature, currents and location of sensitive areas.

- The criteria of capacity, reliability, robustness, field performance, weight, handling, versatility, power source, maintenance and cost should be considered when selecting the most appropriate skimmer.

- Skimmer performance should be continuously monitored to ensure optimum efficiency.

- Regular inspections and testing of equipment should be arranged to maintain of personnel training standards and rectify any equipment faults

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