Mobile surface water filtration system

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Aim: To design a mobile system for surface water filtration
Methodology: the filtration of surface impurities begins with their retraction to concentrated thickness using non ionising surfactants, then isolation using surface tension property and sedimentation of impurities in process chamber using electrocoagulation.
Result:following studies done to determine the rate of spreading of crude oil on water a method for retraction of spread crude oil to concentrated volumes is developed involving addition of non -ionising surfactants in contrast to use of dispersants. Electrocoagulation process involves multiple processes taking place to lead to deposition of impurities such as oil, grease, metals. Studies of experiments conducted reveals parameters necessary for design of electrocoagulation process chamber though a holistic approach towards system designing is still required. Propeller theory is used in determining the required design of propeller and the desired thrust, the overall structure will finally contribute in deciding the choice of propeller.
Conclusion: An alternate take on water surface filtration is primarily discussed which is aimed at removal of impurities by using chemicals, mechanical and electrical processes. Continuous efforts have to be made in effective implementation of this assembly of different disciplines into a functioning full scale system. Its implementation extends to all still water bodies
Key words:
Surface tension, Autonomous, Electrocoagulation, Oil spills, Navigation

Introduction

The need for autonomous water surface cleaning devices has become paramount as the quantity of metals, chemicals, wastes and oil being dumped into water bodies is increasing every day , the number of oil spills have gone up in recent times and the magnitude of the disaster is so great that the world is still recovering from it. The actions taken by authorities is when the oil reaches near cost and till that time great damage has already been done to the marine life present. An autonomous/RC approach towards water cleaning involves the size and nature of the disaster and its nature in its design. In the recent oil spills 48, 0000 barrels of crude oil had leaked into the sea. It took nearly 3 weeks to contain the spill and by then 50%-60% of the crude oil had evaporated and 30% per cent was collected, the remaining was dispersed in the sea. Techniques of open burning, chemical dispersants, and booms have been limited in efficiency due to the time it takes for deployment and the magnitude of the disaster. In deep sea conditions the waves formed follow surface tension principle and electrocoagulation process reduces the oil to a smaller volume by deposition. Surface tension proper utilisation reduces the energy requirements for operation. On a general note it is also very practically usable at still water sites from which eutrophication, dissolved metals, chemicals can be removed.

Materials and methods:

Spreading of crude oil on water

The spreading of crude oil on water depends upon many factors such as density, surface tension, spreading pressure, gravitational forces, and hydrodynamic resistance which are a function of the crude oil viscosity. Studies have been conducted which relate these properties to the spreading of crude oil by assessing the behaviour of its individual components on surface of sea water in a controlled environment. Crude oil consists of heptane, decane, toluene and other organic compounds in mixture primarily.
S, the spreading coefficient is given as:

$S = W_a – W_c$

Where
W_a is the work of adhesion
W_c is the work of cohesion
Now considering a liquid b on liquid a, then the spreading coefficient can be given in terms of the surface tensions of the liquids a and b as:
$W_a= y_a – y_b - y_{ab}$
$W_c = 2y_b$
Where

y_a: surface tension of fluid a
y_b: surface tension of fluid b
y_{ab} : surface tension between a and b
Which implies that S, the spreading coefficient
$S = y_a - (y_b + y_{ab})$
Crude oil spreads rapidly on sea water due to high value of S (25- 35 Nm/m)
The surface tension of water equals to the sum of depression forces (Y_w^d) and polar hydrogen bonding forces (Y_w^p)the values for these are usually 21.8 and 51 respectively.The water molecule on the interface is subjected to 2 different forces of attraction: one by the interior water phase and that towards oil phase (h bonding), similarly the oil molecule is subjected to 2 forces of attraction: to the oil phase (dispersive forces) and to the water phase. Hence the spreading coefficient S, depending on the surface tension of oil can be given as:
$S=2\sqrt{Y_w^d Y_o^d} - Y_o$
Preferential accumulation of aromatics on interface due to weak H bonding between H atoms of water and pi bonds of aromatics.
By conducting experiments under controlled conditions it was determined that the concentration of different constituents of crude oil can be given at differential thickness of the float:

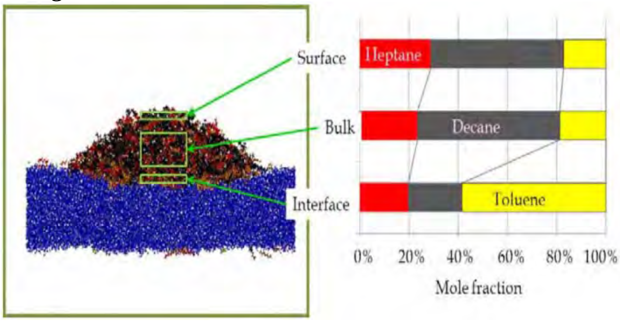


Figure1 (a) position of different components

The most important aspect of these studies was towards the retraction of crude oil which has been spilt over the sea water.The use of water insoluble monomodular films can be used to compress the spilt oil into increased thickness so that they occupy less surface area.
Addition of non-ionic surfactants to water would prevent spreading of crude oil; a possible surfactant is BIO-SOFT® N91-8 which has proven to be highly effective. Air spray of non-ionic surfactants is an alternate approach to dispersant spraying.

Crude Oil	Aromatics %	Asphaltenes (n-C_6)%	Resins %	Density g/cm^3	Surf. Ten. mN/m	Int. Ten.[1] mN/m	S mN/m	Visc. mPa s
Lustre	18	1.0	9.0	0.840	25.2	20.5	**27.8**	5.0
Gulfaks	26	0.3	16	0.894	28.1	18.4	**27.0**	35
Cottonwood	23	2.9	17	0.893	27.3	21.6	**24.5**	26
LC	25	3.2	12	0.903	28.0	25.7	**19.8**	39
Minnelusa	20	9.1	13	0.904	28.8	27.4	**17.2**	58

1. against sea water at pH=6-7

Table1.The table shows the properties of different types of crude oils. The S value for different crude oils is tabulated against their values of density, surface tension and viscosity.

PHYSICAL DESIGN

The physical design of the mobile device is based on maintaining the top layer of the body at a constant height. When the device is in navigation mode i.e. is looking for presence of oil then the top surface is above water and when activated the top surface is at water level, breaking the surface tension.

CHASSIS

The chassis is constructed keeping in mind the stability and strength required for operation. It contains the electrical system and hence water proofing is of upmost importance. The operation of the system takes place in isolation and sedimentation phases, the chassis has an opening to allow water and impurity mixture to enter. The opening pipe is fixed at one end, while the other end traces a complete circle of variable diameter and is reinforced by a circular ring to support the load carrying (water) pipe.

BATTERY

A 5v output chargeable battery is being used at present and though a limitation of discharging remains, the expected output of the battery will provide sufficient performance time. Back up battery can be installed to continue operation.

A DC to AC converter will have to be used to operate the pump inside the device.For testing phase AC supply is used and for DC driven components a AC to DC converter will be used.

ISOLATION PROCESS

The isolation process involves application of surface tension principle; if a lower pressure path is present then water will flow from higher to lower pressure. By initiating this process the impurities occupying the top layer will enter into the processing chamber. The simple mechanism will be initiated using the movable pipe. This pipe opening will be connected to a movable arm which is capable of moving 5-10 cm upwards and downwards, this is achieved by using PVC pipes having male and female groves and a motor capable of moving in clockwise and anticlockwise directions.

This process can be switched on and off using a shutter on the opening similar to that of a camera shutter.

The combined ability to switch off and on and adjust height of the opening bring many benefits:

1) The opening attached with a camera shows the position of the opening w.r.t the water level hence it removes dependency on sensors and microprocessor to keep a fixed level for the opening.
2) The device can be used to remove colloidal impurities as seen in oil spills when heavier components of crude oil begin to settle down towards the sea bed.
3) In case of overload or emergency conditions the device can be shutoff to any further input.

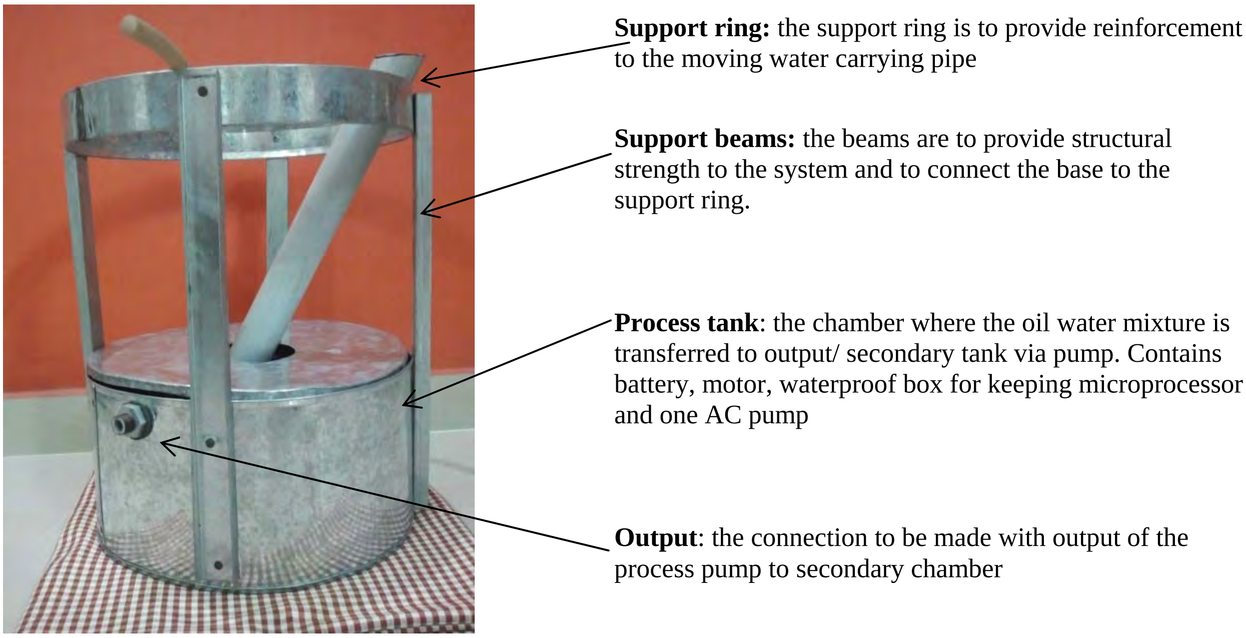


Figure1 (b) Side view

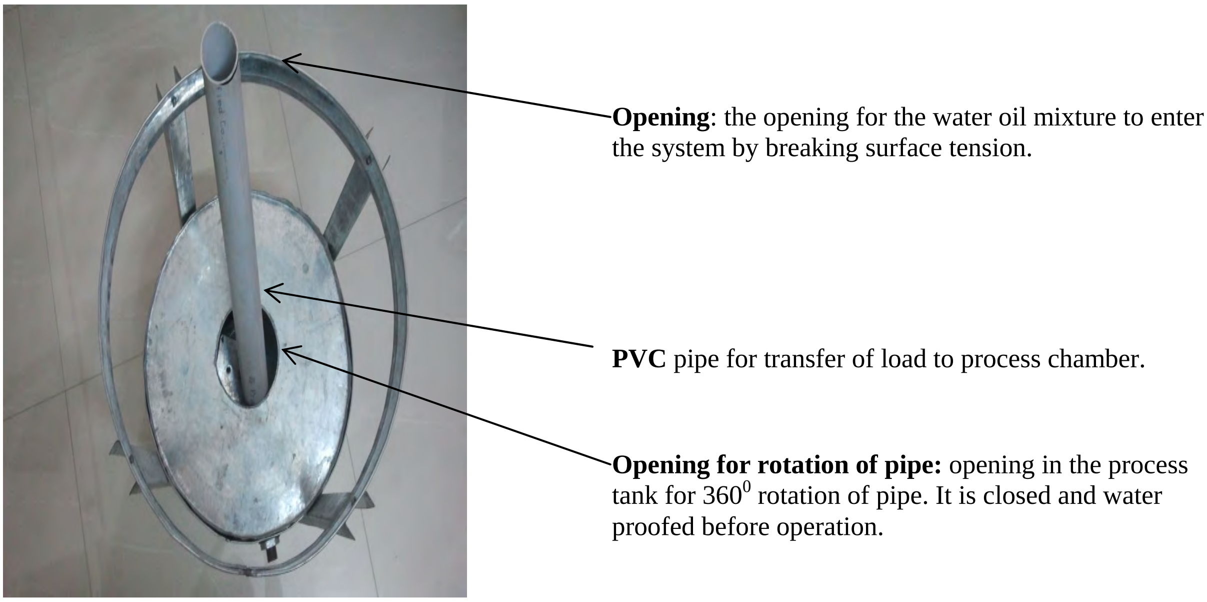
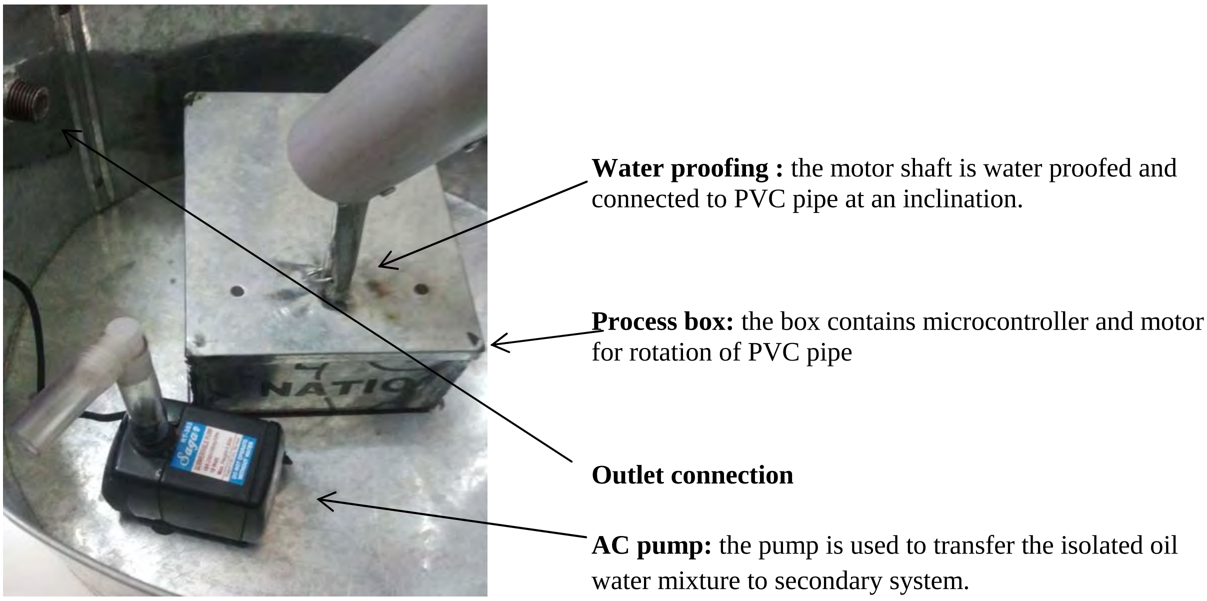
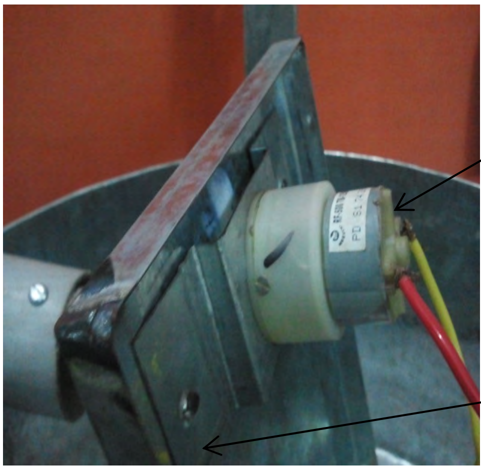


Figure1 (c) Top view



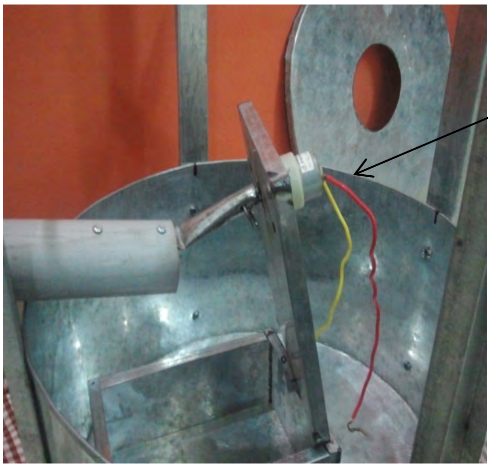
Figures1 (d) Inside-view of process



Motor: high torque, low rpm motor selected and connected, it can be changed in case of damage.

Connection with cover: the connection is made to not allow any stray movement of motor during run time.

Figure1 (e) motor attachment



Terminal connections: the motor has terminal (+ & -) connections to be connected to dc 5v battery.

Complete expansion of the process tank components

Figure 1(f) connections

FLOATS

The float assembly is unique and has the propulsion system incorporated with it. There are 2 floats on 1:3 ratios in volume connected 180 degrees opposite to each other. The floats are connected by aluminium rods and are made of hard rubber. The shape will be spherical to limit air drag effects.

PROPULSION

The propulsion system consists of 1 main propeller, 2 auxiliary propellers.The propeller is connected near the centre of the body so as to remove torque effects. The main propeller is positioned in the front with two auxiliary propellers on the side.The physical design of the mobile device is based on maintaining the top layer of the body at a constant height. When the device is in navigation mode i.e. is looking for presence of oil then the top surface is above water and when activated the top surface is at water level, breaking the surface tension.The choice of propellers is based on basic propeller theory which consists of parameters used for determining the required width, expected thrust.

Propeller thrust

Single blade

Taking an arbitrary radial section of a blade at *r*, if revolutions are *N* then the rotational velocity is **2piNr**. If the blade was a complete screw it would advance through a solid at the rate of *NP*, where *P* is the pitch of the blade. In water the advance speed is rather lower, V_a, the difference, or *slip ratio*, is:

$$\text{Slip} = \frac{NP - V_a}{NP} = 1 - \frac{J}{P}$$

Thrust and torque

The thrust, *T*, and torque, *Q*, depend on the propeller's diameter, *D*, revolutions, *N*, and rate of advance, V_a, together with the character of the fluid in which the propeller is operating and gravity. These factors create the following non-dimensional relationship:

$$T = \rho V^2 D^2 [f_1(ND/V_A), f_2(v/V_a D), f_3(gD/V_a^2)]$$

Where f_1 is a function of the advance coefficient, f_2 is a function of the Reynolds' number, and f_3 is a function of theFroude number. Both f_2 and f_3 are likely to be small in comparison to f_1 under normal operating conditions, so the expression can be reduced to:

$$\mathbf{T = \rho\, V_a^2 D^2 \times f_r\, (ND/\, V_a)}$$

For two identical propellers the expression for both will be the same. So with the propellersT_1, T_2, and using the same subscripts to indicate each propeller:

$$\frac{T_1}{T_2} = \frac{\rho_1}{\rho_2} \times \frac{V_{a1}^2}{V_{a2}^2} \times \frac{D_1^2}{D_2^2}$$

For both Froude number and advance coefficient:

$$\frac{T_1}{T_2} = \frac{\rho_1}{\rho_2} \times \frac{D_1^3}{D_2^3} = \frac{\rho_1}{\rho_2}\lambda^3$$

Where λ is the ratio of the linear dimensions.Thrust and velocity, at the same Froude number, give thrust power:

$$\frac{P_{T1}}{P_{T2}} = \frac{\rho_1}{\rho_2}\lambda^{3.5}$$

For torque:

$$\mathbf{Q = \rho V_a^2 D^3 \times f_q\, (ND/V_a)}$$

ELECTROCOAGULATION

Electrocoagulation is the process of neutralizing the electrostatic charges present between colloidal or insoluble components and promote aggregation by Vander walls forces.The charge is neutralized by using monopolar electrodes which consists of a sacrificing anode and a passivation.The double electric layer formed by the electrolyte reduces the surface charges between the impurities which prevents them from forming sediments. Highly charged cat ions de stabilizes any colloidal particle by formation of polyvalent polyhydroxides. Electrocoagulation follows many processes simultaneously which are aimed at removal of impurities which would be tiresome to be removed by mechanical methods. Advanced and automated electrocoagulation systems do not need change of filters and provide good efficiency.Electrocoagulation process involves mainly the following mechanism:

- **Electrophoresis**: migration of current from one to other oppositely charged electrode.
- Aggregation of impurities due to charge neutralization.
- OH^- (cat ion) forms precipitate with pollutant
- **Bridge coagulation**: metallic hydroxide increases in size and has a high adsorption property towards the pollutant and hence adsorbs it.
- **Sweep coagulation**: the hydroxide forms a large lattice structure
- Removal of impurities by **electro floatation** and adhesion to the bubbles

The net process is the combination of ionization+ hydrolysis + free radical formation

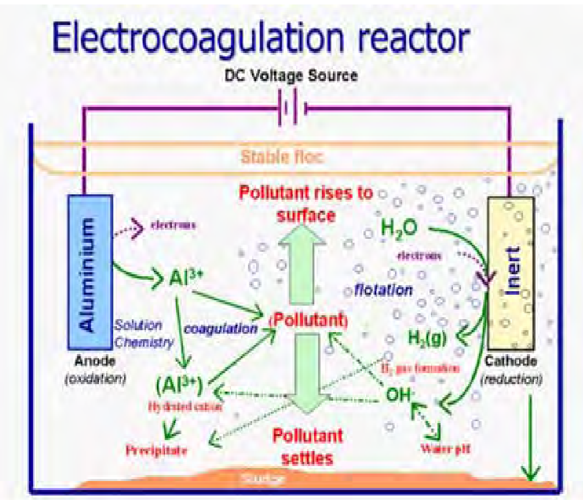


Figure1 (e) Electrocoagulation reactor

The usualchoice for anodes is iron or aluminium. There are several discussions on the benefit of one over the other but it has been determined that the efficiency of the electrode is specific to the nature of the impurity i.e. the main process that takes place in the electrocoagulation reactor.

Factors affecting electrocoagulation:

- PH
- Pollution type
- Concentration
- Bubble size
- Floc stability
- Agglomerate size

The optimum PH for operation has been determined as between 6.5 to 7.5

If aluminium is selected for the sacrificial anode then the relevant reactions:

$\mathbf{Al^{+3} + H_2O \rightarrow AlOH^{+2} + H^+}$ (1)

$\mathbf{AlOH^{+2} + H_2O \rightarrow Al(OH)_2^+ + H^+}$ (2)

$\mathbf{Al(OH)_2^+ + H_2O \rightarrow Al(OH)_3^0 + H^+}$ (3)

$\mathbf{Al(OH)_3^{0} + H_2O \rightarrow Al(OH)_4^- + H^+}$ (4)

This shows the formation of polyvalent poly hydroxide complex that increases in lattice structure and amalgamates impurities.Main components of electrocoagulation chamber:

- Parallel metal conducting plates
- Input DC supply
- A multi meter for measurement and display of input supply
- Resistance to limit the input
- Mono polar electrodes assembly

Parameters considered while making electrocoagulation reactor:

Physical considerations:

- Size of reactor
- Volume of process fluid
- Downstream unit to remove the sediment impurities
- Proper input (oil water) and output of process fluid (water)
- Surface to volume ratio (for up scaling small model)

Chemical consideration:

- Maintaining correct PH level
- Current density : the amount of current released per unit area of the electrode(usually from 10- 15 A per M2)
- Presence of inhibiting agent
- Use of correct electrode and electrolyte
- Reynolds number – indication of the fluid flow regime
- Froude number – indication of buoyancy
- Weber criteria – indication of the surface tension
- Gas saturation similarity
- Geometric similarity

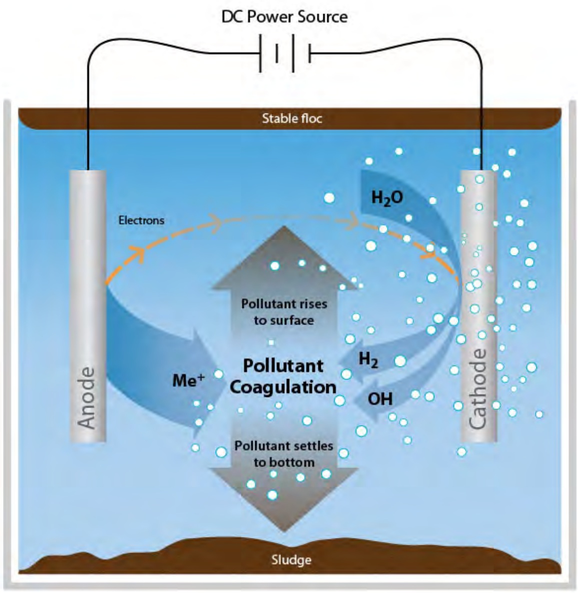


Figure1 (f) Electrocoagulation Process

Navigation

The mobile device is equipped with 5 body placed oil sensors. The navigation of the device is based on the inputs from these oil sensors. On the basis of the inputs the oil or hydrocarbon sensors movement can be explained to be in 3 modes:

1) **Working**: when all 5 sensors (ideal condition) on the body of the mobile device give positive signal indicating oil in surroundings then the propeller 1, 2 and 3 are OFF.
2) **Paddle**: when 3 detectors on either side give a positive signal then the propeller 2 or 3 are switched OFF depending on the direction of turn required (left or right respectively) and propeller 1 stays ON at half the max rpm value.
3) **Scout**: when the mobile device is not detecting oil in any of its sensors the propeller 2 stays OFF and propeller 1 and 3 remain ON. The mobile device traces circles increasing in diameter with respect to time by changing position of rudder from extreme left to neutral.

This process keeps happening till the mobile device detects oil. On encountering oil it will either go into 'working mode' or into 'paddle mode'

Work in progress:

For implementing the desired objective a simple chassis has been constructed which allows the rotation of the inlet opening pipe. The chassis is water proof for all the electrical parts which are to be used. It is in a cylindrical shape having reinforcement for the pipe to rotate on when carrying load (water and oil mixture). Pictures of the mechanical chassis have been displayed. The choice for sensors to detect oil are primarily optical or hydrocarbon sensors.

Additions in progress:

1) Addition of floats
2) Instalment of sensors
3) Enabling remote control
4) Instalment of camera to provide live feed
5) Adding a camera shutter similar mechanism in the opening of inlet to allow on/off states
6) Adding locomotion
7) Designing a dc 5 volt to 220 volt ac converter to operate ac water pump
8) Designing and electrocoagulation system to meet input quantity requirements
9) Attaching the electrocoagulation system with or in vicinity of chassis
10) Enabling efficient transfer of data from and to the mobile system

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