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A Novel Method to Improve Oil Spill Cleanup in Niger Delta Region of Nigeria

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Abstract

This paper describes the production of a Gang Flushing System (GFS) to improve oil spill clean-up in the Niger Delta region. The pollution caused by oil spill has consequently led to increased mortality rate of marine animals and organisms. In a bid to avoid oil from the sediment re-impacting already cleaned up and certified site, this study has devised the gang flushing system. The GFS has 100% capacity to excite crude trapped in as low as 0-0.9m below the sediment to the free surface for easy recovery unlike the conventional hose flushing method. A 807mm long, 807mm wide and 1004mm high Gang Flushing System weighing 60kg was produced. Results from comparative cost analysis between the use of conventional hose flushing and GFS show that 50% cost would have been saved in 2012 if GFS was used; 47% cost would have been saved in 2013; 50% in 2014, 49% in 2015; 50% in 2016; 46% in 2017 and 47% cost would have been saved in 2018. This study is significant as it has proffered solution to the inevitable oil spill challenges faced in the affected areas. The solution would save cost for the oil and gas companies and equally reduce the propensity of oil spill causing harm to human and aquatic life, the environment and the economy.

***Keywords*:** Seabed; Conventional Method; Gang Flushing System; Oil Spill; Sediment; Marine Life.

1. Introduction

It is very true to say that crude oil and its production has been a profitable source of a nation's resources. The economic benefits notwithstanding, there are associated disasters during crude oil production. Such disasters range from human, plant to aquatic life impacts, arising mainly from oil spills. According to [1], oil spill involves the release of liquid petroleum to the environment such that it has a negative impact on the environment. Oil spills occur accidentally, deliberately or due to poor industrial facility management. Oil spills can be categorized into minor, medium and major disasters.

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Oil from spills at the surface sink to the seabed in the form of oil droplets (precipitate) which are subject to various degradation processes and are reported to have accumulated following several oil spills [2].

According to [3], oil spills contaminate beaches as well as infrastructures, such as harbors and boats for which cleanup can be time consuming and labor intensive and therefore costly. In addition, shorelines contaminated with oil affect a number of recreational activities such as boating, bathing, and angling.

Disasters such as the Deep Water Horizon oil spill and the Exxon Valdez oil spill, provide evidence that coastal oil spills pose danger to the economy and natural resources, and could directly affect the public's health [4]. According to [5], well-known major oil spills around the world include the Amoco Cadiz spill in France in 1978, Exxon Valdez spill in Alaska in 1989, Gulf War spill in Kuwait in 1991, Erica spill in France in 1999, Aegean Sea spill in Galicia, Spain in 1992, Prestige spill in Spain and France in 2002, and British Petroleum platform Deepwater Horizon spill in the Gulf of Mexico in 2010, and Shell Petroleum Development Company (SPDC) spill in Niger Delta of Nigeria in 1995, to mention a few. It was viewed that oil spills originate from oil platforms, refineries, oil tankers that have an accident, or from tank cleaning in the ocean water ways.

More often than not, the Niger Delta region of Nigeria is known to be faced with the challenges of oil spill due to seeps of oil from oil and gas production sites, as well as transportation sites. The land and sea water pollution that have bedeviled the Ogoni tribe in the Niger Delta is a more recent incidence of oil spill which has drawn international concern.

A recurrent issue in the oil rich Niger Delta region of Nigeria is the prevalent old and new oil spills which totals about 9343 incidences in the last 10 years, according to official records by [6]. This translates to an average of nearly a thousand spills yearly, the highest rate of spills globally [7]. Reference [6] reported that, within the period from 2006 to 2015, there were over 5000 spillage sites with over 9000 spills. Furthermore, the average volume of oil spill annually is about 115,000 barrels, which is worth about $4.58 million (current oil price is: US$23 a barrel). The situation is worsened by the reluctance of oil companies to clean up the environment after spillage [7].

It is one thing to clean up the surface of an oil spilled area, and yet a greater cause to clean up the spilled oil trapped in the mud at the sediment. Operators are observed to have been in the practice of cleaning up oil spill superficially without much respite to the underlying sediment. Hence, the concern of this work is to produce a mechanical system for cleaning the sediment to avoid oil trapped in the mud (which are situated in the sediment) from floating again and therefore save clean-up time and energy.

It is observed that during the cleanup exercise, equipment such as oil skimmers, boom vanes, dispersant application systems and incinerators, used for the process, lack the synergy to clean down the sediment. This inadequacy had always led to making the affected area uninhabitable for plant, animals and aquatic life; and to the subsequent poping up of trapped oil, thereby re-contaminating the already cleaned up site. Therefore, devising a mechanical means of controlling the re-pollution of an already cleaned up site or the cleanup of a newly impacted site is desired.

Based on field experience, flushing by the use of hose has done no much good, despite the high cost of using it. A high pressure water hose flushing technique is as shown in Figure 1.

Figure 1: An Oil Spill Response Using High Pressure Water Technique.

According to [8], combating oil pollution is a very complex task and requires coordination of emergency response resources at different levels. They further stated that removing traces of oil for various types of coastline is difficult as it is not always clear at what stage the shoreline or the specific work area is sufficiently cleaned and the response terminated. For this reason, more suitable techniques for cleaning up oil spills from shorelines need to be investigated.

2. Materials and methods

The materials used for this study were selected with respect to the exposure of the Gang Flushing System (GFS) to extreme environmental elements such as saline water and hydrocarbons. Factors considered in the design and fabrication of the GFS are discussed as follows:

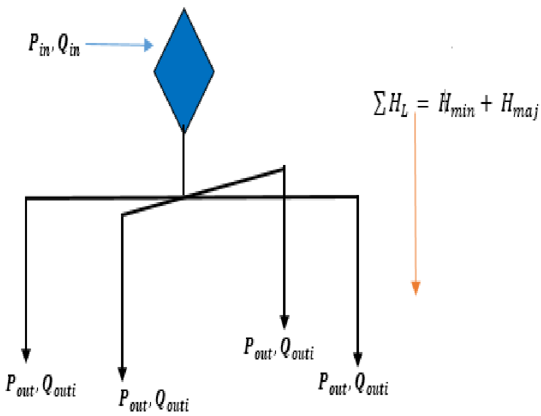

Figure 1: Line Diagram of the GFS

Figure 1 shows the pressure and flow rating of the GFS. The variables are defined as follows:

P_{in} = Pressure of Water from the Pump to the Distribution head, N/m^2.

Q_{in} = Flow rate of Water from the Pump to the Distribution head, m^3/s.

$P_{out'}$ =Pressure of Water at the exit of the ith pipe, N/m^2.

Q_{outi} = Flow rate of Water at the exit the ith pipe, m^3/s.

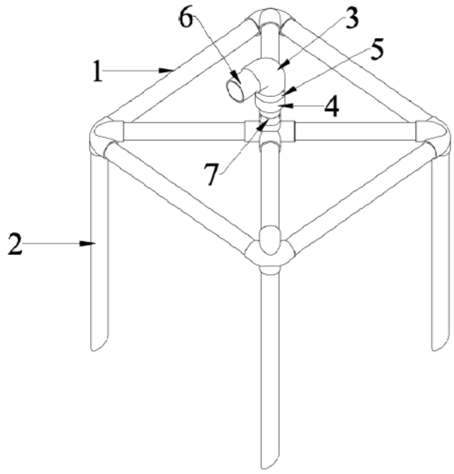

Figure 2: Pipework of Gang Flushing System: Isometric View

Meanwhile, Figure 2 is an isometric drawing of the GFS pipework. In The labelled pipework are described as follows:

Distribution head (1), Flushing Leg (2), Inlet Elbow (3), Reducer (4), Connecting Nipple (5) and Inlet Nipple (5).

A nondestructive test (NDT) such as dye penetrant inspection (DPI) which ascertains the material integrity of the GFS was carried out. Generally, the dip galvanized steel was found to possess the following properties which made it the choice [9]:

i. High corrosion resistance
ii. Weldability
iii. Ability to withstand maximum temperature of 200^{0}C in long term and continuous exposure.

Specifically, the system was fabricated to attain the following parameters:

a. Strength: The thickness of the GFS material used is sufficient to withstand a pressure of 50MPa which is rated as suitable [10].

b. Weight: The weight of the GFS is 60kg which allows for stability during operations.

Steps taken for the fabrication are shown in Figure 3.

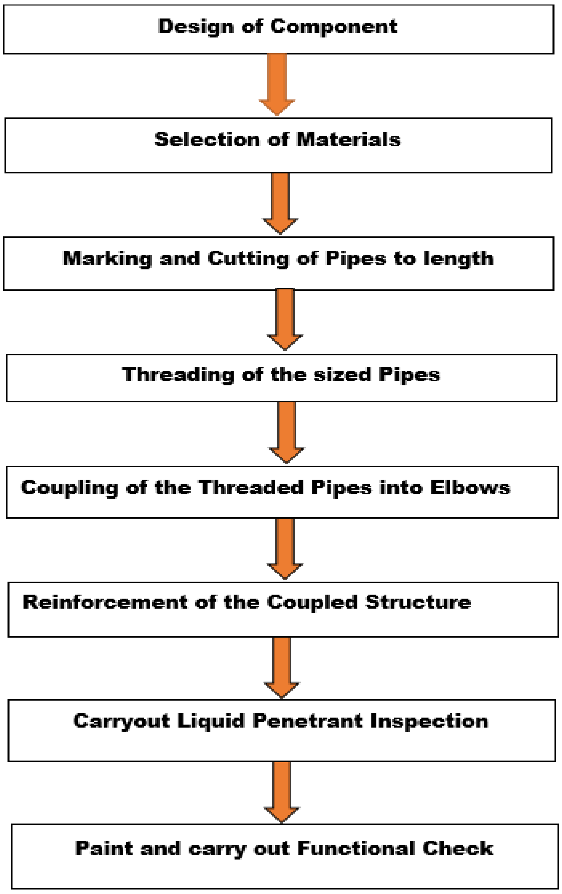

Figure 3: Production Process Block Diagram of Gang Flushing System

In the course of production of the GFS, the product quality is ensured by deploying quality control measures which are outlined in the flowchart of Figure 4.

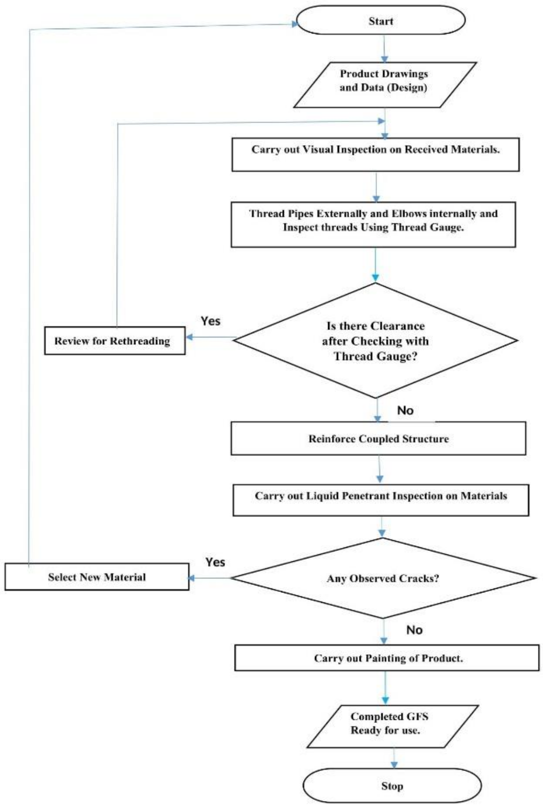

Figure 4: Quality Control Flowchart for GFS Production.

An oil spill site in Patrick waterside, Bodo in Ogoni, Niger Delta, was visited to test the functionality and performance of the GFS.

The mathematical equation which are cached for this study are such that they will help in making estimations and equally comparatively show how much cost is being saved when Hose or GFS is used for clean-up. The models are as follows:

$$H_{ft} = \frac{KV^2}{2g} \quad (1)$$

where

H_{ft} = Head Loss due to Fittings.

K = Minor Loss coefficient [K = 0.9 for elbow, and 1.8 for other fittings [11]].

V = Velocity of Fluid, m/s.

g = Gravitational Force Constant.

$$V = \frac{4Q}{\Pi D^2} \quad (2)$$

where

Q = Flow Rating of Fluid.

D = Diameter of the Hose, m.

$$H_i = 0.5\frac{V^2}{2g} \quad (3)$$

where

$H_i = Losses\ due\ to\ entry\ of\ pipe.$

$$H_e = \frac{V^2}{2g} \quad (4)$$

$H_e = losses\ due\ to\ exit\ of\ pipe.$

$$h_f = \frac{4fLV^2}{2Dg} \quad (5)$$

where

$h_f = Losses\ due\ to\ friction\ of\ pipe.$

$f = Darcy - Weisbach\ friction\ factor.$

$L = Length\ of\ pipe,\ m\ .$

$$f = \frac{0.0791}{(Re)^{1/4}} \quad (6)$$

$$R_e = \frac{VD}{\mu} \quad (7)$$

where

$R_e = Reynolds\ Number\ of\ Fluid.$

μ = *Kinematic Viscosity of Water*.

$$\mathrm{P_{out}} = \mathrm{P_{in}} - \sum \mathrm{H_L} \quad (8)$$

where

P_{out} $= Pressure\ Loss\ of\ Exiting\ Fluid\ (m)$.

P_{in} $= Designed\ Pressure\ Loss\ of\ \ Pump\ (m)$.

H_L $= Head\ Losses, m$.

$$\sum H_L = H_{min} + H_{maj} \qquad (9)$$

where

$\sum H_L$ = Sum of Losses, m.

H_{min} = Minor Losses, m.

H_{maj} = Major Losses, m.

$$Q_{in} = \sum Q_{out} \qquad (10)$$

where

Q_{in} = Flow Rate into GFS (m^3/s).

Q_{out} = Flow Rate at GFS Exit (m^3/s).

$$Q_{out} = \frac{Q_{in}}{4} \qquad (11)$$

$$C = C\sigma + C_O + C_h \qquad (12)$$

where

C = Cost of Clean-up (₦)

C_{σ}= Cost of flushing in a year (₦)

C_O= Pump Operational cost in year (₦).

C_h = Cost of hiring pump in a year (₦).

$$C\sigma = \sigma \text{x } \theta \qquad (13)$$

where

σ = Number of worker Flushing crude oil impacted area.

θ = Flushing cost per worker in 1 year (₦).

$$C_O = \gamma \text{ x } \emptyset \quad (14)$$

where

γ = Number of Water Pump Operators.

$\emptyset$ = Water pump operating cost per worker in 1 year (₦).

$$C_h = \rho \text{ x } \alpha \quad (15)$$

ρ = Number of Water Pump for Flushing.

α = Fuel cost per water pump in 1 year (₦).

3. Results and discussion

Parameters of the designed gang flushing system (GFS) are as shown in Table1. However, it is worthy to state that these design parameters were used for the fabrication of GFS.

Table 1: Design Parameters for Manufacturing GFS.

S/N	PARAMETER	VALUE
1	Discharge inlet	$0.01667m^3/s$
2	Discharge outlet	$0.004167m^3/s$
3	Pressure inlet	19.11MPa
4	Pressure outlet	19.09MPa
5	GFS Total Head loss	2.36m

The flow rate at the exit nozzle of the pump accounts for the flowrate at the GFS inlet nozzle, which is $0.01667m^3/s$. Meanwhile the water flowrate at each of the four discharge outlet of the GFS is $0.004167m^3/s$. Also, the pressure at GFS inlet is the same as pressure rating of the pump at the discharge nozzle, which is equal to 19.11MPa. It was observed that the sum of water pressure exiting the GFS (19.09 MPa) is less than the inlet pressure (19.11 MPa). This was as a result of losses along the pipe (GFS). Irrespective of the pressure difference, the pressure at the GFS outlet is sufficient to flush contaminated soil which requires a minimum pressure of 19.07MPa. In a bid to know the velocity rating of the GFS the following calculations were done:

(1) That the flowrate of the GFS at inlet is same as the pump discharge rating, hence

$$Q_{in} = 60m^3/\text{h}$$

$$= 60\, m^3/60x60\ sec$$

(2) That the flowrate of GFS at the inlet is 4times the flowrate at each of the exit point of the GFS, therefore

$$Q_{out} = \frac{60/3600}{4}$$

$$= 0.004167m^3/sec$$

The velocity of the fluid discharged at each GFS exit is obtained from Equation (2), we have

$$V \quad = \frac{4\times 0.04167}{\pi(0.058)^2}$$

$$= \ 1.577167\, m/s$$

Minor Loss

Loss of head in pipe fittings is obtained from Equation (1) as follows:

$$h_{ft} \ = \frac{1.8\times 1.577167^2}{2\times 9.8} \times 8$$

$$= \mathbf{1.827518m}$$

Loss of head at the entrance of pipe is obtained from Equation (3) as follows:

$$h_i \quad = 0.5 \times \frac{1.577167^2}{2\times 9.8}$$

$$= \mathbf{0.063455m}$$

Loss of head at the exit of a pipe, is obtained from Equation (4) as follows:

$$h_e \quad = \frac{1.577167^2}{2\times 9.8}$$

$$= \mathbf{0.126911m}$$

Minor losses = $1.827518 + 0.063455 + 0.126911$

$$= \mathbf{2.017884m}$$

Major Loss

Major loss being loss of head due to friction can be obtained from the Darcy-Weisbach formula, based on Equation (5), which can be obtained from the respective values of the Reynold's number and friction factor.

Therefore, Reynolds number is obtained from Equation (7) as follows;

$$R_e = \frac{1.577167 \times 00.58}{0.012 \times 10^{-4}}$$

$$= 76{,}230$$

Also, the friction factor is obtained from Equation (6) as follows:

$$f = \frac{0.0791}{(76.230)^{1/4}}$$

$$= 0.004760$$

Therefore the major loss is calculated from Equation (5);

$$h_f = \frac{4 \times 0.004760 \times 8.2292 \times 0.126911}{0.058}$$

$$= \mathbf{0.342843m}$$

Then, total head loss from Equation (9) is

$$\sum H_L = 2.017884 + 0.342843$$

$$= \mathbf{2.36072m}$$

$$= 9804.139432 \times 2.360727$$

$$= 23137.769059\ Pa = 0.02MPa$$

From Equation (8)

$$P_{out} = 19.11 - 0.02 = \mathbf{19.09MPa}$$

Dimensions and quantity of the pipes and fittings of the resulting GFS are shown in Table 2.

Table 2: Result of Selected Components for GFS Fabrication

S/N	Description of Component	Dimension of Component		Quantity
		Diameter (mm)	Thickness (mm)	
1	Distribution Head	50.8	5	1
2	Flushing Leg	50.8	5	4
3	Inlet Elbow	76.2	5	1
4	Reducer	76.2 - 50.8	5	1
6	Connecting Nipple	76.2	5	1
7	Inlet Nipple	50.8	5	1

After design, the result of the GFS which is constructed by assembling of components (shown in Table 2) and welding of support structure is shown in Figure 5.

Figure 5: A Pictorial View of the Fabricated Gang Flushing System (GFS)

The Gang Flushing System was tested in Bodo oil spilled site, to test how effective the water jetting out of it was able to penetrate the mud within which the oil was trapped.

3.1 Operational Benefit of GFS

A comparative table, shown in Table 3 depicts the cost of operation of a four-hose system against a single GFS system. For a period of 7 years.

Table 3: Comparative Cost Analysis of Flushing using Hose and GFS.

HOSE FLUSHING					GANG FLUSHING SYSTEM				
Year	Cost of clean-up (x10^6)₦	Cost of flushing per year(x10^6) ₦	Cost of Operation per year (x10^6)₦	Cost of hiring per year(x10^6)₦	Year	Cost of clean-up (x10^6)₦	Cost of flushing per year(x10^6) ₦	Cost of operation per year(x10^6)₦	Cost of hiring per year(x10^6)₦
	C	C_σ	C_0	C_h		C	C_σ	C_0	C_h
2012	13.20	4.80	4.80	3.60	2012	6.90	4.80	1.20	0.90
2013	14.52	4.80	4.80	4.92	2013	7.23	4.80	1.20	1.23
2014	14.78	4.80	4.80	5.18	2014	7.29	4.80	1.20	1.29
2015	17.16	5.84	5.84	5.84	2015	8.67	5.84	1.46	1.37
2016	17.29	5.84	5.84	5.61	2016	8.70	5.84	1.46	1.40
2017	17.51	6.43	6.43	5.95	2017	9.48	6.40	1.40	1.48
2018	25.80	9.65	9.65	6.03	2018	13.55	9.64	2.41	1.50

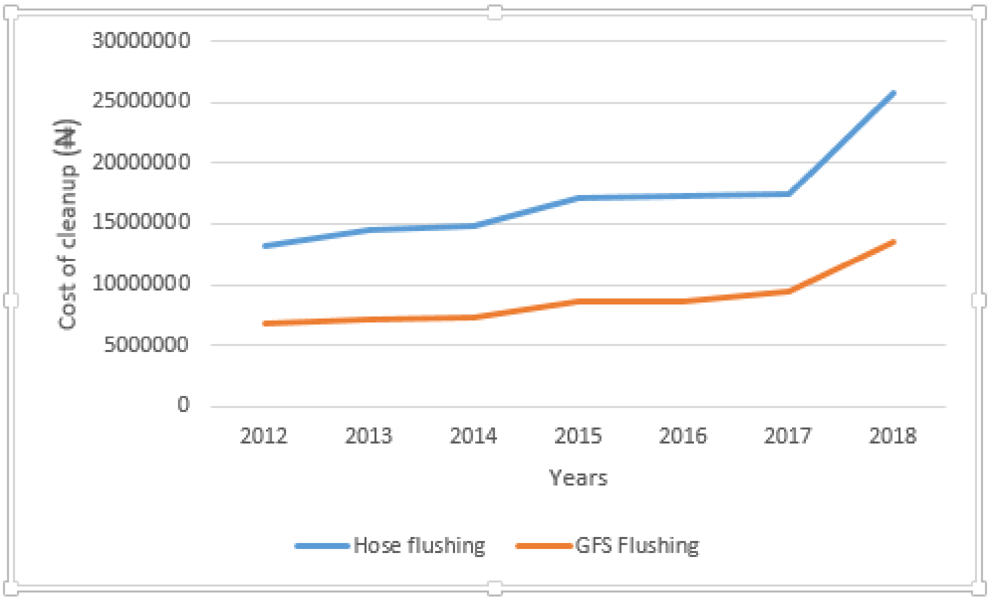

Figure 6: Comparative Cost Analysis of Flushing using Hose and GFS.

Figure 7 show that GFS has a better comparative advantage than hose flushing. This is owing to the use of single pump for GFS in place of four pumps for hose flushing, single pump operator for GFS in place of four pump operators for hose and four workers at the flushing point for GFS in place of sixteen workers at the hose flushing unit for the same areas of crude –contaminated site to be impacted. A percentage analysis that the use of GFS had a gain of 47% in cost when compared to an equivalent hose flushing system.

4. Conclusion

Firstly, this work was able to design the components of the Gang Flushing System, which involves sizing and dimensioning of parts, determining flushing pressure, flow rate and pump rating. Also, components of GFS were selected based on the design requirements, and materials for the construction was with much consideration to corrosion control and material durability. A field test was carried out in an oil spilled site to check the performance of the Gang Flushing System. Furthermore, the cost of constructing the Gang Flushing System was estimated in the course of this work.

5. Limitation of the Study

Sequel to this research the following limitation were recorded:

- The Gang Flushing System which should have had more water discharge outlets in order to cover larger impacted area in a short time was not achieved, Owing to financial constraints
- The cost of fabricating the modification of the Gang Flushing System design to hydraulically or pneumatically operated type, which would comparatively save cost and time than when operators are hired, was a major constraint.

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