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(Research Article)

Process and pit design for waste water-based mud treatment and drilled cuttings stabilization for cluster of oil wells

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Abstract

Environmental degradation through crude oil and gas exploration has attracted international attention over the past decades. This prompted the development of dewatering and clarification processes to treat the waste water-based mud emanating from drilling activities. There is also the need to carry out proper solidification and inertisation and stabilization process for the drilled solids. It has caused the development of many chemicals to assist solidification and inertisation and stabilization process. The costs of treatment of waste water based mud and drilled solidification and stabilization are high. Economy of proper waste pit design is also necessary to enhance fluid and process control to minimize the cost of operation. This research work is coming out from practical field operation and is used to illustrate how proper process and pit design can enhance effective and economic waste water based mud and drilled solids inertisation and stabilization process in the oil and gas industry.

Keywords: Water based mud; Dewatering; Pit design; Process design; Solidification; Stabilization

1. Introduction

Oil and gas are very important energy source globally. During drilling process several chemicals are used such as bentonite, barite and brine to withstand downhole pressure, lubricate the bit and enhance drilled cuttings removal at a faster rate. Water based mud is one type of drilling fluid, though other types of drilling fluids have been developed like oil based mud, water based mud still finds application where cost and safe environment is of paramount interest. However, after usage disposal may constitute a problem if the wastes both liquid and solids are not properly handled. For decades now attention has been focus on drilled wastes treatment emanating from all wastes generated from all drilling fluids. Oil based drilled wastes are amendable to collection of the drilled solids using skips and transported to thermal distillation unit (TDU) for treatment. At the TDU some quantity of oil is recovered from the solids, while the heated, dried solids are collected as disposed at approved designated site by the regulatory body.

Crude oil prospecting began in Nigeria in 1908, with the production and export of its Oloibiri field by Shell D' Archy-Shell Petroleum Development Company of Nigeria, SPDC in 1959. Over the years all the oil companies operating in the country have paid deaf ears to the treatment of waste mud and cuttings having being the standard all over the world. Only in 1992 that SPDC made an attempt in this direction which was propelled by the Ogoni crises, in Rivers State of Nigeria. Some companies had adopted a practice, whereby the waste mud/ water and drilled solids were injected and dumped into old wells that were no more producing .The practice is economical, but the after effect on the environment is gruesome. The waste mud and cuttings are toxic. They contain dangerous substances such as: Arsenic, barium, cadmium, lead, selenium, copper, zinc, which are soluble and insoluble. It is important to note that these substances have been dumped in Nigeria since 1908 up to the late 1990's that oil drilling started in Nigeria.

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Apart from this attempt, no other company as at that time showed practical commitment to treat waste water based mud and cuttings in the country until in the mid- 1990s that Agip Oil Nigeria Limited started the treatment of its waste water based mud and cuttings. In 1992 Elf made attempt, but the political situation in the country then did not allow for its introduction. In 1997Elf Petroleum Nigeria limited, now Total (Obite gas drilling clusters) awarded a contract to an oilfield environmental company to treat its waste drilled water based mud and cuttings. That began waste mud treatment and stabilization in Nigeria. This has now been applied by all oil companies operating in the country

Drilling fluid and drill cuttings together form the second largest volume of residues generated by Exploration and Production (E and P) industry. The physiochemical treatments present the highest treatment efficiency when compared with other methods [1].

Drilling waste has serious effect on the water quality and the aquatic environment. Solidification treatment of drilling waste mud is important to protect the environment [2].

A solidified waste is an amorphous solid which is partly saturated with water. It is composed of one or more solid phases with entrapped air in the form of air voids and a liquid phase, all which are in chemical equilibrium [3]. Rain surface water and ground surface water contain some constituents that can directly increase or decrease the leaching rate – redox potential, pH anions such as carbonate, sulphates and silicate, organic chelating agents and absorptive particulates [3]

The advantage of solidification treatment is its protection of human health and the environment by preventing the penetration of hazardous constituents into the environment. It is one of the best methods of waste treatment for environmental protection practice. It is simple and can be completed in a very short time and the equipment required occupy a small area or footprint

Cement-based stabilization and solidification (S/S) is a quick 'low-tech' and inexpensive waste treatment by converting them into a less soluble form (Stabilization); and encapsulating them by the creation of a durable matrix (solidification)> Its use for inorganic wastes is to some extent well accepted and has been widely reported[4].S/S is a technique used to improve the physical and chemical characteristic of waste and its handling to improve the mobility, solubility and toxicity of the contaminants [3]. Stabilization method has been identified as the best practical available technology in use to clean up 57 types of resources conservation and recovery act (RCRM) as listed by [5].It has also been used to remediate contamination involving heavy metals to immobilize organic pollutants in soil, sediment and waste[6,7,8.] S/S requires the use of numerous inorganic binders such as cement, lime, clay, fly ash fume and other pozzolanic material for stabilization [9]. The method is also suitable for organic materials like Bitumen products, epoxy and resins [10].

The limitation of cement based stabilization is its non-functionality where organic content is above 45% by weight, and when the waste is less than 15% of solids, when large quantities of fire solid particles are present, and when many too large particles are present. The commonly used materials have high pH value which can pose a serious problem in the stabilized wastes and on the subsequent land applied on.

High Iron contents results in contribute to the waste water and brings about undesirable taste in beverages, stains on sanitary wares and laundry, if it leaks into water sources. Cadmium is present in large quantity can lead to kidney damage.

Table 1 shows the quality control for pollutants and effluents characteristics allowed by DPR in Nigeria Similarly Table 2 shows the maximum concentration of contaminant for characteristics of EP toxicity for metals.

Table 1 Quality Control

S/N	Pollutants or Effluent Characteristics	Compliance limits: Maximum for any conservative 30 day period		
		Inland	**Near shore Area**	**Offshore Area**
1	pH	6.5-8.5	6.5-8.5	No limit
2	Temperature	35	40	-do-
3	Oil and grease content mg/l	10	20	48
4	Salinity Cl: mg/l	600	2,000	No limit
5	Turbidity (NTU)	10	15	-do-
6	Total dissolved Solids (TDS) mg/l	2,000	5,000	-do-
7	Total Suspended Solids (TSS) mg/l	30	50	-do-
8	COD, mg/l	40	No limit	-do-
9	BOD mg/l	10	-do-	-do-
10	Pb^{+5} mg/l	0.05	-do-	-do-
11	Total Iron (Fe), mg/l	1.0	-do-	-do-
12	Cu^{2} mg/l	1.5	-do-	-do-
13	Cr^{+6} mg/l	0.03	-do-	-do-
14	Zn^{+2} mg/l	1.0	-do-	-do-

Table 2 Maximum Concentration of Contaminant for Characteristics of EP Toxicity

S/N	Contaminant/	Maximum Concentration mg/l
1	Arsenic	5
2	Barium	100.0
3	Cadmium	1.0
4	Chromium	5.0
5	Lead	5.0
6	Mercury	0.2
7	Selenium	1.0
8	Silver	5.0

* Compressive Strength of Stabilized Solids > 200 psi (1,378,952 N/m^2)

The objective of this research is to demonstrate how proper process and pit design can enhance a good mud/water waste management in the oil and gas industry. This is shown with practical illustration

2. Material and methods

In waste water based mud treatments, the equipment used was: Dewatering and Treatment Physical and Chemical (TPC) unit, Tipper truck, excavator and Chemicals

In the treatment of waste mud, the first process is dewatering. This is performed by the addition of certain chemicals called coagulants and flocculants which result in coagulation and flocculation of the water based mud. It is thereafter passed through the centrifuge for the removal of the particles (solids). The effluent contains some suspended particles and has unsuitable pH value, odour, oil and bad colour. These have to be removed by passing it through another chemical process or unit (TPC) to have a clarified water. If the water from the unit contains oil, it is further passed through the API tank for the removal of oil. Oxygen was added for chemical oxygen demand (COD) and biological oxygen demand (BOD) using Aerator turbine or compressor for the process. The clarified water has to meet directorate of Petroleum Resources (DPR) standard before it was discharged into the environment.

The solids were stabilized with the addition of cement and Geosta at appropriate ratio. This immobilized and neutralized the poisonous and toxic metals in the cuttings. Increment in compressive strength. The waste cuttings should meet the required standard before dumping it in the borrow pit or dump site. It needs be emphasized here that with fine grains (sharp sand) which normally come from the top hole, the stabilized cuttings can be used for road construction. The mud treatment and stabilization increases the overall drilling well cost but its advantages to the environment outweigh this additional cost.

Table 3 shows the range in which the mixing ratio can be obtained.

Table 3 Mixing Ratios of Chemicals

S/N	Chemical	Mixing ratio	Remarks
1	Polymer	2.5-3.5g mg/l	Consult the author (expert)
2	Acid $(Al_2(so4)_3$ and $Fecl_3$	250-350 mg/l	Same
3	Lime	35-50 mg/l	Same
4	Cement	130-170 kg: m^3 mud cuttings	Same
5	Geosta	$1kg:1m^3$	Same

Table 4 is the basic composition of Geosta used for stabilization.

Table 4 Composition of Geosta

S/N	Chemicals	% Composition
1	NH_4cl	5
2	$Fecl_3$	2
3	$Nacl$	20
4	C	1
5	$Mgcl_2$	22
6	Kcl	25
7	$Cacl_2$	15
8	Others	10
9	Total	100

The general pit information for a cluster of well drilled is provided in Table 5.

Table 5 Pit information Design

S/N	Volume	Remarks
1	$500-540m^3$	Consult the author (expert)
2	$180-200m^3$	Consult the author (expert)
3	$200-280m^3$	Consult the author (expert)
4	$190-210m^3$	Consult the author (expert)
5	$250-290m^3$	Consult the author (expert)
6	$250-290m^3$	Consult the author (expert)

Figure 1 shows the flow diagram for dewatering and TPC units

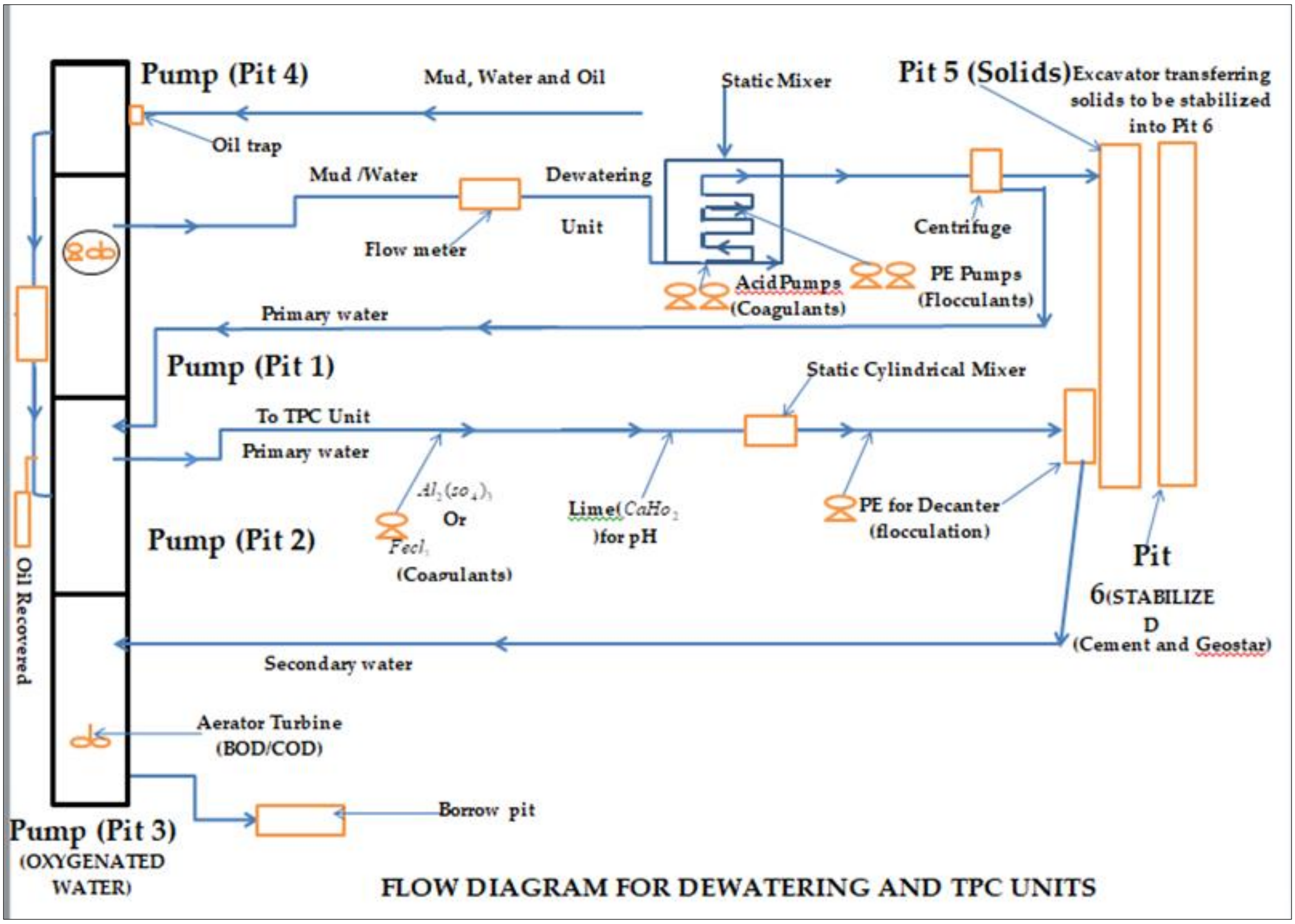

Figure 1 Flow diagram for dewatering and TPC units

3. Results

Practical data obtained from drilling water based mud campaign for a cluster of wells is provided in Tables 6 to Table 10.

Table 6 Meters drilled with Fluids

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Remarks
Drilled Days	107	45	45	36	39	39	304 days
Meters Drilled	6290	4344	4198	4181	3730	4150	26893 m
Water (Water well) m^3	9334	6698	7269	2556	3943	2410	32210
Water (water well) m^3 /day	87	149	162	71	101	62	106 m^3
Mud Built(m^3)	1431	1932	1629	1746			6738 m^3

Table 7 Solids Control Equipment

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Remarks
Centrifuge 1(hours)	636	486	314	301	329	144	2208 hours
Centrifuge 2(hours)	627	437	316	301	329	82	2094 hours

Table 8 Inertisation and Stabilization

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Remarks
m^3 of Cuttings	1440	1220	1510	1445	1510	1650	8775 m^3
m^3 /meter drilled	0.229	0.281	0.360	0.346	0.405	0.398	0.326 m^3
Cement (T)	148	153	143	145	294.50	179.50	972.5 Tons
T/ m^3 Stabilized	0.102	0.125	0.095	0.100	0.135	0.109	0.111Tons/ m^3
Geosta (T)	1.150	1.220	1.510	1.300	1.510	1.650	8.340Tons
Kg/ m^3 Stabilized	0.001	0.001	0.001	0.001	0.001	0.001	0.001Kg/ m^3

Table 9 Dewatering Unit

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Remarks
m^3 Treated	5422	3350	4868	3022	2880	2193	21735 m^3
Running hours	908	403	553	371	474	330	3039 hours
Average Flow rate(m^3)	6	8	8.803	8.146	6.076	6.645	7 /hour m^3
Treated/day(m^3)	51	74	108.178	79.526	73.846	73.100	71 m^3 /day

Table 10 PCT Clarification Unit

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Remarks
m^3 Treated	5152	3806	5441	1990	3520	2410	22319 m^3
Running hours	761	461	575	171	200	212	hours
Average Flow rate(m^3)	7	8.256	9.463	11.637	17.600	11.368	9 m^3 /hour
Treated/day(m^3)	48	84.578	120.911	52.368	90.256	80.333	73 m^3 /day

Table 11 shows a typical cost profile for treatment, inertisation and stabilization.

Table 11 Chemicals

Wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Costs			
Chemicals	m^3 /T	m^3 ?T	m^3 /T	m^3 /T	m^3 /T	m^3 /T	m^3 /T	Price	Total	%
Hydrochloric Acid	0.230	0.120	0.400	0.700	0.120	0.390	1.960	4500	8820	0.38
Flocculant FA 421	1.175	1,050	1.365	0.800	1.665	0.75	6.805	10400	70772	3.06
Lime	6.980	4.345	2.730	0.900	1.540	1.020	17.515	1000	17515	0.76
Iron Chloride	8.680	6.390	2.570	5.910	5.490	3.440	32.480	1700	55216	2.39
AluminiumSulphate	8.650	6.650	9.840	4.470	7.500	4.950	42.060	5000	210300	9.10
Cement	147.5000	153.000	143.000	145.000	204.500	179.500	972.500	237	230483	9.97
Geosta	1.150	1.220	1.51	1.28	1.51	2	8.320	10000	83200	3.60
MOB/DEMOB $	3233	3233	3233	3233	3233	3233, 3233	22631			0.98
Equipment Costs $	695567	350337	238725	201590	206895	159150	5305 1612720			70
Total/ Well $	695567	350337	363244	296755	339924	262598, 3233	Total cluster 2,311,657 $			
Cost/day	6501	7785	8072	7809	8716	8753	Average cost day 7604 $			
Cost/m drilled	111	81	87	71	91	63.3	Average cost/m drilled 86$			
Cost/ m^3 Treated	101	77	57	66	77	68	Average cost/ m^3 Treated :76$/			

4. Discussion

The operational target is to meet up with the regulatory requirements as provided in Table1.To ensure compliance, treated effluent are put inside a pit e.g pit 4 and pumped out after meeting the required properties. Sampling of the process through the process plant is done at intervals to ensure that the fluent flowing into the final pit (4) is of good quality.

Table 6 shows the actual number days used in drilling all the six wells in the cluster. Well one took hundred and seven days, while well two, three, four, five and six took, 45days, 45 days, 36 days, 39 days and another 39 days respectively, making a total of 304 days. The depths drilled per well was:.6290m, 4344m 4198m, 4181m, 3730m, 4150m resulting in 26,893 m of total drilled depth. The quantity of water generated was: 9334 m^3 , 6698 m^3 , 7269 m^3 , 2556 m^3 , 3943 m^3 , 2410 m^3 .Thus the total water generated during the drilling of the six wells was 32210 m^3 .However the mud build up per well were: 1431 m^3 , 1932 m^3 , 1629 m^3 and 1746 m^3 making a total volume of 6738 m^3 . Two centrifuges were used for the drilling operation. The running hours per centrifuge per wall is presented in Table 7. It can be seen that centrifuge one had a total running hours of 2208 and centrifuge two a running hour of 2094 respectively.

In the dewatering process the volume of waste mud treated per well is presented in Table 9 for the six as 5422 m^3 , 3350 m^3 , 486 m^3 , 3022 m^3 , 28880 m^3 and 2193 m^3 volumes of treated mud at 908 ,403,553,371,474 and 330 hours. A total of 21735 m^3 volume of waste mud/water was treated in 3039 hours. This resulted in an average flow rate for each well are: 6, 8, 8.603, 8.146, 6.076, 6.645 cubic meter per hour or cumulative average of 7 per hour. The effective volume of waste mud/water treated per day was for wells 1, 2, 3, 4, 5 and 6 was: 51, 74, 108.178, 79.526, 73.846, 73.100giving a total volume of 71 m^3 per day.

For the clarification (PCT unit), the running hours per well was 761 m^3 , 461 m^3 , 575 m^3 , 171 m^3 , 200 m^3 and 212 m^3 ; a total of 22319 m^3 . This resulted in 7, 8.256, 9.463, 11.637, 17.600 m^3 and 11.368 .It is an average of 9 m^3 per hour. This translates into 48, 84.578, 120.911, 52.368, 90.256 and 80.333 m^3 per day; an average of 73 m^3 per day.

Dewatering and PCT units are the two principal units used in the mud treatment .The major chemicals used are shown in Table 11. They include: Hydrochloric acid, Iron Chloride, Aluminiumsulphate , lime and flocculant FA 421. The average cost per day may vary between $8000-:$7604, average cost per meter drilled; $90-$86 and average cost per volume treated $80-$76 [11]

Pit design and construction is an important element in waste management operations. Poor pit design and construction will render the waste management operations difficult or infective as it will not allow room for fluid control and management. The size of the pit is also an important factor. Large pit size, though good may is not economical, while small pit size will lead to the discharge of untreated fluid through leakages and overflow into the surroundings and environment. Table 5 shows practical volume sizes of pits for rig site waste mud treatment and drilled solids stabilization.

The materials used for stabilization process are cement and Geosta. Lime can also be used as it has the capacity to absorb oil. These materials have the ability to neutralize the heavy metals. They served as binders and prevent leaching of the dangerous metals into the soil. The appropriate ratios for cement and Geosta are recommended are presented in Table 3. The drilled solids when stabilized are allowed to cake for some days. Samples are taken to ensure it meets the required compressive strength of 200 psi (1,378,953 $\frac{N}{m^2}$).This will prevent leaching of the hazardous metals into the environment. Maximum values of the contaminants are provided in Table 2. It takes a minimum of hundred years for the stabilized solids to be completely soil attain the state of the soil in its surroundings in which it was dumped. For this it highly recommended that the stabilized cuttings should be used in road construction where necessary .Further researches should be conducted to determine many other uses of the stabilized solids to minimize its wastage. Also there is a need to investigate how the effluent from the water based mud can be used for other industrial purposes.

5. Conclusion

Good process and pit design enhances cost effective water waste mud treatment, inertisation and stabilization process. It reduces spill within the vicinity of drilling operation and the immediate surroundings. Research study such as this and further studies will continue to improve cleaner environments for oil and gas bearing communities in Nigeria and around the globe.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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