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RESEARCH ARTICLE

INVESTIGATING THE ISOLATION, IDENTIFICATION OF MICROORGANISMS AND PRESSURE BUILD UP OF DEAD OIL WELL UPON THE INFLUENCE OF MICROBIAL ENHANCED OIL RECOVERY IN NIGER DELTA OF NIGERIA

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ABSTRACT

This study assessed the rate of production of lighter hydrocarbon, pressure build up, isolation and identification of the different species of microorganisms capable of degradating the heavier hydrocarbon in the reservoir. The analysis was performed using a pilot batch reactor set up in the Department of Chemical/Petrochemical Engineering Laboratory, Rivers State University of science and Technology, Port Harcourt. Mathematical model was developed in terms of effect of velocity, depth and porosity on microbial activity in bio-batch reactor and the significant of the functional parameters were examined in this paper. The functional parameters that governance the dynamic characteristics of oil well was examined as well as saturation coefficient, product generation and consumption of substrate. The concentration of the heavier hydrocarbon decreases with increase in the lighter hydrocarbon, water, microbial population and pressure build up in the reservoir. This paper demonstrated the useful of microorganism in improving dead oil well using the necessary conditions that will favour the microbial activities in a reservoir.

INTRODUCTION

In the system of microbial ecology for oil reservoir, parts of hydrocarbon-oxidating bacteria; saprophytia bacterial and fermentative bacteria are able to produce bio-surfactant, which is the main product of metabolism in the activation process for indigenous microbes. The bio-surfactant production can contribute to oil recovery by decreasing interfacial tensions of oil/rock and oil/water phases improving the wet-ability of rock surface, removing oil film from porous phase, dispersion or emulsification of crude oil and reducing oil viscosity. The current system is regarded as one component. Therefore, these models don't reflect ecological laws and two- step activation theory (aerobic and anaerobic) of the bio- surfactant production bacteria for M EOR and they usually are used for exogenous microbial enhanced oil recovery microbial enhanced oil recovery (EMEOR) (Ukpaka, 2006, 2006a, 2006b: Al-lawati, Saich, 1996; Babadagli, 1996; 2003; Banat, makkar, Canieotra, 2000; Bailey, Kenny and Schneeder, 2001; Sun, Yang and Chen, 2007). Microbes, nutrients and products of metabolism also influence on porous flow field. This complex procedure is similar to biological wastewater treatment, and both the problems are part of coupling issues porous flow field and microbial field (Ukpaka, 2009, 2009a, 2009b: BBhatt, Cajthan and Sasek, 2002; Oboh, Ilori, Akinyemi and Adebusoye, 2006; Reardon, Mosteller, Rogers, Duteau and Kim, 2002; delucas, Rodriquez, Villasenor and Femandez, 2005; Mohan, Nakhla and Yanful, 2006; Smith, Cutright and Qammar, 2000; Wammer and Peters, 2005; Xu and Obbard, 2004). Therefore, the oil displacement mechanisms for bio-surfactant production bacteria were expressed with coupling theory of porous flow field and microbial field, and equation, about microbial metabolism for microbial ecosystem in reservoir were established too. In this study, the tertiary microbial oil recovery was investigated using the microorganism isotated, identified from the crude oil samples collected from the oil fields in Niger Delta area of Nigeria and the biochemical process that involved the reaction which leads to produce surfactin as a biosurfactant, the chemical structure of which is well documented (Abtabi, Roostaa and Ghadth, 2003; Banat, 1995: Ukpaka, 2005, 2005a, 2005b). The microorganisms introduced into the system are able to produce substantial amounts of capable of producing substantial amount of lighter hydrocarbon (Zhang, 2004, Ukpaka, 2005, 2006 and 2007, and Sun, Song and Wang, 2010). In addition, to analyze the oil recovery efficiency of the MEOR in fractured models, the effect of bacteria on wettability, oil viscosity and permeability of the media was also studied. The final goal of our study was to ensure that the microorganisms, isolated and identified are the best bacterium for microbial enhanced oil recovery in fractured reservoirs of oil with regard to the bioproducts of the bacterium (Anderson, 1956; Babadagh, Al-Bemani and Boukade, 1999; Tushar, Dipankar, Kartic and Khilar, 2005; Akpofure, Efere, and Ayawei, 2007; Chunga and King (2001;

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Lotfabad and Gray, 2002; Levenspiel, 1999; nwachukwu, 2001; Ojo, 2006; Oleszczuk and Baran, 2001).Baran, 2001: Ukpaka, 2010, 2010a, 2010b). Three identically patterned micromodels with different fracture angle orientation of inclined, vertical and horizontal with respect to the flow direction were utilized. Babadagli, (1997), revealed that a non-fractured model was also used to compare the efficiency of MEOR in fractured and non-fractured porous media. Two types of bacteria were employed: Bacillus subtilis (a biosurfactantproducing bacterium) and pseudomonas sp. (an exopolymerproducing bacterium). Babadagli and Eishaghi, 1992; Babadagli, 2001; Ukpaka, 2007; 2009; Huckins, Petty, Orazio, Lebo, Clark, Gibson, Gala and Echols, 1999; Owabor, Ogbelde, and Susu 2002; Ramaswami and Luthy, 1997; Asuquo, Ewa-Oboho, Asuquo and Udo, 2004; Janikowski, Velicogna, Punt and Dangulis, 2004; Ebuchi, Abibo, Shekwole, Sigismund, Adoki and Okoro, 2005; Boochan, Sudarat and Grant 2000; and Buchholz, Wick, Harmand Meskow, 2007). The characteristics of these two type of microorganisms in enhancing microbial oil recovery was higher as observed in this research work. Similarly, in microbial enhanced oil recovery, oil recovery efficiency can be achieved by using biosurfactant-producing bacterium in fractured porous media. Further investigation on the effect of the mentioned bacteria on oil viscosity, porous media permeability and wettabiity suggests that the plugging of matrix- fracture interfaces by an exopolymer is the main reason for the low performance of the exopolymer-producing bacterium, Oil viscosity reduction as well as the reduction of IF]' was also found to be the reason for better microbial recovery efficiencies of biosurfactant producing bacterium in the fractured models (Babadagli and Eishangli, 1992; Kong, 2007; Lec, 2001; Wang, 1993; Xiu, Dong, Yu, 2009; Zhang, 1992; and Ukpaka, 2011, 2011a, 2011b). The research work focus on the following concepts: (A) to isolate, identified and characterized the possible microorganism in different oil wells studied in Niger Delta area of Nigeria, (B) evaluating the degradation of the heavier hydrocarbon leading to the production of the lighter hydrocarbon, (C) determination of the microbial population of two species of microorganisms used in the bioreactor (Ukpaka, 2006, 2006a, 2006b).

Several decades of research and successful applications support the claims of MEOR as a mature technology. Despite those facts, disagreement still exists. Successful stories are specific for each MEOR field application, and published information regarding supportive economical advantages is however in existent. Despite this, there is consensus considering MEOR as one of the cheapest existing methods. However, obscurity exists on predicting whether or not the deployment of MEOR will be successful. MEOR is, therefore, one of the future research areas with great priority as identified by the Oil and Gas in the 21st Century "Task Force". This is probably because MEOR is a complementary technology that may help recover the 377 biffion barrels of oil that are unrecoverable by conventional technologies. Before the advent of environmental molecular microbiology, the word "bacteria" was utilized indistinctively in many fields to refer to uncharacterized microbes, and such systematic error affected several disciplines. Therefore, the word "microbe" or "microorganism" will therefore be preferred hereafter in the text.

MATERIALS AND METHODS

Conceptualization Model

Development of detailed mathematical models for MEOR is a uniquely challenging task, not only as a result of the inherent complexity of the microbes, but also because of the variety of physical and chemical variables that control their behaviour in subsurface porous media. Specific or general goals can be envisaged for modelling studies. In specific cases, it is desired to use the models to maximize the yield and minimize the costs of the MEOR process. In a more general sense, a mathematical model can be used to identify the most important parameters and their functional relationships. While the specific models invariably require intensive numerical computation, some important physical insights can be produced by quite simple analytical models. An example of such an analytical approach is the engineering analysis of MEOR carried out by Babadgli, 2001, involving examination of the relationships between microbial performance, reservoir characteristics, and operating conditions (such as well spacing, injection rates and residual oil saturation.) The most important point made by the authors is that the chemical reaction of the microbial process imposes quite severe. These are expressed by the relation between the residence time of the bacteria in a cylindrical reaction region of radius i-rn and depth h and porosity ϕ, which is

$$\tau_{res} = \pi r^3 \, h\phi \, \frac{1 - S_{or}}{Q} \tag{1}$$

Where Q is the volumetric flow rate and S_{or} is the residual oil saturation, and the time τ_{rxn} required for the microbial reaction to a desired concentration C_{req} of some metabolite C from nutrient N, according to the stoichiometric relationship.

$$N \rightarrow V_N^C \tag{2}$$

To estimate the reaction time, the authors assumed isothermal plug flow through the reactor, that consumption of N is first order and irreversible, and that it is injected at initial concentration η_o The rate equation is expressed as;

$$\frac{dc}{dt} = -V_N \frac{dn}{dt} = k_1 V_N^n \tag{3}$$

Where the stoichiometric coefficient V_N defines the efficiency of nutrient into product. When integrated subject to the initial condition n (0) = η_o,

$$n = n_o e^{-k_1 t} \Rightarrow \frac{dn}{dt} = k, n.c^{-k_1 t} \tag{4}$$

The kinetic equation for change in concentration (e) can be writer as;

$$\frac{dc}{dt} = -V_N k_1 n_0 e^{-k_1 t} \tag{5}$$

Which, when integrated subject to the initial condition C (0) = 0, the equation (5) gives

$$c = V_N n_0 \left[-\frac{e - k_1 t}{k_1} \right] = V_N n_0 \left[1 - e^{-k_1 t} \right] \tag{6}$$

The limiting state implied by this equation is complete consumption of the nutrient, and from this result the reaction time needed to establish the desired concentration C_{req} is from equation (6) gives:

$$C_{req} == V_N n_0 \left[1 - e^{-k_1 t}\right] \Rightarrow \tau_{rxn} = -\frac{1}{k_1} In \left[1 - \frac{C_{req}}{V_{Nno}}\right] \quad (7)$$

Investigation conducted by various research groups reverted that the fundamental design criterion identified by the authors is that $t_{rxn} < \tau_{res}$; since τ_{rxn} can be changed only through the nutrient concentration, this condition is satisfied for large values of η_o, for large values of V_N, and for small values of Q. It can of course be argued that the physical model on which the above argument is based is overly simplistic, but the analysis draws attention to the important issue of reaction kinetics that has to be addressed by more sophisticated treatments. It is in principle possible to write a balanced equation for the production of a given metabolite (biosurfactant, for example), but the overall rate of production can only be determined experimentally, and must be controlled for bacterial growth rates. An interesting discussion of chemostat models, in which nutrient levels and organism densities are determined by solving coupled differential equations expressing the laws of mass action, is given by Bailey *et al.*. 2001. None of the individual species of bacteria proposed as candidates for use in MEOR appear to have been characterized in this way, and the dynamics of populations of different microbes competing for the same food supply have not been considered at all. Most of the published mathematical models for behaviour of bacteria and viruses in porous media were originally motivated by problems arising in water filtration and wastewater treatment (Kong, 2007 and lei, 2001). Such models have three main component. The carrying out this research work the following assumptions were put in place.

Assumptions: Non-structural model by deterministic view is used, regardless of internal construction and differences between cell., without consideration the arrearage period for the growth, the substrates limited to bacterial are carbon source and oxygen, while other nutrients are abundant, the characters of migration, chemotaxis sedimentation, adsorption in microbial oil displacement are considered and sedimentation rate, chemotaxis and death rate of various microbial components are equal. For the porous flow field the following assumptions were considered: the presence of two fluid phases (oil and water) is considered; the volume of fluid is able to be added up, and both oil and water are slightly compressible; thermodynamics balance exists instantaneously, and extended law of Darcy is applied to the system of multiphase; bacteria, bio- surfactant and carbon dioxide generated from microbial metabolism mainly contribute to enhanced oil recovery, and the reservoir is isothermal.

The Porous Flow Filed Model

Flow characters of fluid have great influences on microbial growth and metabolism into MEOR, and it is the fundamental difference between the bacterial growth in oil reservoir and fermentation on the ground. Considering the effects of convection dispersion, adsorption-desorption and sedimentation of nutrients. microorganism and the metabolic products on the premise of current technology, a general material balance equations for component k in microbial field can be written as the following 6 in view of above ideas and assumptions.

$$\frac{\partial}{\partial t} d\left(\frac{\varphi S_w}{B_w} C_{k1} + \varphi C_{k3}\right) = -\nabla\left(\frac{u_1}{B_w} C_{k1}\right) + \nabla\left(\frac{\varphi S_w}{B_w} C_{k1} \nabla C_{k1}\right) - \frac{q_w}{V_b} C_{k1} + \frac{\varphi S_w}{B_w} R_k \quad (8)$$

But U_K can be expressed as:

$$u_k = u_w + u_g + u_c \quad k = 1,2 \text{ ---- } n \quad (9)$$

$$u_k = u_w \quad (10)$$

$$u_g = \frac{b + 06.7\left(\rho_b - \rho_w\right) g d^2{}_b}{b + (0.93/\xi) 18 \mu_w} \quad (11)$$

$$u_c = k_c \nabla In\left(C_3\right) \quad (12)$$

$$\frac{\partial C_{k3}}{\partial t} = \left[k_{1k} C_{k1} f_k + k_{2k} C_{k1}\left(1 - f_k\right)\right] |u_w| - k_{3k}\left(\sigma_k \rho_b\right) |\nabla \phi_w| \quad k = 1,2 \quad (13)$$

$$\frac{\partial\left(\sigma_k \rho_b\right)}{\partial t} = \frac{\partial C_{k3}}{\partial t} + r_k \sigma_k \rho_b \quad k = 1,2 \quad (14)$$

$$C_{k3} = \min\left(C_{k\max,} \frac{\alpha_k C_{k1}}{1 + b_k C_{k1}}\right) k = 3,5,6 \quad (15)$$

where, C_{k1} is the concentration for each component in water phase, g/L; C_{ks} is the concentration for each component in adsorbed phase, g/L; $\overline{D}_{kw}$ is convection-diffusion coefficient, m^2/s; u_g and u_c are , are sedimentation and chemotaxis rates respectively, m/s; k, is chemical chemotaxis rate $b \cong 1; \xi$ is experience correction factor affected by grain surface $(0 \leq \xi \leq 1)$; ρ_b is bacterial density, g/L; d_b is the diameter of microbe (microbe is considered to be ball), m; k_{1k}, k_{2k} and k_{3k} is bacterial reversible adsorption coefficient, irreversible adsorption coefficient, and release coefficient respectively, 1/s; f_k, is the fraction of bacteria with reversible adsorption in the total adsorption; σ is the percentage of porous volume occupied by adsorption microorganism; α_k and b_k are both adsorption constants for component k; B_w, is formation volume coefficient; φ_w is the potential energy for water phase, J; b is the subscript indicating the microbial component.

Model of Reaction Equations

Equations of reaction dynamics are expressed by matrix including ρ_1, and υ_1, which are process rate equation matrix and coefficient matrix respectively, the variety of concentration for component i in oil reservoir can be shown as:

$$r_i = \sum v\ ji\ \rho_i \quad (16)$$

The model of reaction equation in terms of switch function for restrain and saturation coefficient, product generation and consumption of substrate are presented in various equation shown below.

Switch function for restrain:

$$1_i = \frac{S_1}{K_i + S_i} \quad (17)$$

Switch function for saturation coefficient:

$$M_i = \frac{S_i}{K_i + S_i} \quad (18)$$

$$\mu_{gi} = \mu_{ml} M_3 . I_4 \quad (19)$$

$$\mu_{g2} = \mu_{m2} . M_3 \quad (20)$$

$$\mu_{g2} = \mu_{m2} . M_5 \quad (21)$$

$$r_k = \left(\mu_{gk} - \mu_d\right) k = 1,2 \quad (22)$$

$$R_k = r_k \left(C_{k1} + \sigma_K \rho_b\right) \text{ k} = 1,2 \quad (23)$$

Dynamics formulation for product generation

$$r_k \sum_{I=1}^{2} m_{kl} + \sum_{I=1}^{2} B_{kI} \mu_1 \quad k\ 5,6,7 \quad (24)$$

$$R_k \sum_{I=1}^{2} A_{kl} \left(C_n + \rho_b \sigma_1\right) + \sum_{I=1}^{2} B_{kl} R_1 \quad k\ 5,6,7 \quad (25)$$

Dynamics formulation for consumption of substrate

$$r_k \sum_{I=1}^{2} m_{kl} + \sum_{I=1}^{2} \frac{1}{Y_{kl}} \mu_1 \quad k\ 3,4,5 \quad (26)$$

$$R_k \sum_{I=1}^{2} m_{kl} \left(C_n + \rho_b \sigma_1\right) + \sum_{I=1}^{2} \frac{1}{Y_{kl}} R_{l1} \quad k\ 3,4,5$$

where, μ_{gk}, μ_{mk} and μ_{dk} are specific growth rate, maximum specific growth rate and specific death rate for component k respectively, 1/s; k, is half-saturation coefficient, g/L; A_{kl}, is formation rate of metabolic product while microbe survives, 1/s; B_{ki}, is the metabolic product yield factor for component I, g/g; Y_{kl} is the bacterial yield factor, g/g; m_{kl}, is maintain factor, 1/s; r_k is the specific change rate for component k,l/ s; R_k is variety rate for component k, g/L; μ_{g2} is the specific growth rate for the second microorganism with the presence of the first microorganism on base of metabolic products in the first phase, 1/s in the activation system of electron acceptor on the base of injected substrate, as the specific growth rate for the second microorganism without the presence of the first microorganism on the base of metabolic products in the first phase, I/ s.

Porous Flow Field Model with Impacts of Microbial Field

The conventional porous flow equations haven't considered the variety of viscosity, absolute permeability, relative permeability and capillary pressure. These coupling porous flow equations not only involve in the fluid flow, which means that the fluid point unit has itself porous flow rate, but also include the impacts of microorganism and the products of metabolism on porous flow parameters, which interact with that in microbial field. Porous flow equations meet conservation of mass law. The governing equations in porous flow field for the model are shown as the following.

Equations of Motion

$$u_o = -\frac{KK_{ro}}{\mu_o}\left[\nabla p_o - \rho_o g \nabla D\right] \quad (28)$$

$$u_o = -\frac{KK_{ro}}{\mu_o}\left[\nabla p_w - \rho_o g \nabla D\right] \quad (29)$$

where, u_o and u_w, are rates of Darcy for oil and aqueous phases respectively, m/s; ρ_o *and* ρ_w, are pressures of oil and water phases respectively, MPa; μ_o and, μ_w are viscosities of oil and water, rnPa.s; ρ_o *and* ρ_w, are densities of oil and water respectively, kg/rn^3; K is absolute permeability, 10^{-3} μm^2; K_{ro} and K_{rw} are relative permeabilities of oil and aqueous phases respectively, dimensionless: g is gravity acceleration, rn/s^2; D is altitude depth, m; o and w are the subscripts reflecting oil and water phases respectively.

Continuity Equations

$$\nabla\left[\frac{KK_{ro}\rho_o}{\mu_o}\nabla\left(\rho_o \quad \rho_o g D\right)\right] + q_o = \frac{\partial \varphi \rho_o s_o}{\partial t} \quad (30)$$

$$\nabla\left[\frac{KK_{rw}\rho_o}{\mu_w}\nabla\left(\rho_w \quad \rho_w g D\right)\right] + q_w = \frac{\partial \varphi \rho_w s_w}{\partial t} \quad (31)$$

where, φ is porosity, f; q_o and q_w are source items of oil and phases respectively; S_o and S_w are saturation of oil and water respectively, f.

Supplementary Equations

$$S_o + S_w = 1 \quad (32)$$

$$P_w + P_o - P_{cow} = 0 \quad (33)$$

where, p_{cow} is capillary pressure for oil-water, MPa.

Equations for Variety in Physical Property Parameters

Among equations (18) to (27), all the parameters of movement speed for point unit, pressure and saturation always change with the growth and increase for microorganism. These parameters of viscosity, porosity, permeability, relative permeability and capillary pressure are not constants any more. These parameters should be solved by combining the equations about microbial field for microorganism and products of metabolism. Equations for variety in physical property parameters are shown in following formulations.

$$\mu_o = f\left(\mu_{oi},\ C_k\right) k = 1,2,6 \quad (34)$$

$$\varphi = \varphi_o - \sigma \quad (35)$$

$$\frac{k}{k_o} = \left(\frac{\varphi}{\varphi_o}\right)^3 \quad (36)$$

$$R_7 = 1 + \frac{\left(R_7, \max -\right) b_{r7} C_7}{1 + b_{r7} C_7} \quad (37)$$

$$\log(\sigma_{ow}) = \log(\sigma_{\min}) + \left[\log\left(\frac{\sigma_{\max}}{\sigma_{\min}}\right)\right]\left(\frac{C_{6,\max} - C_6}{C_{6.\max} - C_{6,\min}}\right) \quad (38)$$

$$S_n l = f(C_3) \quad (39)$$

$$K_{rl}^{o} = f(C_3) \quad (40)$$

$$K_{rl}^{o} = K(S_{nl})^{el} \quad (41)$$

$$S_{nl} = \frac{S_1 - S_{lr}}{1 - S_{lr} - S_{2r}} \quad (42)$$

$$P_c = P_{cow}\frac{\sigma_{ow} - \sigma_{\min}}{\sigma_{\max} - \sigma_{\min}} \quad (43)$$

where, μ_{oi} and μ_{wi} are viscosities of oil and water phases respectively before activation, mPa.s; μ_{om}, and p, are viscosities of oil and water phases respectively after activation, mPa. s, where μ_{ow} is only related to gas volume if microbial degradation is ignored, and μ_{wm} is only related to polymer concentration if gas is ignored. Both the parameters can be obtained by regression equations from lab experiments; f is flow efficiency coefficient; K is the relative permeability for I phase, dimensionless; S_{nl} and k°, $k_r/1$ are the residual phase saturation and the relative permeability for oil phase respectively at the end point of corresponding curves, which can be obtained by experimental methods regression; el is the factor determined by rock pore structure and wettability of oil reservoir; $\sigma_{ow}, \sigma_{\min,}$ *and* $\sigma_{\max}$ are instantaneous, minimum, and maximum interfacial tensions between oil and water phases respectively, mN/rn ; Es is power exponent; S_{or} is the residual saturation for oil phase, f ; R_{kmax} is the maximum resistance factor for permeability; b_{rk} a permeability reduction constant to be determined.

The variety of physical parameters in equations (34) (43) reflects the mechanisms of mulsification and viscosity reduction for MEOR. Particularly the change of relative permeability shows the synergistic effect of bio- surfactant production bacteria and metabolic products, working out the unexplained problem about satisfying effect for MEOR in view of known mechanisms with current knowledge.

Initial and boundary conditions in the model

Initial conditions

$$K_{ro} = k_{ro}(S_w), K_{rw} - k_{rw}(S_w) \quad (44)$$

$$P_{cow} = P_{cow}(S_w) \quad (45)$$

$$\mu_o = \mu_o(P_o, P_b), \mu_w = \mu_w(P_w) \quad (46)$$

$$C_{ki}/_{t=0} = C_o(x,y,z), C_{K3}/_{t=0} = a.C_{k1} \quad (47)$$

In equation (47), $Ck,/_{t=0}$ is the initial concentration of microbial component in suspended phase, which is related to spatial location, and $C_{k3}/,_{t=0}$, is the initial concentration of adsorbed phase. The a is the constant of proportionality. In addition, the microbial concentration in the injected water from oil field is normally low, and the curve of microbial adsorption meets Freundlich isotherm. The concentration of adsorbed microorganism on the rock surface has a linear relationship with that in the water phase. Over a long period of water injection, the concentrations of adsorbed microorganism on the rock surface almost reach the maximum adsorption capacity or the adsorption equilibrium. Therefore, the microbial concentration of adsorptive phase has a positive correlation with that of suspended phase.

Experimental Set-up

The flow diagram illustrating the experimental set-up to investigate the effect of porosity on the characteristics of oil well upon the influence of microbial enhanced oil recovery in Niger Delta area of Nigeria is presented in Figure 1.

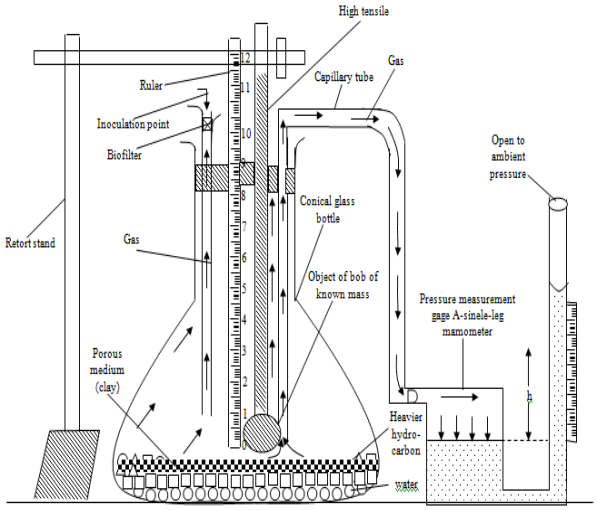

Figure 1: Experimental set-up to investigate the effectiveness of microorganisms in MEOR

The materials used in setting up the experiment includes, ruler, A-single-leg manometer, tube, high tensile rope, object of bob of known mass, retort stand, conical glass bottle, heavier hydrocarbon mixed with water, clay and microorganism.The heavier hydrocarbon mixed with water was introduced into the conical glass bottle and the porous medium of clay then added. The system was stirred for more than 5minutes to achieved proper mixing, after than the microorganism was inoculated into the batch reactor as shown in Figure 1. The capillary tube was immersed into the batch bioreactor and connected to the pressure measurement gauge (A-single-leg manometer) to enable one measure the pressure build up in the system as a result of biodegradation of the lighter hydrocarbon.

The microorganisms were introduced (inoculated into the reactor) with the aim to breakdown the heavier hydrocarbon into the lighter component as well to increase the pressure build up in the system. These were achieved as soon as the bonds of the heavier hydrocarbon were broken down; leading to the production of gases, lighter hydrocarbon and water. The pressure in the batch reactor increases daily as the volume of gases produced increases. The pressure measurement gauge inserted was monitored daily to ascertain the pressure build up per day. Similarly, the high tensile rope was tide with object of bob of known mass, the mode of operation in the system is that bob moved up ward with respect to pressure build up in the system and the displacement experienced is being measured with respect to the height of displacement in connection to the ruler. This method was applied as a check to determine the accuracy in the single leg manometer. The mass of the heavier hydrocarbon, clay and microbes were measured

before introducing into batch reactor and the biofilter was inserted to remove the undesired substance.

RESULTS AND DISCUSSION

The results obtained from the research work are presented in Tables and Figures. The result presented in Table 1 illustrates the isolation and identification the various species of microorganism present in different oil wells of Niger Delta area of Nigeria. The population rating of the microorganisms were defined in terms of high and low as well as positive (+) and negative (-) sign. The microbial population of *pseudomonas mallei* was high in all the oil wells of the following sampled area A, B, C, E, F, G, h and I but absent in D and J. for *pseudomonas aeruginosa*-high in A, B, C, D, E, F, G, h, I and J whereas in *pseudomonas dimmuta*-low in microbial population for the various oil wells of C, E, h, I and J, then absent in A, B, D, F and G. Results obtained from sampled oil well A illustrates the presence of the following microorganisms, *pseudomonas pseudomallei*- high, *pseudomallei spp* – high, *Klebsiella spp* – high, *Bacillus subtillis* – high, *bacillus species*-high, *Bacellusalve*i – high, *Bacillus macerans* – absent, *Bacillus circulans* – low, *Bacclus cerus* – high, *bacillus wagulans* – high, *Bacillus pastenri*i – low, *Bacillus licheniformis* – absent; *Bacillus panthothemicue* – absent, *micrococcus spp.* – high, *micrococcus varians* – absent, *Neisseria spp.* - high, *streptococcus spp* – high, *streptococcus homonis* – absent, *proteus spp* – high, *sterratia spp* – high, *serratia marcesscens* – absent, *arthrobacter spp* – absent, *staphylococcus spp* – high *staphylococcus aureus* – absent, *sarcina moxima* – low and *enterobacter ssp* – high as presented in Table 1.

Similarly, each of the microorganism isolated and identified as presented in table 1 illustrates the present and absent of some species from the characteristics of the oil wells in terms of classification is viewed for the following oil wells B, C, D, E, F, G, H, I and J by considering the various microorganisms. Table 2 illustrates the pressure build up per day due to the microbial activity in the batch bioreactor. The presented in Table 2 shows increase in pressure build up with increase in time. Similarly, it is also seen that the single leg manometer height increase with increase in pressure and time. The increase in height can be attributed to increase in microbial activity in the batch bioreactor set-up to investigate the useful of microorganisms in achieving lighter hydrocarbon from a dead oil wells due to the accumulation of heavier hydrocarbon that are less viscose.

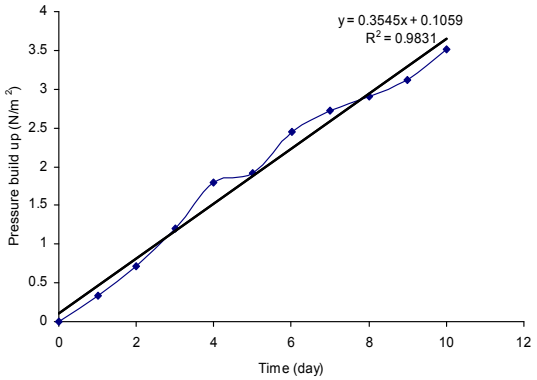

Figure 2: Graph of Pressure buildup versus time

Table 1: Experimentally determine different species of microorganisms in oil well in Niger Delta Area of Nigeria

Isolates	Population rating of micro-organism	Identified from oil well									
		A	B	C	D	E	F	G	H	I	J
Pseudomonas mallei	high	+	+	+	-	+	+	+	+	+	-
Pseudomonas aeruginosa	high	+	+	+	+	+	+	+	+	+	+
Pseudomonas diminuta	low	-	-	+	-	+	-	-	+	+	+
Pseudomonas pseudomallei	high	+	+	-	+	+	+	+	+	-	+
Pseudomonas spp.	high	+	+	+	+	+	+	+	+	+	+
Klebsiella species	high	+	-	+	+	+	+	+	+	+	+
Veillonella spp	high	+	+	-	+	+	+	-	-	+	+
Bacillus subtillis	high	+	+	+	+	+	+	+	+	-	+
Bacillus species	high	+	+	+	+	+	+	+	+	+	+
Bacillus alvei	high	+	+	+	+	+	+	+	+	+	+
Bacillus macerans	low	-	-	+	-	+	-	-	+	+	+
Bacillus circulans	low	+	-	+	+	+	-	-	-	+	+
Bacillus cereus	high	+	+	+	+	+	+	+	+	+	+
Bacillus coagulans	high	+	-	+	+	-	-	-	-	-	-
Bacillus pastenrii	low	+	+	+	-	+	+	-	-	+	+
Bacillus licheniformis	low	-	+	-	-	+	+	+	+	+	+
Bacillus panthothemicus	low	-	-	-	-	-	+	-	+	-	-
Micrococcus spp	high	+	+	+	+	+	+	+	+	+	+
Micrococus varians	low	-	-	-	-	-	+	+	-	-	-
Neisseria spp.	high	+	+	+	+	-	-	-	-	+	-
Streptococcus spp	high	-	-	-	-	-	-	+	+	-	-
Streptococcus homonis	low	-	-	-	+	-	-	-	-	+	-
Proteus spp.	high	+	+	+	+	+	+	+	+	+	+
Serratia spp	high	+	+	+	+	-	-	+	+	+	+
Serratia marcesscens	low	-	-	-	+	+	-	-	-	-	-
Arthrobacter spp.	high	-	+	+	+	+	+	-	-	-	-
Staphylococcus spp.	high	+	+	+	+	+	+	+	+	+	+
Staphylococcus aureus	low	-	+	-	-	+	+	+	-	+	+
Sarcina maxima	low	+	+	+	+	+	+	+	+	+	+
Enterobacter spp.	high	+	+	+	+	+	+	+	-	+	+

where A, B, C, D, E, F, G, H, I and J are various sampling oil wells in Niger Delta area of Nigeria.
The sign (+) means present and sign (-)means absent of the different species of the microorganisms in each oil well sampled.

Table 2: Experimental analysis results of pressure build up, hydrocarbon utilization and production

Time (day)	Pressure build up (N/m^2)	Calculated height (m)	Velocity (m/s)	Heavier hydrocarbon conc. (%)	Lighter hydrocarbon conc. (%)	Conc. of water and other components (%)
0	0	0	0	100	0	0
1	0.33	0.0040	0.012	98.3	1.1	0.6
2	0.71	0.0057	0.008	95.1	3.2	1.7
3	1.20	0.0072	0.006	93.9	5.0	1.1
4	1.80	0.0080	0.004	90.0	7.8	2.2
5	1.91	0.0125	0.007	87.5	10.1	2.4
6	2.45	0.0138	0.006	83.2	13.5	3.3
7	2.73	0.0146	0.005	80.1	15.8	4.1
8	2.90	0.0157	0.005	76.4	18.6	5.0
9	3.12	0.0180	0.006	71.3	22.4	6.3

Figure 2 illustrates the pressure build up per unit time. The variation in the pressure build up can be attributed to the variation in time as well as microbial activity. Increase in pressure build up was experienced with increase in time for each of the reactor set up. The equation of the best fit was established as y = 0.3545x + 0.1059 with root value of R^2 = 0.9831.

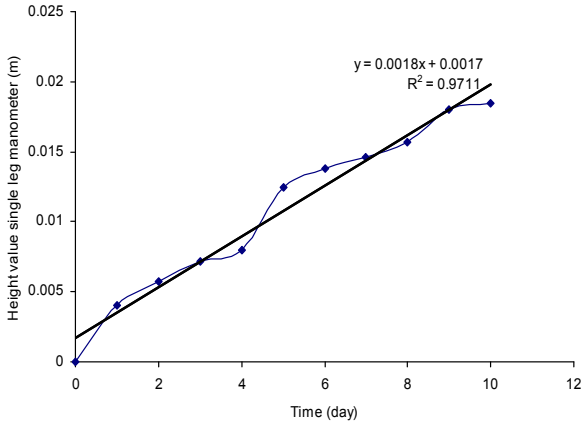

Figure 3: Graph of Height of single leg from manometer versus time

From Figure 3, it is seen that the height of the single leg manometer increases with increase in time as a result of increase in pressure build up in the bioreactor. The variation in the height of the single leg manometer can be attributed to the variation in the time as well as variation in the pressure build up in the bioreactor. The equation of the best fit is given as y = 0.0018x + 0.0017 with its root R^2 = 0.9711.

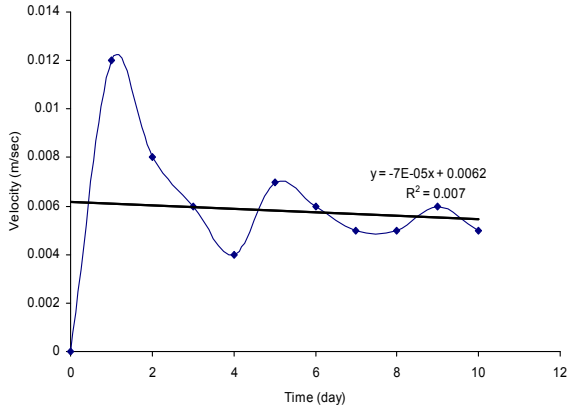

Figure 4: Graph of velocity versus time

The relationship between velocity and time is illustrated in figure 4, with increase in velocity at time range of 0 to 1.8days and sudden decrease in velocity was observed with increase in time. The variation in the velocity can be attributed to variation in time as well as variation in biomass concentration on the bioreactor as shown in Figure 4. The equation of the best fit is given as y = -7E-0.5x + 0.0062 with its root of R^2 = 0.007. From Figure 5, the characteristics of the heavier and lighter hydrocarbon and other components were examined. The result obtained in Figure 5 illustrates decrease in heavier hydrocarbon concentration with increase in lighter hydrocarbon concentration as well as other components of importance in the bio-reaction with increase in time.

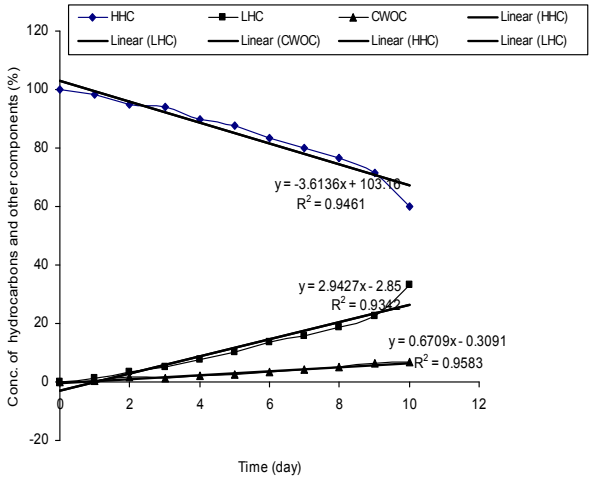

Figure 5: Graph of hydrocarbon concentration and other components versus time

The variation in the heavier, lighter hydrocarbon and other components can be attributed to the variation in time, biomass build up, pressure build and other functional parameters that control the system. The equation of the best fit for each curve is sown in Figure 5.

Conclusion

The following conclusion was drawn from the research work:

1. Each of the microorganism isolated and identified are capable of facilitating MEOR.
2. The activities of the microorganism will be at optimum when the bioreactor or the reserviour operating conditions is favourable.

3. the rate of pressure build up increases with increase in microbial activity
4. The physicochemical properties of the reserviour influences the pressure builds up as well as microbial concentration.
5. The pressure build up as well influences the microbial activity in the reserviour by reducing the rate of conversion of the heavier hydrocarbon into lighter hydrocarbon and other useful components of interest in the system.
6. The velocity of the system depends on the pressure build up as well as biomass concentrations.

The research work finally illustrates the usefulness of microorganisms in increasing the revenue of country with less expenditure and time. The process is not hazardous in nature to both underground and surface environment.

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