Supplementary information

Environmental Friendliness and High Performance of Multifunctional Tween 80/ZnO-Nanoparticles-Added Water-Based Drilling Fluid: An Experimental Approach

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Supporting information

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Fig. S1. (a) Drilling fluid additives used for preparation of traditional and T80ZnO nanoparticles added drilling fluids (b) the colour of mixture varied at every step (c) sedimentation test of nanomaterial added drilling fluid
Table S1. Shrimp collection point and information regarding compliance with regulatory restrictions

<table>
<thead>
<tr>
<th>type of marine animal</th>
<th>collection point</th>
<th>feed</th>
<th>age and size</th>
<th>regulatory restriction</th>
<th>compliances</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Litopenaeus Vannamei</em>&lt;sup&gt;a&lt;/sup&gt; (known as white leg shrimp or Pacific white shrimp)</td>
<td>Hatchery Asia Aquaculture (M) Sdn. Bhd, Kota Tingi, Johor</td>
<td>Dry shrink food twice a day (morning and evening)</td>
<td>Age: Postlarvae shrimp (age of four weeks), size: 2.5 to 3.5 cm long</td>
<td>Physical health and behaviour needs such as, water quality, ease in transport and and food supply</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transportation must be provided by operator</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pain and distress must be minimum</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clean and adequate facility for laboratory and transportation</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Animals should not be sold to 12 year old persons or younger</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: <sup>a</sup>Shrimps were acclimatized in an aquarium for three weeks at ambient temperature. Shrimps were tested in sea water; salinity of sea water was between 25 – 38 ppt.
Figure S2  (a) Molar solution placed in oven  (b) filtration of synthesized T80ZnO nanoparticles  (c) collection of synthesized of T80ZnO nanoparticles into the capsules

Figure S3. T80ZnO nanofluid after sonication at different last three high concentrations
Drilling fluid was prepared according to API standard. Drilling fluid additives such as, KCl, NaOH, polyanionic cellulose and xanthan gum were added into the water so that total volume of the drilling fluid may not exceed 350 cc as indicated in following equation S1.

\[
1 \text{ppb} = \frac{1\text{g}}{350 \text{cc}} \quad (S1)
\]

Plastic viscosity, yield point, 10-sec gel strength, 10-min gel strength were determined both at natural and 150 °F temperature using rheometer. The Fann viscometer was used to measure rheological properties. Drilling fluid was poured into the rheometer cup and the drilling fluid was mixed for a few second at 600 rpm and the viscosity reading was measured. Later, drilling fluid was mixed for a few seconds. Plastic viscosity and yield point were determined using following equations S1 and S2.

\[
\text{Plastic viscosity} = \phi_{600} - \phi_{300} \quad (S2)
\]

\[
\text{Yield point} = \text{PV} - \phi_{300} \quad (S3)
\]

Whereas,

\[\phi_{300}=\text{reading of viscosity at 300 RPM}\]

\[\phi_{600}=\text{reading of viscosity at 600 RPM}\]

10-s Gel strength was determined at very first reading at 3 rpm after the drilling fluid was undisturbed for the period of 10-s and similarly 10-min GS was determined while drilling fluid was undisturbed for the period of 10-min.
Figure S4. Hot plate placed in the holding chamber of Fann viscometer 35SA for the measurement of rheological properties at 150 °F elevated temperature.

API filtrate loss volume was determined at natural temperature and 100 psi pressure. The drilling fluid was poured into API filtrate loss volume tester cup emptying 1/4\textsuperscript{th} volume from top and capped properly using upper chamber cap. Test was carried out for the period of 30
min and drilling fluid’s filtrate volume was retrieved at different time (min): 0.5, 1, 1.5, 3.5, 7.5, 10, 12, 15, 20, 25 and 30. Similarly, HPHT filtrate loss volume was recorded however, pressure and temperature were set to 500 psi and 250 °F, respectively.

Figure S5. (a) Parts of API filter press (b) filter screen followed by filter paper and gasket assembled into lower cap and attached to the bottom of drilling fluid chamber (c) upper cap attached to the top of drilling fluid chamber
Lubricity of the drilling fluids was determined using Fann lubricity tester. Following equations were used to measured the coefficient of friction (CoF) of drilling fluids.

The equations S4 to S5 describe the CoF calculation as under;

\[
Coefficient\ of\ friction = \frac{L}{100} \tag{S4}
\]

Dial reading was set to 60 rpm and pressure was set to 100 lb,

Thereby, following equations were used;

\[
100 = \frac{L_{150}}{L_{1.5}} \tag{S5}
\]

\[
Coefficient\ factor = \frac{D_{\text{water}}}{D'_{\text{water}}} \tag{S6}
\]

\[
Coefficient\ of\ friction = \frac{(D_{\text{water}})\ Coefficient\ of\ factor}{100} \tag{S7}
\]

Whereas,

L= reading of Torque,

\(L_{150}\) = Torque applied 150-inch lbs,

\(L_{1.5}\) = Torque applied 1.5 inch torque,

\(D_{\text{water}}\) = standard dial reading in water,

And \(D'_{\text{water}}\) = dial reading observed in water calibration
Fig. S6 (a) FTIR of synthesized T80ZnO nanoparticles (b) median diameter of T80ZnO nanoparticles (c) TEM of T80ZnO nanoparticles yellowish solution at 200 nm scale shows no agglomeration
Weight of minerals in API bentonite was determined using pdxl software. XRD results displayed that API bentonite has high percentage of smectite and smectite is more susceptible in swelling compared to all three mineral such as, illite, kaolinite and Sepiolite.

**Table S2:** Mineralogy and weight percent of API bentonite

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**Fig. S7.** (a) XRD of clay (b to e) FESEM of clay and measurement of pore sizes
<table>
<thead>
<tr>
<th>mineralogy</th>
<th>weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smectite</td>
<td>52</td>
</tr>
<tr>
<td>Zeolite</td>
<td>Trace</td>
</tr>
<tr>
<td>quartz high</td>
<td>1.12</td>
</tr>
<tr>
<td>Volkonskoite</td>
<td>Trace</td>
</tr>
<tr>
<td>Khademite</td>
<td>Trace</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>0.1</td>
</tr>
<tr>
<td>Sepiolite</td>
<td>47</td>
</tr>
</tbody>
</table>

**Figure S8** (a) Heated clay pellet immersed in 140 ml of water (b) heated clay pellet immersed in 140 ml of conventional WBDF (c) heated clay immersed in 4 % of KCl water (d) heated clay immersed in 0.1 % of synthesized T80ZnO nanoparticles water
Table S3. Effectiveness of T80/ZnO based drilling fluid in enhancing the rheological properties, filtrate loss volume, lubricity, and clay inhibition relative to last 5 years published technical literature on water-based drilling fluid

<table>
<thead>
<tr>
<th>Type of nanomaterial added in drilling fluids</th>
<th>Fe$_2$O$_3$ nano, Bentonite</th>
<th>Fe$_3$O$_4$ nano</th>
<th>Poly-L-arginine</th>
<th>Nano Lapo nite</th>
<th>Gr-$\text{Al}_2$O$_3$</th>
<th>Graphene oxide/ZnO nanocomp osite</th>
<th>Carboxyl ated cellulose nano crystal</th>
<th>T80ZnO nanoparticles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (g)</td>
<td>0.5, 7.0</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.8</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Environmental check</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Yes</td>
</tr>
<tr>
<td>API standard</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
<td>Yes</td>
<td>American standard required</td>
</tr>
<tr>
<td>Drilling fluid vol. (ml)</td>
<td>100</td>
<td>350</td>
<td>100</td>
<td>335</td>
<td>100</td>
<td>100</td>
<td>350</td>
<td>350 cc</td>
</tr>
<tr>
<td>Filter cake thickness (1/32&quot; inch)</td>
<td>0.16</td>
<td>0.1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.0394</td>
<td>0.6</td>
<td>Thin/impermeable</td>
</tr>
<tr>
<td>PV (mPa.s)</td>
<td>N/A</td>
<td>15</td>
<td>56</td>
<td>N/A</td>
<td>N/A</td>
<td>23</td>
<td>N/A</td>
<td>21 @ 12%</td>
</tr>
<tr>
<td>YP (Pa)</td>
<td>3.2</td>
<td>5.64</td>
<td>12</td>
<td>N/A</td>
<td>N/A</td>
<td>17</td>
<td>0.7</td>
<td>12@71%</td>
</tr>
<tr>
<td>10-s/10-min GS (Pa)</td>
<td>3.0/4.8&quot;</td>
<td>4.7/7.9</td>
<td>2.50/4.0</td>
<td>N/A</td>
<td>N/A</td>
<td>4/5</td>
<td>N/A</td>
<td>4.3@32%/5.3@54%</td>
</tr>
<tr>
<td>Fluid loss API (ml)</td>
<td>10</td>
<td>4.2</td>
<td>12 approx.</td>
<td>N/A</td>
<td>4.5</td>
<td>25</td>
<td>4.8@17%</td>
<td>2.7 to 11</td>
</tr>
<tr>
<td>Fluid loss HPHT (ml)</td>
<td>11</td>
<td>7.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>64</td>
<td>11@30%</td>
<td>Average</td>
</tr>
<tr>
<td>Lubricity (CoF)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.26@7%</td>
<td>0.17 to 0.28</td>
</tr>
<tr>
<td>Clay/shale inhibition (%)</td>
<td>N/A</td>
<td>50% compared to water</td>
<td>31%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>17% compared to water &amp; 9% compared to traditional WBDF</td>
<td></td>
</tr>
</tbody>
</table>

*Optimization percent of properties indicates the efficiency of T80/ZnO over plastic viscosity, yield point, 10-sec gel strength, 10-min gel strength, lubricity, API filtrate loss volume and HPHT filtrate loss volume is determined by using following equation 8.
Optimization (%) = (CDF_{ref} - NDD_{value})/CDF_{ref} \quad (S8)

Whereas,

CDF_{ref} = Conventional drilling fluid Property (reference or controlled)

NDD_{value} = Nanomaterial based drilling fluid

References


