###### APPENDICE

##### APPENDIX A1

**RELEVANT EQUATIONS FOR RHEOLOGICAL PROPERTIES**

1. **Equation for increasing the Mud Weight**

A1.1

A1.2

1. **Equations for Rheological Properties Determination**

**Viscometer Dial Readings**

Shear-stress (τ) (lb/100ft²) = 1.067 × ф A1.3

Shear-rate (γ) (1/sec) = 1.704 × ω A1.4

**Bingham Plastic Model**

PV (cP) = ф600 – ф300 A1.5

YP (lb/100ft²) = (ф300 – PV) A1.6

AV (cP) = ф600/2 A1.7

AVe (cP) = 300 × (ф/ ω) A1.8

**Power Law Model**

A1.9

n = 3.23 × log A1.10

K = /170.3n A1.11

Where,

Ф = Dial reading (lb/100 ft²)

Ф3 = Dial reading at 3 rpm

ω = Rotor speed (rpm)

ф300 = Dial reading at 300 rpm

ф600 = Dial reading at 600 rpm

= Shear stress (lb/100 ft2)

= Shear-rate (1/s)

= Shear-stress at ф600 (lb/100 ft²)

= Shear-stress at ф300 (lb/100 ft²)

n = Flow behavior index, and

K = Consistency index (lb/100 ft.².n)

PV = Plastic viscosity (cP)

YP = Yield point (lb/100 ft²)

AV = Apparent viscosity (cP)

AVe = Effective viscosity (cP)

1. **Lubricity Determination**

CoF = A1.12

100 = A1.13

100 = A1.14

100 = A1.15

Where,

CF = Coefficient factor

CoF = Coefficient of friction.

**APPENDIX A2**

**PRELIMINARY RESULT OF BINGHAM PLASTIC MODEL**

**RHEOLOGICAL AND FILTRATION PROPERTIES OF DRILLING FLUIDS MEASURED AT 78 °F AND 250 °F**

**Bingham plastic model for basic WBM before aging (test temperature = 78 °F)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Basic WBM measured at LPLT (78 °F)** | | | | |
| **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 37 | 1022 | 39.48 | 18.5 |
| 300 | 25 | 511.0 | 26.68 | 25.0 |
| 200 | 21 | 340.6 | 22.41 | 31.5 |
| 100 | 13 | 170.3 | 13.87 | 39.0 |
| 30 | 9.0 | 52.20 | 9.603 | 90.0 |
| 6 | 3.0 | 10.22 | 3.201 | 150 |
| 3 | 2.0 | 5.11 | 2.134 | 200 |

**Bingham plastic model for basic WBM after aging for 16 hours (test temperature = 78 °F)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Basic WBM measured after aging for 16 hours (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 29 | 1022 | 30.94 | 14.5 |
| 300 | 19 | 511.0 | 20.27 | 19.0 |
| 200 | 14 | 340.6 | 14.94 | 21.0 |
| 100 | 10 | 170.3 | 10.67 | 30.0 |
| 30 | 4.0 | 52.20 | 4.268 | 40.0 |
| 6 | 1.0 | 10.22 | 1.067 | 50.0 |
| 3 | 0.8 | 5.11 | 0.854 | 80.0 |

**Bingham plastic model for different concentrations of PHPAdrilling mud before aging (test temperature = 78 °F)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **0.3 g of PHPA + WBM at LPLT (78 °F)** | | | | | **0.6 g of PHPA + WBM at LPLT (78 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 60 | 1022 | 64.02 | 30.0 | 600 | 70.5 | 1022 | 75.22 | 35.3 |
| 300 | 35 | 511.0 | 43.75 | 35.0 | 300 | 43 | 511.0 | 45.88 | 43.0 |
| 200 | 31 | 340.6 | 33.08 | 46.5 | 200 | 35 | 340.6 | 37.35 | 52.5 |
| 100 | 21 | 170.3 | 22.41 | 63.0 | 100 | 20 | 170.3 | 21.34 | 60.0 |
| 30 | 13 | 52.20 | 13.87 | 130 | 30 | 15 | 52.20 | 16.01 | 150 |
| 6 | 7 | 10.22 | 7.469 | 350 | 6 | 9 | 10.22 | 9.612 | 450 |
| 3 | 5 | 5.11 | 5.335 | 500 | 3 | 7 | 5.11 | 7.469 | 700 |
| **0.9 g of PHPA + WBM at LPLT (78 °F)** | | | | | **1.2 g of PHPA + WBM at LPLT (78 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 61.5 | 1022 | 65.62 | 30.5 | 600 | 59 | 1022 | 62.95 | 29.5 |
| 300 | 37.5 | 511.0 | 40.01 | 37.5 | 300 | 36 | 511.0 | 38.41 | 36.0 |
| 200 | 29 | 340.6 | 30.94 | 43.5 | 200 | 27 | 340.6 | 28.81 | 40.5 |
| 100 | 19 | 170.3 | 20.27 | 57.0 | 100 | 17 | 170.3 | 18.14 | 51.0 |
| 30 | 12 | 52.20 | 12.80 | 120 | 30 | 11 | 52.20 | 11.74 | 110 |
| 6 | 5.5 | 10.22 | 5.869 | 275 | 6 | 5.0 | 10.22 | 5.335 | 250 |
| 3 | 4.0 | 5.11 | 4.268 | 400 | 3 | 3.5 | 5.11 | 3.735 | 350 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **1.5 g of PHPA + WBM at LPLT (78 °F)** | | | | |
| **Raw data** | | **Interpretation** | | |
| Rotor speed, ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 57 | 1022 | 60.82 | 28.5 |
| 300 | 35 | 511.0 | 37.35 | 35.0 |
| 200 | 25 | 340.6 | 26.68 | 37.5 |
| 100 | 15 | 170.3 | 16.01 | 45.0 |
| 30 | 10 | 52.20 | 10.67 | 100 |
| 6 | 4.7 | 10.22 | 5.015 | 235 |
| 3 | 3.3 | 5.11 | 3.521 | 330 |

**API filtration properties of basic WBM and different concentrations of PHPA drilling mud before aging**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **API filtrates loss volumes (ml) before aging (78 °F)** | | | | | |
| **Time (min)** | **0.0 g** | **0.3 g** | **0.6 g** | **0.9 g** | **1.2 g** | **1.5 g** |
| 1 | 1.5 | 0.2 | 0 | 0.7 | 1.0 | 1.3 |
| 2 | 1.8 | 0.7 | 0.3 | 1.0 | 1.5 | 1.6 |
| 3 | 2.5 | 1.0 | 0.6 | 1.8 | 2.1 | 2.3 |
| 4 | 3.0 | 1.4 | 1.0 | 2.1 | 2.6 | 2.8 |
| 5 | 3.2 | 1.8 | 1.5 | 2.5 | 2.9 | 3.0 |
| 7.5 | 4.1 | 2.3 | 2.0 | 3.1 | 3.5 | 3.7 |
| 10 | 5.3 | 3.1 | 2.7 | 3.9 | 4.6 | 4.8 |
| 15 | 6.1 | 3.7 | 3.5 | 4.8 | 5.8 | 5.9 |
| 20 | 6.8 | 4.3 | 4.0 | 5.5 | 6.0 | 6.1 |
| 25 | 7.4 | 5.1 | 4.9 | 5.9 | 6.3 | 6.4 |
| 30 | 11.2 | 9.5 | 9.1 | 9.7 | 10.2 | 10.4 |
| **Filter cake thickness (mm)** | 2.57 | 1.47 | 1.43 | 2.10 | 2.31 | 2.35 |

**Improved rheological and filtration properties of basic WBM and different concentrations of PHPA drilling mud measured at LPLT (78 °F) before aging**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Concentration of PHPA (g)** | **Density** | **pH** | **PV (cP)** | **AV (cP)** | **YP (100lb/ft²)** | **Initial GS (100lb/ft²)** | **10 min GS (100lb/ft²)** | **CoF (%)** | **API fluid loss (ml)** | **Filter cake thickness (mm)** |
| WBM + 0.0 | 9.5 | 9.1 | 12 | 18.5 | 13 | 6.0 | 9.0 | 0.24 | 11.2 | 2.57 |
| WBM + 0.3 | 9.5 | 9.3 | 25 | 30.0 | 10 | 6.5 | 7.6 | 0.22 | 9.5 | 1.47 |
| WBM + 0.6 | 9.6 | 9.3 | 27.5 | 35.3 | 15.5 | 5.5 | 8.0 | 0.21 | 9.1 | 1.43 |
| WBM + 0.9 | 9.6 | 9.3 | 24 | 30.5 | 13.5 | 5.5 | 8.5 | 0.23 | 9.7 | 2.10 |
| WBM + 1.2 | 9.6 | 9.3 | 23 | 29.5 | 13 | 5.0 | 9.0 | 0.23 | 10.2 | 2.31 |
| WBM + 1.5 | 9.6 | 9.4 | 22 | 28.5 | 13 | 5.0 | 9.0 | 0.23 | 10.4 | 2.35 |

**Bingham plastic model for different concentrations of synthesized PP-SiO2 NCdrilling mud before aging (test temperature = 78 °F)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **0.3 g of PP-SiO2 NC + WBM at LPLT (78 °F)** | | | | | | | **0.6 g of PP-SiO2 NC + WBM at LPLT (78 °F)** | | | | | | |
| **Raw data** | | | | **Interpretation** | | | **Raw data** | | | **Interpretation** | | | |
| Rotor speed,  ω (rpm) | | Dial readings,  θ (lb/100 ft²) | | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | | AVe (cP) |
| 600 | | 53.5 | | 1022 | 57.08 | 26.8 | 600 | | 58 | 1022 | 61.89 | | 29.0 |
| 300 | | 33.5 | | 511.0 | 35.74 | 33.5 | 300 | | 36 | 511.0 | 38.41 | | 36.0 |
| 200 | | 27 | | 340.6 | 28.81 | 40.5 | 200 | | 30 | 340.6 | 32.01 | | 45.0 |
| 100 | | 23 | | 170.3 | 24.54 | 69.0 | 100 | | 25 | 170.3 | 26.68 | | 75.0 |
| 30 | | 14 | | 52.20 | 14.94 | 140 | 30 | | 17 | 52.20 | 18.14 | | 170 |
| 6 | | 4 | | 10.22 | 4.268 | 200 | 6 | | 5.5 | 10.22 | 5.869 | | 275 |
| 3 | | 3 | | 5.11 | 3.201 | 300 | 3 | | 4.0 | 5.11 | 4.268 | | 400 |
| **0.9 g of PP-SiO2 NC + WBM at LPLT (78 °F)** | | | | | | | **1.2 g of PP-SiO2 NC + WBM at LPLT (78 °F)** | | | | | | |
| **Raw data** | | | | **Interpretation** | | | **Raw data** | | | **Interpretation** | | | |
| Rotor speed,  ω (rpm) | | Dial readings,  θ (lb/100 ft²) | | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | | AVe (cP) |
| 600 | | 60.5 | | 1022 | 64.55 | 30.3 | 600 | | 63.5 | 1022 | 67.75 | | 31.8 |
| 300 | | 37.5 | | 511.0 | 40.01 | 37.5 | 300 | | 39.5 | 511.0 | 42.15 | | 39.5 |
| 200 | | 31 | | 340.6 | 33.08 | 46.5 | 200 | | 33 | 340.6 | 35.21 | | 49.5 |
| 100 | | 27 | | 170.3 | 28.81 | 81.0 | 100 | | 28 | 170.3 | 29.88 | | 84.0 |
| 30 | | 19 | | 52.20 | 20.27 | 190 | 30 | | 21 | 52.20 | 22.41 | | 210 |
| 6 | | 6.0 | | 10.22 | 6.402 | 300 | 6 | | 7.0 | 10.22 | 7.469 | | 350 |
| 3 | | 4.5 | | 5.11 | 4.802 | 450 | 3 | | 5.0 | 5.11 | 5.335 | | 500 |
|  | | | | | | | | | | | | |
|  | | | | | | | | | | | | |
| **1.5 g of synthesized PP-SiO2 NC + WBM at LPLT (78 °F)** | | | | | | | | | | | | |
| **Raw data** | | | | **Interpretation** | | | | | | | | |
| Rotor speed, ω (rpm) | | Dial readings,θ (lb/100 ft²) | | Shear-rate, γ (1/secs) | | | Shear-Stress, τ (lb/100 ft²) | | | | AVe (cP) | |
| 600 | | 64 | | 1022 | | | 68.29 | | | | 32.0 | |
| 300 | | 40 | | 511.0 | | | 42.68 | | | | 40.0 | |
| 200 | | 35 | | 340.6 | | | 37.35 | | | | 52.5 | |
| 100 | | 29 | | 170.3 | | | 30.94 | | | | 87.0 | |
| 30 | | 22 | | 52.20 | | | 23.47 | | | | 220 | |
| 6 | | 7.5 | | 10.22 | | | 8.003 | | | | 375 | |
| 3 | | 5.5 | | 5.11 | | | 5.869 | | | | 550 | |

**Improved rheological and filtration properties of basic WBM and different concentrations of synthesized PP-SiO2 NC drilling mud measured at LPLT (78 °F)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Concentration of PP-SiO2 NC (g)** | **Density** | **pH** | **PV (cP)** | **AV (cP)** | **YP (100lb/ft²)** | **Initial GS (100lb/ft²)** | **10 min GS (100lb/ft²)** | **CoF (%)** | **API fluid loss (ml)** | **Filter cake thickness (mm)** |
| WBM + 0.0 | 9.5 | 9.1 | 12 | 18.5 | 13.0 | 6.0 | 9.0 | 0.24 | 11.2 | 2.57 |
| WBM + 0.3 | 9.5 | 9.1 | 20 | 28.6 | 13.5 | 4.0 | 6.0 | 0.22 | 10.2 | 2.10 |
| WBM + 0.6 | 9.5 | 9.1 | 22 | 29.0 | 14.0 | 4.5 | 6.2 | 0.21 | 9.8 | 1.83 |
| WBM + 0.9 | 9.5 | 9.2 | 23 | 30.3 | 14.5 | 4.5 | 6.5 | 0.21 | 9.6 | 1.42 |
| WBM + 1.2 | 9.6 | 9.2 | 24 | 31.8 | 15.5 | 5.2 | 6.7 | 0.20 | 9.3 | 1.33 |
| WBM + 1.5 | 9.6 | 9.2 | 24 | 32 | 16.0 | 5.5 | 7.1 | 0.20 | 9.2 | 1.28 |

**API filtration properties of basic WBM and different concentrations of synthesized PP-SiO2 NC drilling mud before aging**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **API filtrates loss volumes (ml) before aging (78 °F)** | | | | | |
| **Time (min)** | **0.0 g** | **0.3 g** | **0.6 g** | **0.9 g** | **1.2 g** | **1.5 g** |
| 1 | 1.5 | 1.4 | 1.2 | 1.1 | 0.8 | 0 |
| 2 | 1.8 | 1.6 | 1.5 | 1.4 | 1.0 | 0.2 |
| 3 | 2.5 | 2.4 | 2.1 | 1.8 | 1.2 | 0.7 |
| 4 | 3.0 | 2.7 | 2.4 | 2.1 | 1.7 | 1.4 |
| 5 | 3.2 | 3.0 | 2.7 | 2.5 | 2.4 | 1.9 |
| 7.5 | 4.1 | 3.6 | 3.3 | 3.1 | 3.0 | 2.6 |
| 10 | 5.3 | 4.3 | 4.0 | 3.7 | 3.5 | 3.1 |
| 15 | 6.1 | 4.8 | 4.5 | 3.9 | 3.7 | 3.5 |
| 20 | 6.8 | 5.0 | 4.8 | 4.4 | 4.1 | 3.8 |
| 25 | 7.4 | 5.7 | 5.3 | 4.9 | 4.4 | 4.2 |
| 30 | 11.2 | 10.2 | 9.8 | 9.6 | 9.3 | 9.2 |
| **Filter cake thickness (mm)** | 2.57 | 2.10 | 1.83 | 1.42 | 1.33 | 1.28 |

**Bingham plastic model for different concentrations of PHPAdrilling mud after aging for 16 hours (test temperature = 78 °F)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **0.3 g of PHPA + WBM at HPHT (250 °F)** | | | | | **0.6 g of PHPA + WBM at HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 28 | 1022 | 29.88 | 14.0 | 600 | 33 | 1022 | 35.21 | 17.5 |
| 300 | 17 | 511.0 | 18.14 | 17.0 | 300 | 20 | 511.0 | 21.34 | 20.0 |
| 200 | 13 | 340.6 | 13.87 | 19.5 | 200 | 15 | 340.6 | 16.01 | 22.5 |
| 100 | 9.0 | 170.3 | 9.603 | 27.0 | 100 | 11 | 170.3 | 11.74 | 33.0 |
| 30 | 6.0 | 52.20 | 6.402 | 60.0 | 30 | 7.0 | 52.20 | 7.469 | 70.0 |
| 6 | 2.0 | 10.22 | 2.134 | 100 | 6 | 3.0 | 10.22 | 3.201 | 150 |
| 3 | 1.5 | 5.11 | 1.601 | 150 | 3 | 2.0 | 5.11 | 2.134 | 200 |
| **0.9 g of PHPA + WBM at HPHT (250 °F)** | | | | | **1.2 g of PHPA + WBM at HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 35.5 | 1022 | 37.88 | 17.8 | 600 | 37 | 1022 | 39.48 | 18.5 |
| 300 | 21.5 | 511.0 | 22.94 | 21.5 | 300 | 22.5 | 511.0 | 24.01 | 22.5 |
| 200 | 17 | 340.6 | 18.14 | 25.5 | 200 | 18 | 340.6 | 19.21 | 27.0 |
| 100 | 12 | 170.3 | 12.80 | 36.0 | 100 | 15 | 170.3 | 16.01 | 45.0 |
| 30 | 9 | 52.20 | 9.603 | 90.0 | 30 | 10 | 52.20 | 10.67 | 100 |
| 6 | 3.3 | 10.22 | 3.521 | 165 | 6 | 3.5 | 10.22 | 3.735 | 175 |
| 3 | 2.5 | 5.11 | 2.668 | 250 | 3 | 3.0 | 5.11 | 3.201 | 300 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **1.5 g of PHPA + WBM measured at HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | |
| Rotor speed, ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 42 | 1022 | 44.81 | 21.0 |
| 300 | 25.5 | 511.0 | 27.21 | 25.5 |
| 200 | 20 | 340.6 | 21.34 | 30.0 |
| 100 | 17 | 170.3 | 18.14 | 51.0 |
| 30 | 12 | 52.20 | 12.80 | 120 |
| 6 | 5.5 | 10.22 | 5.869 | 275 |
| 3 | 4.5 | 5.11 | 4.802 | 450 |

**API filtration properties of basic WBM and different concentrations of PHPA drilling mud after aging for 16 hours (250 °F)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Filtrates loss volumes (ml) after aging for 16 hours (250 °F)** | | | | | |
| **Time (min)** | **0.0 g** | **0.3 g** | **0.6 g** | **0.9 g** | **1.2 g** | **1.5 g** |
| 1 | 1.5 | 0.2 | 0 | 0.7 | 1.0 | 1.3 |
| 2 | 1.8 | 0.7 | 0.3 | 1.0 | 1.5 | 1.6 |
| 3 | 2.5 | 1.0 | 0.6 | 1.8 | 2.1 | 2.3 |
| 4 | 3.0 | 1.4 | 1.0 | 2.1 | 2.6 | 2.8 |
| 5 | 3.2 | 1.8 | 1.5 | 2.5 | 2.9 | 3.0 |
| 7.5 | 4.1 | 2.3 | 2.0 | 3.1 | 3.5 | 3.7 |
| 10 | 5.3 | 3.1 | 2.7 | 3.9 | 4.6 | 4.8 |
| 15 | 6.1 | 3.7 | 3.5 | 4.8 | 5.8 | 5.9 |
| 20 | 6.8 | 4.3 | 4.0 | 5.5 | 6.0 | 6.1 |
| 25 | 7.4 | 5.1 | 4.9 | 5.9 | 6.3 | 6.4 |
| 30 | 19.4 | 19.1 | 18.7 | 18.2 | 17.8 | 16.9 |
| **Filter cake thickness (mm)** | 4.62 | 4.34 | 4.11 | 3.91 | 3.70 | 3.59 |

**Improved rheological and filtration properties of basic WBM and different concentrations of PHPA drilling mud for HPHT after aging for 16 hours (250 °F)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Concentration of PHPA (g)** | **Density** | **pH** | **PV (cP)** | **AV (cP)** | **YP (100lb/ft²)** | **Initial GS (100lb/ft²)** | **10 min GS (100lb/ft²)** | **CoF (%)** | **API fluid loss (ml)** | **Filter cake thickness (mm)** |
| WBM + 0.0 | 9.3 | 9.1 | 10 | 14.5 | 9 | 4.0 | 6.5 | 0.29 | 19.4 | 4.62 |
| WBM + 0.3 | 9.1 | 8.6 | 11 | 14 | 6 | 2.0 | 2.0 | 0.30 | 19.1 | 4.34 |
| WBM + 0.6 | 9.1 | 8.6 | 13 | 17.5 | 7 | 2.0 | 2.5 | 0.28 | 18.7 | 4.11 |
| WBM + 0.9 | 9.2 | 8.8 | 14 | 17.8 | 7.5 | 2.5 | 3.0 | 0.27 | 18.2 | 3.91 |
| WBM + 1.2 | 9.2 | 8.9 | 14.5 | 18.5 | 8 | 2.5 | 3.0 | 0.26 | 17.8 | 3.70 |
| WBM + 1.5 | 9.3 | 8.9 | 16.5 | 21.0 | 9 | 3.0 | 3.5 | 0.24 | 16.9 | 3.59 |

**Bingham plastic model for different concentrations of PP-SiO2 NC fdrilling mud (Test temperature = 25 °C) after aging for 16 hours**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **0.3 g of PP-SiO2 NC + WBM for HPHT (250 °F)** | | | | | **0.6 g of PP-SiO2 NC + WBM for HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 44 | 1022 | 46.95 | 22.0 | 600 | 46.5 | 1022 | 49.62 | 23.3 |
| 300 | 28 | 511.0 | 29.88 | 28.0 | 300 | 29.5 | 511.0 | 31.48 | 29.5 |
| 200 | 24 | 340.6 | 25.61 | 36.0 | 200 | 26 | 340.6 | 27.74 | 39.0 |
| 100 | 19 | 170.3 | 20.27 | 57.0 | 100 | 21 | 170.3 | 22.41 | 63.0 |
| 30 | 15 | 52.20 | 16.01 | 60.0 | 30 | 15.5 | 52.20 | 16.54 | 155 |
| 6 | 3.0 | 10.22 | 3.201 | 150 | 6 | 3.4 | 10.22 | 3.628 | 170 |
| 3 | 2.4 | 5.11 | 2.561 | 240 | 3 | 2.5 | 5.11 | 2.668 | 250 |
|  |  |  |  |  |  |  |  |  |  |
| **0.9 g of PP-SiO2 NC + WBM at HPHT (250 °F)** | | | | | **1.2 g of PP-SiO2 NC + WBM at HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | | **Raw data** | | **Interpretation** | | |
| Rotor speed, ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear stress, τ (lb/100 ft²) | AVe (cP) | Rotor speed,  ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/sec) | Shear-Stress, τ (lb/100 ft²) | AVe (cP) |
| 600 | 48 | 1022 | 51.22 | 24.0 | 600 | 49 | 1022 | 52.28 | 24.5 |
| 300 | 30.5 | 511.0 | 32.54 | 30.5 | 300 | 31.5 | 511.0 | 33.61 | 31.5 |
| 200 | 27 | 340.6 | 28.81 | 40.5 | 200 | 29 | 340.6 | 30.94 | 43.5 |
| 100 | 23 | 170.3 | 24.54 | 69.0 | 100 | 24 | 170.3 | 25.61 | 72.0 |
| 30 | 16 | 52.20 | 17.07 | 160 | 30 | 17 | 52.20 | 18.14 | 170 |
| 6 | 4.0 | 10.22 | 4.268 | 200 | 6 | 5.0 | 10.22 | 5.335 | 250 |
| 3 | 3.4 | 5.11 | 3.628 | 340 | 3 | 4.5 | 5.11 | 4.802 | 450 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **1.5 g of synthesized PP-SiO2 NC + WBM for HPHT (250 °F)** | | | | |
| **Raw data** | | **Interpretation** | | |
| Rotor speed, ω (rpm) | Dial readings,  θ (lb/100 ft²) | Shear-rate, γ  (1/secs) | Shear-Stress,  τ (lb/100 ft²) | AVe (cP) |
| 600 | 50 | 1022 | 53.35 | 25.0 |
| 300 | 32 | 511.0 | 34.14 | 32.0 |
| 200 | 30 | 340.6 | 32.01 | 45.0 |
| 100 | 25 | 170.3 | 26.68 | 75.0 |
| 30 | 19 | 52.20 | 20.27 | 190 |
| 6 | 6.5 | 10.22 | 6.936 | 325 |
| 3 | 5.7 | 5.11 | 6.082 | 570 |

**Improved rheological and filtration properties of basic WBM and different concentrations of PP-SiO2 NC drilling mud for HPHT after aging for 16 hours (250 °F)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Concentration of PP-SiO2 NC (g)** | **Density** | **pH** | **PV (cP)** | **AV (cP)** | **YP (100lb/ft²)** | **Initial GS (100lb/ft²)** | **10 min GS (100lb/ft²)** | **CoF (%)** | **API fluid loss (ml)** | **Filter cake thickness**  **(mm)** |
| WBM + 0.0 | 9.3 | 9.1 | 10 | 14.5 | 9 | 4.0 | 6.5 | 0.29 | 19.4 | 4.62 |
| WBM + 0.3 | 9.3 | 8.1 | 16 | 22 | 12 | 3.0 | 4.5 | 0.28 | 16.7 | 4.02 |
| WBM + 0.6 | 9.3 | 8.3 | 17 | 23.3 | 12.5 | 3.5 | 4.8 | 0.26 | 15.8 | 3.92 |
| WBM + 0.9 | 9.4 | 8.5 | 17.5 | 24 | 13 | 3.5 | 5.0 | 0.25 | 14.9 | 3.71 |
| WBM + 1.2 | 9.4 | 8.5 | 17.5 | 24.5 | 14 | 4.0 | 5.0 | 0.24 | 13.6 | 3.55 |
| WBM + 1.5 | 9.4 | 8.6 | 18 | 25 | 14 | 4.5 | 5.2 | 0.23 | 12.3 | 3.11 |

**API filtration properties of basic WBM and different concentrations of synthesized PP-SiO2 NC drilling mud after aging for 16 hours (250 °F)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Filtrates loss volumes (ml) after aging for 16 hours (250 °F)** | | | | | |
| **Time (min)** | **0.0 g** | **0.3 g** | **0.6 g** | **0.9 g** | **1.2 g** | **1.5 g** |
| 1 | 3.2 | 3.0 | 2.6 | 2.2 | 1.9 | 1.6 |
| 2 | 3.5 | 3.3 | 3.1 | 2.8 | 2.6 | 2.1 |
| 3 | 4.1 | 3.8 | 3.5 | 3.2 | 2.9 | 2.7 |
| 4 | 4.6 | 4.3 | 4.0 | 3.7 | 3.3 | 3.0 |
| 5 | 5.3 | 4.9 | 4.4 | 4.1 | 3.7 | 3.4 |
| 7.5 | 7.7 | 7.2 | 6.7 | 5.9 | 5.3 | 4.8 |
| 10 | 8.4 | 8.0 | 7.7 | 6.5 | 6.1 | 5.8 |
| 15 | 9.6 | 9.1 | 9.5 | 8.9 | 7.7 | 6.9 |
| 20 | 11.5 | 11.2 | 11.8 | 10.4 | 9.3 | 8.7 |
| 25 | 13.6 | 12.8 | 12.3 | 11.7 | 10.8 | 10.5 |
| 30 | 19.4 | 16/7 | 15.8 | 14.9 | 13.6 | 12.3 |
| **Filter cake thickness (mm)** | 4.62 | 4.02 | 3.92 | 3.71 | 3.55 | 3.11 |

**Rheogram of Power law model for basic WBM and different concentrations of commercial PHPA drilling mud before aging (78 °F) and after aging (250 °F)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Before aging (78 °F)** | | | | **After aging (250 °F)** | | | |
| Concentrations of PHPA (g) | Shear-Stress,  τ2 (lb/100 ft²) | Shear-Stress,  τ1 (lb/100 ft²) | n | K Consistency index (lb/100 ft.².n) | Shear-Stress,  τ2 (lb/100 ft²) | Shear-Stress,  τ1 (lb/100 ft²) | n | K Consistency index (lb/100 ft.².n) |
| WBM + 0.0 | 39.48 | 26.68 | 0.550 | 2.340 | 30.94 | 20.27 | 0.593 | 1.468 |
| WBM + 0.3 | 64.02 | 43.75 | 0.534 | 4.120 | 29.88 | 18.14 | 0.700 | 0.819 |
| WBM + 0.6 | 75.22 | 45.88 | 0.694 | 2.133 | 35.21 | 21.34 | 0.702 | 0.954 |
| WBM + 0.9 | 65.82 | 40.01 | 0.698 | 1.821 | 37.88 | 22.94 | 0.704 | 1.020 |
| WBM + 1.2 | 62.95 | 38.41 | 0.693 | 1.790 | 39.48 | 24.01 | 0.698 | 1.096 |
| WBM + 1.5 | 60.82 | 37.35 | 0.684 | 1.811 | 44.81 | 27.21 | 0.700 | 1.230 |

**APPENDIX A3**

**PRELIMINARY RESULT OF POWER LAW MODEL**

**Rheogram of Power law model for basic WBM and synthesized PP-SiO2 NC drilling mud before aging (78 °F) and after aging (250 °F)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Before aging (78 °F)** | | | | **After aging (250 °F)** | | | |
| Concentrations of PP-SiO2 NC (g) | Shear-Stress,  τ2 (lb/100 ft²) | Shear-Stress,  τ1 (lb/100 ft²) | n | K Consistency index (lb/100 ft.².n) | Shear-Stress,  τ2 (lb/100 ft²) | Shear-Stress,  τ1 (lb/100 ft²) | n | K Consistency index (lb/100 ft.².n) |
| WBM + 0.0 | 39.48 | 26.68 | 0.550 | 2.340 | 30.94 | 20.27 | 0.593 | 1.468 |
| WBM + 0.3 | 57.08 | 35.74 | 0.657 | 1.955 | 46.95 | 29.88 | 0.634 | 1.808 |
| WBM + 0.6 | 61.89 | 38.41 | 0.669 | 1.989 | 49.62 | 31.48 | 0.638 | 1.868 |
| WBM + 0.9 | 64.55 | 40.01 | 0.671 | 2.055 | 51.22 | 32.54 | 0.636 | 1.948 |
| WBM + 1.2 | 67.75 | 42.15 | 0.666 | 2.216 | 52.28 | 33.61 | 0.620 | 2.166 |
| WBM + 1.5 | 68.29 | 42.68 | 0.659 | 2.312 | 53.35 | 34.14 | 0.626 | 2.138 |