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# Hydrate Control in Drilling Mud

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# Preface

Drilling mud design is very crucial in all drilling operations. Drilling muds are normally adjusted to suit any drilling operation depending on the type of rock formation and the stage of the drilling operation. Different than conventional oil and gas wells where temperatures are high, gas hydrate wells have low temperatures and thus require different drilling mud properties for successful drilling. Gas hydrate wells or hydrate sediments are future reservoirs that are believed will produce clean natural gas that will replace the current fossil fuels. These methane hydrate sediments or reservoirs introduces the need for different drilling fluid systems due to their abnormal conditions (such as low temperatures conditions). Drilled cuttings from hydrate sediments are complex due to the presence of hydrates in the in-situ hydrate rock. The dissociated hydrate during drilling may reform in the wellbore or in other parts of the drilling assembly which can lead to serious drilling geo-hazard challenges. Thus, drilling mud systems used in drilling hydrate sediments must provide rheological characteristics that are capable of accommodating the presence of hydrate without blockage.

On the other hand, in offshore drilling, the flow of the drilling muds at relatively low in risers through seabed water depths provides suitable thermodynamic conditions suitable for hydrate formation in the event of a kick. This can cause serious wellbore safety and control problems during the containment of the kick. Hydrate formation incidents during offshore drilling are rarely reported in the open literature, partly because they are not recognized. There are lots of studies on designing effective drilling mud systems to enhance hydrate management in hydrate sediments drilling operations and deep offshore operations.

Hydrate management has now become a part of the drilling operation, and for that matter, relevant knowledge and guidelines of drilling mud design for hydrate management in drilling-related operation would help establish a strong foundation for hydrate-related drilling operations. In this book, we provide such information and guidelines to provide pathways and strategies for mud engineers and drilling students in the future drilling industry. The data on the effect of drilling mud additives on hydrate formation thermodynamics and kinetics is discussed to aid proper additives selection and blending for optimum performance. Almost all data on drilling mud formulation for hydrate management has been summarized with their rheological properties discussed. The hydrate formation thermodynamics and kinetics data in drilling muds have been presented and discussed with guidelines to specially formulate efficient fluids for hydrate drilling activities. Practical field operations of hydrate-related drilling are discussed with insights into future drilling operations. This book is useful to mud engineers, students and industries who wish to be drilling mud authorities in the twenty-first-century energy production industry. It is worth noting that the authors strongly believe that there might be some errors in this book which could be a point of revealing truth scientifically since we know and understand in parts.

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# Contents

# Abbreviations

| | |
|---|---|
| 3D | Three Dimensional |
| API | American Petroleum Institute |
| AV | Apparent Viscosity (mPa s) |
| BM | Base Mud |
| BOP | Blowout Preventer |
| Br | Bromide |
| BSR | Bottom Simulating Reflector |
| $C_3H_6$ | Cyclopentane |
| CD | Carbon Dots |
| Cl | Chloride |
| CMC | Carboxymethyl Cellulose |
| CNT | Classical Nucleation Theory |
| DI | Deionized Water |
| DKIM | Dissociation Kinetic Inhibitive Mud |
| DS | Degree of Substitution |
| DSC | Differential Scanning Calorimetry |
| ECD | Equivalent Circulating Density ($g/cm^3$) |
| EOS | Equation of State |
| FKIM | Formation Kinetics Inhibitive Muds |
| FL | Fluid Loss (ml) |
| GA | Genetic Algorithm |
| Gel | Gel Strength (Pa) |
| GG | Guar Gum |
| GHSZ | Gas Hydrate Stability Zone |
| $H_2S$ | Hydrogen Sulfide |

| | |
|---|---|
| $H_d$ | Enthalpy of Dissociation (KJ/mol) |
| HEN | Heterogeneous |
| H-I-V | Hydrate–Ice–Vapor |
| H-$L_w$-V | Hydrate–Liquid–Vapor |
| HON | Homogeneous |
| HPHT | High Pressure High Temperature |
| ILs | Ionic Liquids |
| I-$L_w$-H-V | Ice–Liquid–Hydrate–Vapor |
| ind | Induction Time |
| KHI | Kinetic Hydrate Inhibitor |
| LCM | Lost Circulation Material |
| LDHI | Low Dosage Hydrate Inhibitors |
| LVER | Linear Viscoelastic Range |
| MD | Molecular Dynamics |
| MEG | Monoethylene Glycol |
| MeOH | Methanol |
| $MgCl_2$ | Magnesium Chloride |
| MS | Modified Starch |
| NA Not | Applicable |
| $NaBr_2$ | Sodium Bromide |
| Na-MMT | Bentonite |
| NGHP | National Gas Hydrate Program |
| NHF | No Hydrate Formed |
| OBM | Oil-Based Mud |
| PAC | Polyanionic Cellulose |
| PAM | Polyacrylamide |
| PEG | Polyethylene Glycol |
| PHPA | Partially Hydrolyzed Polyacrylamide |
| PV | Plastic Viscosity (m Pa s) |
| PVCap | Polyvinylcaprolactam |
| PVP | Polyvinylpyrrolidone |
| RIE | Relative Inhibition Efficiency |
| SD | Standard Deviation |
| SG | Specific Gravity |
| sH | Structure Three |
| sI | Structure One |
| sII | Structure Two |
| sol | Stable |
| STP | Standard Temperature and Pressure |
| TA | Thermal Analysis |
| T-cycle | Temperature Cycle |
| TEG/EG | Triethylene Glycol/Ethylene Glycol |
| THF | Tetrahydrofuran |

| | |
|---|---|
| THI | Thermodynamic Hydrate Inhibitor |
| TIM | Thermodynamic Inhibitive Mud |
| USA | United States of America |
| WBM | Water-Based Mud |
| XGUM/XG | Xanthan Gum |
| YP | Yield Point (Pa) |

# Symbols

| | |
|---|---|
| $G''$ | Loss Mudulus (Pa) |
| $G'$ | Storage Modulus (Pa) |
| I | Ionic Strength |
| K | Consistency Index (Pa s) |
| M | Concnetration (Wt.%) |
| MW | Molecular Weight (gmol$^{-1}$) |
| P | Reactor Pressure (MPa) |
| R | Gas constant (J K$^{-1}$ mol$^{-1}$) |
| tan$\delta$ | Damping Factor |
| $t_i$ | Induction Time (min/h) |
| V | Reactor Volume (ml) |
| z | Compressibility Factor |

## Greek Letters

| | |
|---|---|
| $\Delta n_H$ | Moles of Hydrate Consumed/Uptake (mol) |
| $\Delta G$ | Gibbs Free Energy (kJ/mol) |
| $\eta^*$ | Complex Viscosity (Pa s) |
| $n$ | Flow Index |
| η | Viscosity (Pa s) |
| $\rho$ | Density (g/cm$^{-3}$) |
| $\pi$ | Pii |
| $\gamma$ | Shear Rate (s$^{-1}$) |
| $\tau$ | Shear Stress (Pa) |
| $\sigma$ | Sigma |
| $\bar{T}$ | Average Depression Temperature (K/°C) |