Application of Nanotechnology in the Permafrost Region

Rahul Pandey(1)
(1) Department of Petroleum Engineering, Indian Institute of Petroleum and Energy,
Visakhapatnam, India
rahulpandey@iipe.ac.in

- **Abstract :** The drilling and production in the permafrost region are extremely challenging because of the harsh climatic conditions, the drilling fluid often freezes in the subsurface and the remedial procedures are costly and time-consuming, an innovative drilling fluid has been discussed in the paper below which theoretically eliminates freezing and makes the drilling cheaper by adding nanoparticles which increase the viscosity of the mud and also because of the reduced density due to aerated mud.
  Production in these areas has been none too scarce because of no technology that keeps it safe and produces at an economical level, new technology has been discussed in this paper which involves the self-heating property of the $NiFe_2O_4$ (Nickel Ferrite) nanoparticles thorough hysteresis because of alternating current which will make the production of Natural Gases from the Hydrate environment effectively, $NiFe_2O_4$ is a ferrimagnetic substance which upon alteration of the magnetic field induces heat which destabilizes the hydrates. This dissolves the problem of uncontrolled hydrocarbon flow while production which was a major setback in the industry.

- **Keywords**: Nanoparticles, Ferrimagnetic, self-heating, heat transfer, Hydrate Stability, microspheres.

Introduction

Nanotechnology is the essence of the future and the oil and gas industry is not alienated to this, the application of nanoscience in drilling, EOR, Stimulation, Workover has been a boon for the industry and it is the most actively researched topic currently.
Permafrost areas are the treasure troves to Natural Gases as they have humongous reserves of it, their extraction though is a matter of concern as these gases are trapped in a highly stable environment known as Hydrates under those pressure temperature conditions.
In the Permafrost region, the drilling operations are carried out with a lot of difficulties, whether it be the harsh temperature changes or the extensive thawing, or freeze back. These problems are because of the huge thermal energy transfer between the environment and the Drilling fluid.
Since the temperature in the permafrost region is very less, the drilling mud used (generally water-based) would freeze if initially circulated at room temperature (300K). So, to avoid this freezing of water in the subsurface we use heated drilling fluid and circulate it to get the fluid back to the surface in a liquid condition, but this solution gets the formation heated and that causes a series of problems like the expansion of water in the subsurface causing extensive pressure increment and most likely a kick, after the kick has been controlled the freezeback of the fluid would further loosen the grip of the cement with the formation and may cause the failure of the

wellbore, so any drilling operation in the permafrost region encounters this series of problems.But what if we could actually not spread the liquid's heat in the subsurface and increase its latency.

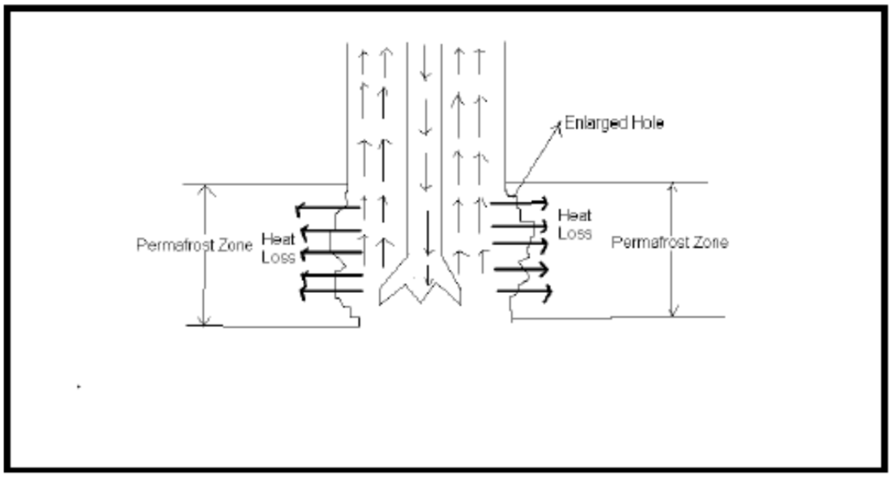

Fig 1 : Heat loss from drilling fluid to the formation causing hole enlargement Microsphere based drilling fluid to control hole enlargement during drilling in permafrost, Soumyadipta Sengupta [5]

Heat Capacity, Heat transfer and its variables

Heat capacity is the amount of heat energy required to increase the temperature (or the heat content) of a substance by a unit change. This is a very interesting phenomenon as a liquid which is having higher heat capacity would require higher heat energy to increase its temperature by a certain value, and if that fluid is circulated in the subsurface we get nothing but a greater amount of heat supplied to the formation, which is undesirable.

Heat Transfer rate is the swiftness of the flow of energy in between two or more bodies having different thermal content. It is of paramount importance to acknowledge the role of heat transfer because if the heat transfer rate of a fluid is too high then no matter how hot the fluid is initially while circulating, it will lose its energy to the formation and ultimately become a bane for us.

The perfect drilling mud design should withstand the harsh climate while incorporating its own heat and not losing it to the surrounding.

Nanoparticles and their aid to the heat transfer rate

As derived by scientists previously, they have obtained an equation that relates the hole enlargement/ formation damage with the heat content of the fluid.

$$\frac{0.558q^{0.8}a^{0.6}T_m\rho_m C_t}{dp^{2.8}(\mu/\rho_m)^{0.4}L.\rho_m.\rho_{soil}} \longrightarrow 0$$

By the above equation, it is clear that if we reduce 'C' i.e the specific heat of the mud or we increase the viscosity (μ) and/or the density (ρ) we come closer to 0 heat transfer of a liquid, these properties of a liquid can be altered with the help of nanoparticles.

Gases have a low heat-conducting capacity and specific heat capacity, so if we use Aerated/Foam/Mist drilling we might think that it serves our purpose but actually, the permafrost areas are pressurized zones and there might be a chance of kick because of that.

A remedy to the above-stated problem is the use of viscosifying nanoparticles in Aerated drilling fluid. Since the Aerated fluids have very low GWR (20:1) their densities are sufficiently larger, also with the help of nanoparticle inclusion the density of the fluid will automatically increase and since these particles are surface-active, they increase the viscosity of the fluid to a greater extent.

Experiments performed with SiO_2 nanoparticles in aerated fluid resulted in extremely great results, the heat transfer rates were reduced to 14-16% of the original fluid also, since it is aerated fluid the circulation would also be faster in the hole and further reduction of the heat transfer could take place.

Production in Permafrost Region

Problem in Extracting Hydrocarbon from Permafrost Region

Industries are yet to produce from the permafrost region majorly due to the high stability of the hydrates in this region and also the huge pressure increment that occurs due to the destabilization of the gas particles.

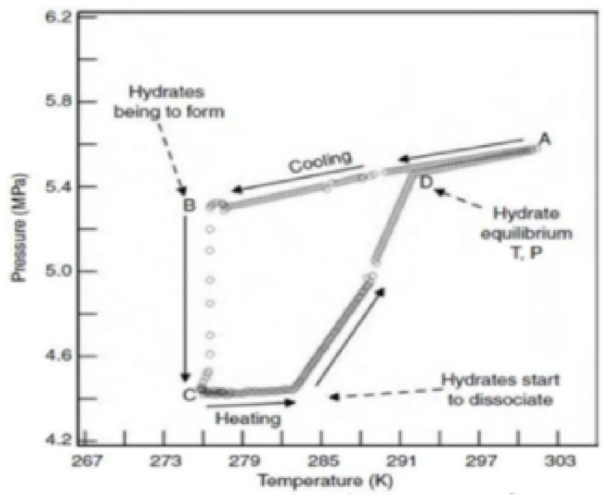

Fig 2: Pressure Vs Temperature Graph of Gas Hydrates

We can see from the figure that at low temperatures and high pressure the hydrates are stable and during the drilling, the pressure is bound to decrease meaning that hydrates come in the unstable zone, but as the figure states the uprise in the pressure is a lot which should be maneuvered at the surface. This major problem has an easy but tricky way to overcome but before coming to the solution let's deeply understand the problem.

Natural Gas Hydrates

When gases like methane, CO2, N2, ethane, and other heavy gases are mixed with the water at low temperature (5℃ - 15℃) the water molecules arrange themselves in a nest of cage-like structures, and the gas molecules get trapped inside them under huge pressure conditions, while the gas molecule gets trapped in the cages there is a huge pressure loss and that's how the Natural Gas Hydrates are formed.

These hydrates are generally found in the subsea environment or in the permafrost regions, and there have been different attempts of recovering the gases, the most efficient being the replacement of methane by other gases.

The replacement of methane by N2 or CO2 through surface injection of these gases have experimented, although this procedure is effective in removing the methane from cages but it is highly inefficient in regulating the production at the surface, so uncontrolled flow of methane at surfaces have been experienced through this method, but what if there was a method that could also alter the rate of methane expulsion from the cages.

Nickel Ferrite ($NiFe_2O_4$)

A ferrimagnetic particle aligns its poles in the direction of the current, and in an alternating the current, the poles move back and forth, which causes a loop in the (M)Flux Density Vs (H) Magnetising Force, the loops thickness ascertains the amount of heat generated in a particular loop. These particles are also useful as they tend to generate higher heat content subjected to alternating current than other particles.

As shown in Fig-3, these particles have their hysteresis effect increased at lower temperatures (hysteresis loop at 10K thicker than hysteresis loop at 300K) which is why they are preferred over their counterpart, ferromagnetic particles.

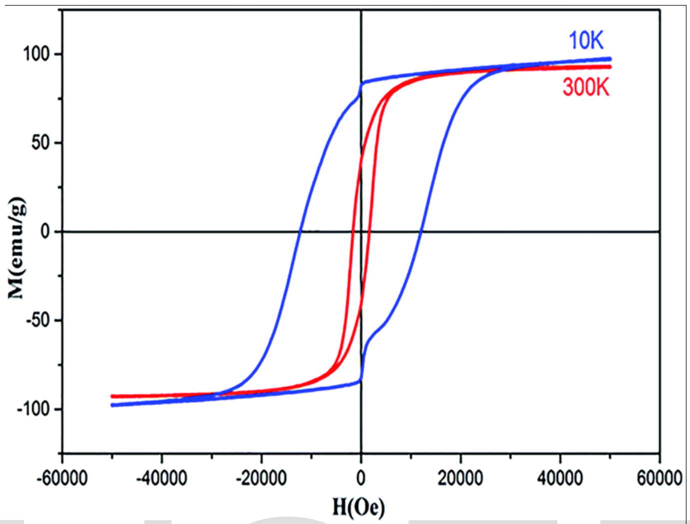

Fig 3: Hysteresis Loop of Nickel Ferrite ($NiFe_2O_4$) in which the 10K loop is thicker than the 300K loop.

Nickel Ferrite Nanoparticle : The Solution

The gases in the hydrates need to be carefully removed from their stable zone in order for them to be producible. The region to the right of the Hydrate Equilibrium curve in Fig (2) is the unstable region, with higher temperature and lower pressure. The earlier production mechanisms were successful in bringing the hydrates in the unstable zone but the problem lay in the effectiveness and sustainability. The mechanisms had less control over the operation, which resulted in frequent pipe bursts, subsidence and failure of the surface equipment. It was expensive to overcome this problem which hindered the production from these regions and asked for a better alternative to be introduced.

The Nanoparticles inclusion is an ulterior form mainly because of its small size and its higher heat generating capacity.

Mechanism

Through seismic surveys and geological mapping the geologists get to know about the whereabouts of the gases in the subsurfaces, only after exploratory drilling do we ascertain the gases presence. When the permafrost region is drilled to the target depth for production it needs to be deviated and formulated into a horizontal well. Through this the maximum area can be covered with minimum cost and a single well can produce economically. Following the casing and cementing job, a mini-frac operation needs to be carried out with the proppants coated with Nickel Ferrite nanoparticles, which will get embedded in the subsurface. A noteworthy point to be mentioned is that the mini-frac will not destabilise the gas hydrates as the frac job is done on pressure higher than the reservoir pressure. After the Completion, production tubing needs to be set up with high tension wires wound around it and controlled through the surface truck. The production will be taken through the annular region.

When the alternating current flows through the wires, they generate an alternating magnetic field around it which creates a flux change in the ferrimagnetic nanoparticles which are embedded in the subsurface, these changes create a hysteresis loop and heat is generated which transgress through the subsurface in the permafrost region and heats the gases. When these gases are in the unstable zone they get out of the hydrate cages and are produced through the annulus.

The small size of the nanoparticles is a key factor as the bulk size is very less so the body heat content is negligible of nanoparticles, also when these particles are subjected to alternating current at lower temperature they generate higher amount of energy, so incase of a production halt or a remedial procedure the surface truck stops the current flow which stops heat generation and since the particles are smaller have negligible heat content, they do not further energise the gases and create a surge pressure at the surface. The subsurface integrity is maintained and surface equipment is not damaged through this production.

Conclusion

The permafrost region is a tricky treasure trove, it has an abundance of reserves for sustainability but it has huge obstacles and hurdles. The drilling in this region is far from easy, the freezing surface materials, drill pipe sticking and drilling fluid freezing are the major issues. When freezing is reduced by heating the fluid, another problem of subsurface thawing is generated which is the root cause for subsidence near the well site in the past. The production is also tough with hydrates being stable in these high pressure and lower temperature regimes.

The paper discussed the ongoing practices related to tackling difficulty in drilling with microsphere based drilling fluid and proposed a novel technique to further advance the drilling process. It also discussed the production techniques inefficiencies and the current industry methods like depressurization, thermal stimulation, CO_2 swapping which could not provide the required control on the surface and proposed a technique using Nano-particles like $NiFe_2O_4$ which could provide the necessary control needed over production to increase its output and site safety of the workers.

References

1. *A Model of Open-hole Extended-reach Limit of Horizontal Wells in Hydrate-Bearing Sediments of Permafrost Regions* - Wenlong Li; Deli Gao; Jin Yang
2. *Lightweight Cement System helps prevent Permafrost Melt,* Maggie Benge; Julio Reyes; Erin Xiao
3. *Temperature Simulation while drilling permafrost,* N.K. Pui; N.M. Kljucec
4. *Transient Thermal model of Drilling fluid in Wellbore under the Effect of Permafrost Thaw during drilling in Arctic region-* Wang Xuerui; Sun Baojiang; Wang Zhiyuan; Zhao Yang; Wang Jintang; Zhang Zhennan; Yonghai Gao
5. *Microsphere based drilling fluid to control hole enlargement during drilling in permafrost,* Soumyadipta Sengupta