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A Unique Technical Solution to Barite Sag in Drilling Fluids

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Abstract

Many attempts have been undertaken to reduce the extent of barite sag both in the field and in the laboratory. This paper describes a unique approach to tackling the problem of barite sag using polymer-coated, ultra-fine barite.

The technology uses a polymer coating that enables effective dispersion of the particles in either a water-based or oil-based drilling fluid. This offers a number of fluid performance benefits, including superior sag performance over conventional drilling fluids without compromising the desired rheological properties of the fluid.

The particle-size range of the weighting agent provides the sag performance benefits without significantly “hiking” rheology, as would normally be expected from the large surface area of particles introduced to the drilling fluid. This unique behaviour is due to the special polymer coating used in the milling process, which diminishes the particle-particle frictional forces, thus maintaining the relatively low rheological properties of the drilling fluid.

This paper discusses how the technology can be used to provide an effective solution to the potential barite sag problems faced in drilling high-angle, extended reach and HTHP wells.

Introduction

The operational consequences of barite sag can be severe and include mud weight fluctuations, well-control problems, downhole mud losses, stuck pipe and induced wellbore instability.

Typically, attempts to minimize barite sag in conventional drilling fluids focus on controlling the rheology in the formulation of the system. The gel structure and viscoelastic properties of the fluid are engineered in an attempt to minimize static settling. Controlling the low-shear rheology of the fluid often controls the dynamic sag potential of a drilling fluid. The potential problems associated with weight-material sag determine the properties of the selected drilling fluid, particularly in the more critical deviated and high-angle wellbores.

A great deal of the new technology focus of drilling fluids has concentrated on the development of additives and systems to minimize the sag potential of the fluid.[1,2,3] Many of these additives and systems use rheology control as a means of minimizing sag, which tends to deliver higher viscosity fluids and consequently higher equivalent circulating densities (ECDs).

Another approach to minimizing weight-material sag in drilling fluids has been the use of weight materials with finer particle sizes. Stokes law established that the smaller a particle, the slower it is likely to settle in a fluid. Owing to the shear increase in the number of particle-particle interactions, which cause an undesirable increase in the plastic viscosity (PV), using fine materials for weighting drilling fluids tends to lead to higher viscosity fluids.

A new polymer-coated barite weighting agent for oil-based drilling fluids has been developed to minimize the sag potential whilst maintaining low rheology. This new material uses ultra-fine barite particles, with 60% of the particles typically less than 2 microns. The ultra-fine barite particles are coated with a specially developed polymer during the grinding process. The high-energy wet grinding process used in the production of this product is critical in ensuring efficient coating of the barite particles. The result is a stable, high-density, low-viscosity oil-based slurry. Afterwards, the slurry-weighting agent can be used to formulate high-performance drilling fluids with minimal sag potential. Despite the ultra-fine particle size of the polymer-coated barite, drilling fluids can be formulated from the stable slurry with low rheologies, thereby increasing the potential for improved ECD management.[4]

The Technology

This paper discusses the use of the ultra-fine polymer-coated (UFPC) barite technology in oil-base drilling fluids. This technology uses a polymeric wetting agent with functional groups along the chain, which allow it to adhere to the surface of the relatively inert barite particles. The coated barite particles are preferentially oil wetting. In this case, the barite weighting agent and polymer additives are milled in an enhanced mineral oil using high-performance milling technology. Manufacturing the weighting agent slurry in this way ensures that while the barite is milled, the newly exposed surfaces immediately are coated with the polymer additive.

This milling technique is critical for this technology and the technical gains cannot be achieved simply by adding the polymeric coating agent to the drilling fluid.

The milling process gives a broad distribution of ultra-fine particle sizes. This broad particle size distribution enables good fluid loss control in the formulated drilling fluids, which can be a problem when using other ultra-fine weighting agents with a narrower particle size distribution. The high-density slurries produced are combined with emulsifiers, organoclays and brine to formulate the drilling fluids in much the same way as using conventional powdered weighting agents.

A different approach to formulating drilling fluids can be taken when using UFPC barite. Standard oil-based muds which use API-grade barite, are formulated to a conventional rheology property specification to provide the required resistance to sag and hole cleaning. With this technology, rheology specifications can be radically reduced without inducing sag. The lower rheology enables higher flow rates to be achieved to provide the hole cleaning efficiency.

Applying the polymer coating using this wet-milling process provides effective oil-wetting of the barite and consequently offers a number of technical benefits in the formulated drilling fluid over conventional oil-based fluids.

Results

Five drilling fluids were prepared according to the formulation given in Table 1. Each fluid was prepared to a mud weight of 14 lb/gal, with an oil-water ratio of 80/20, and aged for 16 hours at 250ºF. In comparing the physical properties of these fluids, only the weight material was replaced. The type and amount of emulsifier, organoclay and lime was unchanged. This simple fluid formulation was used specifically to demonstrate the extremely low 6- and 3-rpm readings that can be achieved on a Fann 35 VG meter at 50ºC (122ºF), with UFPC barite weight material.

Particle Size. Figure 1 shows the typical particle-size distribution for the UFPC barite, as well as the other four commercially available barite weight materials used. This data demonstrates the broad distribution of particle sizes achieved by using the wet-milling process compared with the narrower distribution given by some of the other barite materials in the ultra-fine size range. The measured d_{50} and d_{90} are given in Table 2.

Fluid Loss Control. A benefit of using a weight material with such a broad distribution is excellent fluid-loss control due to the efficient packing of particles as they form a thinner, tighter filter cake against the wall of the wellbore. Thinner filter cake reduces the potential for stuck pipe; the reduced volume of base fluid entering the formation from a more efficient filter cake reduces the potential for formation damage.

This inherent fluid-loss property of the UFPC barite weight material is illustrated in Fig. 2. The fluid made from this material gives excellent fluid-loss control, despite no fluid-loss additive being used in the formulation. In some cases it may be possible to formulate drilling fluids without requiring a fluid-loss additive. The data shown in Fig. 2 demonstrates that the narrow particle-size distribution of Barites #1 and #2 provide poor fluid loss control. It can be seen from this data that the three barites with the broadest particle size distributions (UFPC Barite, Barite #3 and #4) provide better fluid loss control.

This fluid-loss benefit of the UFPC barite is further demonstrated when the fluid is aged under more rigorous conditions. Figure 3 shows the results of two 16-lb/gal drilling fluids - one formulated with UFPC barite and the other with Barite #2. The preparation of the 16-lb/gal fluids were similar to the formulation given in Table 1, with a high-temperature stable Gilsonite fluid-loss additive also incorporated, at a dosage of 5 lb/bbl for the Barite #2 fluid and 2.5 lb/bbl for fluid using the UFPC barite. The data shows the fluid loss of the base fluid and after contamination with OCMA clay. These results suggest that the inherent fluid-loss control of the UFPC barite is perhaps not due solely to its broad size distribution, but also to the polymer coating on the surface of the barite particles.

Rheology. Typically, a standard 14-lb/gal oil-based drilling fluid formulated to a conventional rheology specification would need a Fann 35 3-rpm reading of at least 7-9, in order to minimize the barite sag potential. When formulating fluids with this unique weight material, much lower 6- and 3-rpm readings can be realized without compromising the sag performance. The polymer-coating helps to provide a low rheology and the ultra-fine particle size reduces the barite sag potential.

The data shown in Fig. 4 demonstrate the effect on the oil-based drilling fluid plastic viscosity by introducing ultra-fine barite as the weight material. The plastic viscosity increases almost proportionally to the reduction in particle size, in this case d_{50}. However, the fluid with the UFPC barite, which has the finest particles, has a relatively low PV. This is thought to be due to the polymer coating on the barite particles causing some repulsion between particles of barite, thereby minimizing the frictional forces caused by particle-particle interactions in the drilling fluid.

The low-shear rheology of fluids formulated with this UFPC barite also tends to be lower than that in conventional fluids. Accordingly, this tendency increases the potential for ECD benefits in conjunction with lower PV. Figure 5 shows the 100-, 6- and 3-rpm results obtained for the 14-lb/gal fluids. The data shows the low 6 and 3rpm readings obtained with the fluid formulated with UFPC barite, compared to the other barite weight materials.

A Fann 70 was used to obtain fluid rheology data at different temperatures and pressures for both the UFPC barite-containing drilling fluid and a typical oil-based mud. This data, together with well-specific information such as casing and drill-pipe configuration, and well and temperature profiles, were inputted into a proprietary hydraulics management software program to determine the effect on ECD, pump pressure and flow rates. The simulations presented here were conducted on an 8½-in. section of an actual well. The data shown in Fig. 6 compare the two 13.3-lb/gal fluids. The data shows that at a pump rate of 1800 L/min, ECD is reduced from 14.5 lb/gal to 13.8 lb/gal, while pump pressure is reduced from 3495 psi to 3060 psi when changing the standard oil-based fluid to the UFPC barite fluid.

The software program also was used to simulate tripping speed when running in with 7-in. liner. A 20% increase in tripping speed was obtained for this specific well, at given surge pressure limitations of 14.6 lb/gal.

The ECD benefits of this low-rheology fluid mean that higher pump rates can be achieved compared to a standard oil-based fluid, and these higher flow rates provide for more effective hole cleaning.[5]

Barite Sag. Both the dynamic and static sag potential of the formulated fluids have been evaluated. Dynamic sag can be measured by various techniques and gives an indication of the potential for barite sag whilst the drilling fluid is subject to low shear conditions. The data shown in Fig. 7 and 8, uses a Fann 35 VG meter and measures the sag potential at 120ºF after 30 minutes at 100 rpm.

The effect of particle size on the dynamic sag properties of this fluid are shown in Fig. 7, which gives the dynamic sag factor obtained after 30 minutes at 100 rpm at a temperature of 120ºF. The dynamic sag factor is calculated by:

$$Dynamic\,Sag\,Factor = \frac{{}^{lb}\!/_{gal}\ at\,bottom}{{}^{lb}\!/_{gal}\ at\,top\ +\ {}^{lb}\!/_{gal}\ at\,bottom}$$

The results clearly demonstrate the sag benefits from using a barite weight material with a d_{50} of 3 microns or less.

The results shown in Fig. 8 compare the dynamic sag properties of a 12-lb/gal oil-based drilling fluid formulated with different weighting agents. Each fluid was formulated to an oil-water ratio of 80/20, met the same fluid loss specification, and had a rheology specification of 6 as measured from the Fann 35 6-rpm reading. This sag test was conducted at 120ºF and 180ºF after 30 minutes at 100 rpm in the Fann 35 cup. This data, illustrated as change in density, demonstrates the excellent sag performance obtained from the UFPC barite fluid. It is quite plausible that a lower 6-rpm reading would achieve a similar sag performance using this fluid.

The static sag test gives an indication of the stability of the fluid and its potential for barite sag whilst the drilling fluid is static in the hole. The test is conducted after the fluid has been aged statically for a set time period and the density of the fluid typically is measured at the top of the column of mud, below any free oil that may be present, and at the bottom of the column of mud.

The static sag properties of the 14-lb/gal fluids are compared in Fig. 9, which illustrates the density of the fluid at the bottom of the column of mud after static aging. The benefits of using an ultra-fine particle size barite are clearly demonstrated. Minimal sag is achieved with barite with a d_{50} of 3 microns on less. The fluids formulated with the coarser barite material significantly increase the risk of barite sag. There also is more synergises in these fluids. The fluid formulated with the UFPC barite had no free oil after aging, whereas the fluid formulated with the coarser barite #4 had 58 mL of free oil above the column of mud.

Conclusions

The work discussed in this paper demonstrates a new approach to formulating oil-based drilling fluids using new sag-reduction technology. The ultra-fine polymer-coated barite weighting agent allows fluids to be formulated with low rheological properties without compromising the sag potential of the fluid.

The particle-size distribution obtained using the milling process in combination with the oil-wetting polymer adhered to the surface of the barite particles provides low rheology and inherent fluid-loss control properties.

The improved settling stability from these ultra-fine polymer-coated barite fluids in combination with the reduced ECD during drilling means that this oil-based fluid will have beneficial effects when drilling complicated wells with limited operational windows.[4]

These unique fluids will reduce the risk of induced well-control situations due to the markedly improved resistance of these fluids to barite sag. Lower achievable fluid rheology will lower the risk of lost-circulation events during both drilling and tripping due to the reduced ECD and surge pressures..

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Table 1 – Oil-Based Fluid Formulation	
14 lb/gal, O/W ratio 80/20	
Product	**lb/bbl**
Low Toxicity Mineral Oil	As required
UFPC Barite or Powdered Weight Material	As required
Emulsifier	10
Lime	6
Organoclay	4
$CaCl_2$ Brine (25wt%)	As required

Table 2 – PSD of Weighting Agents Evaluated		
Weight Material	**D_{50}**	**D_{90}**
Barite #1	1.7	3.2
Barite #2	2.4	4.6
Barite #3	4.3	10.4
Barite #4	8.8	26.8
UFPC Barite	1.3	3.3

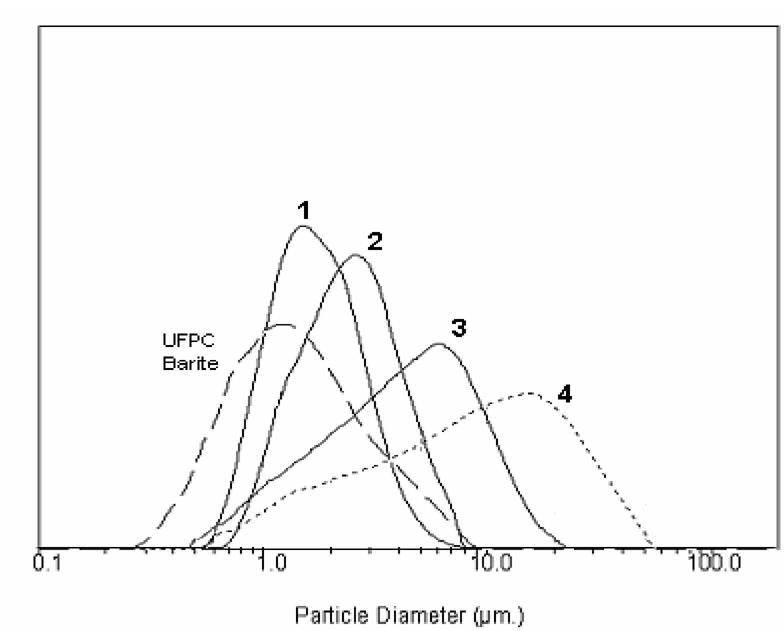

Figure 1 – Particle Size Distributions

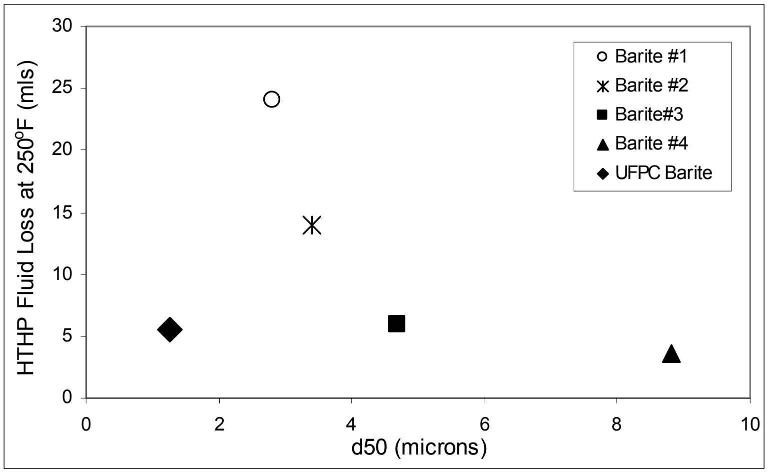

Figure 2 – Comparing HTHP Fluid Loss at 250ºF

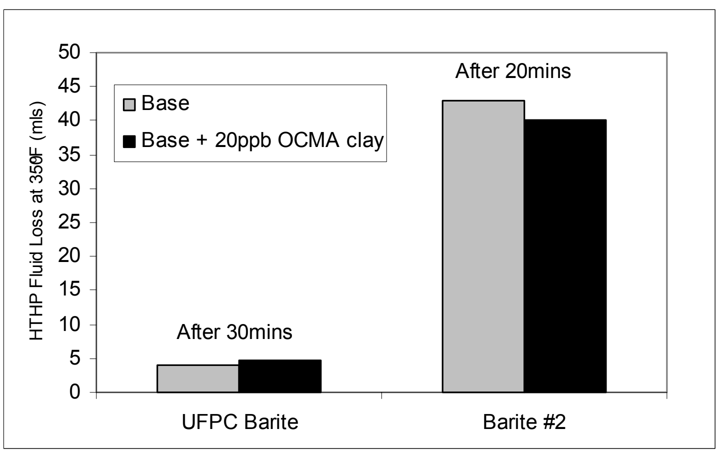

Figure 3 – Comparing HTHP Fluid Loss at 350°F

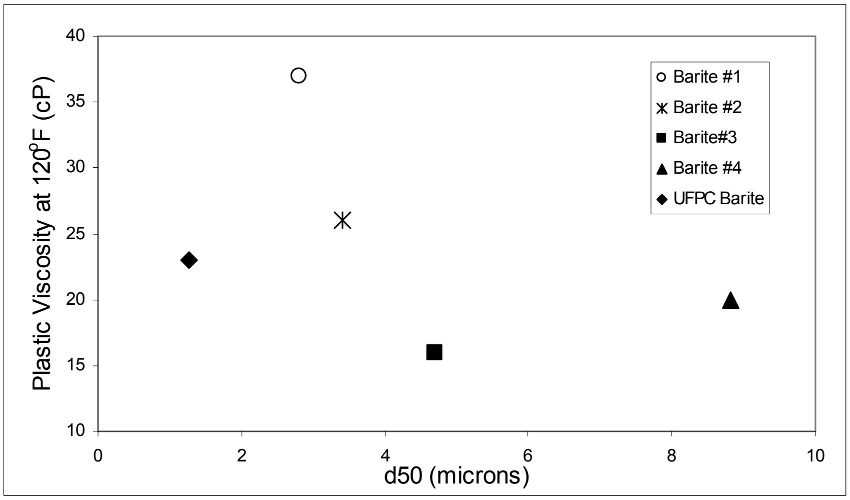

Figure 4 – The Effect of Particle Size on Plastic Viscosity

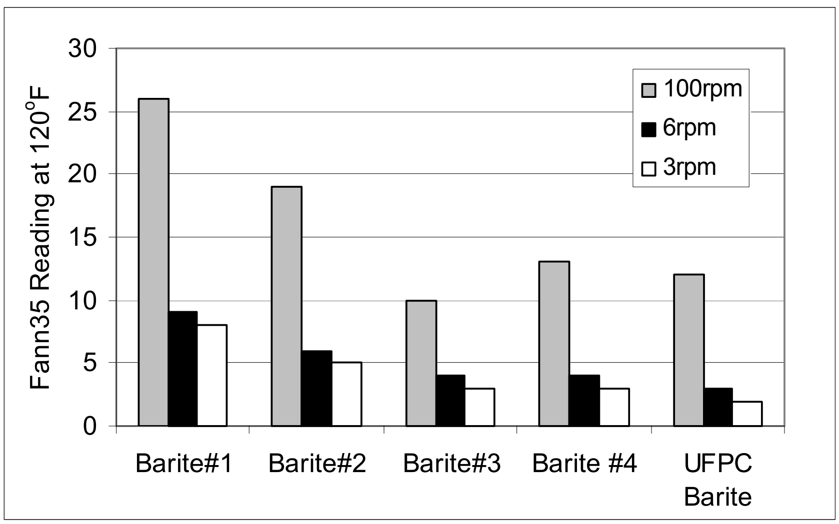

Figure 5 – Low Shear Rheology of 14-lb/gal fluids

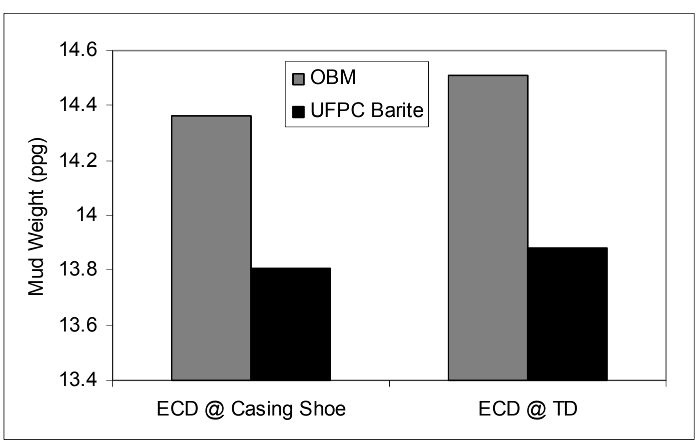

Figure 6 – Calculated ECD's at a Flow Rate of 1800 L/min

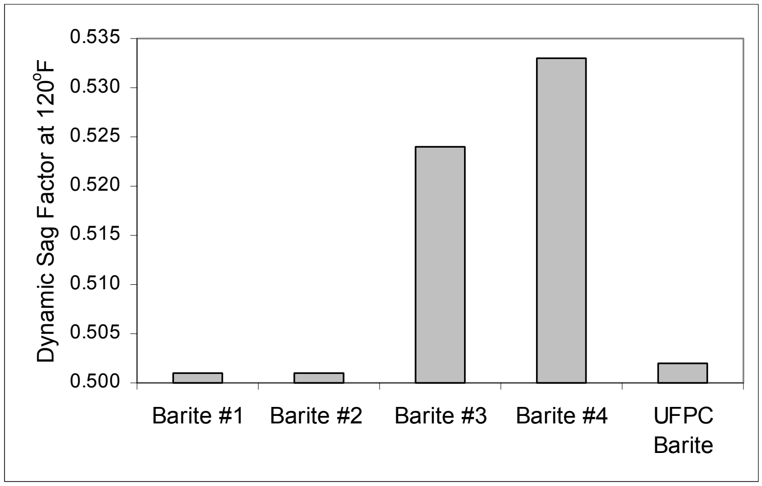

Figure 7 – Dynamic Sag after 30 min at 100-rpm at 120ºF

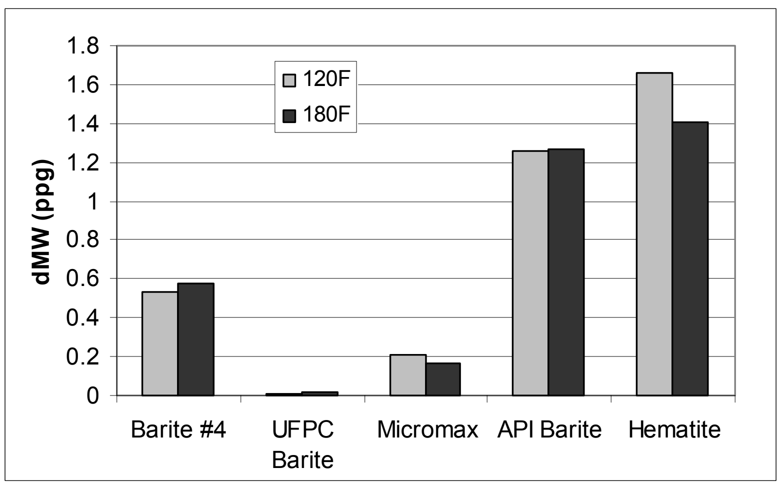

Figure 8 – Dynamic Sag Comparisons of 12-lb/gal Fluids

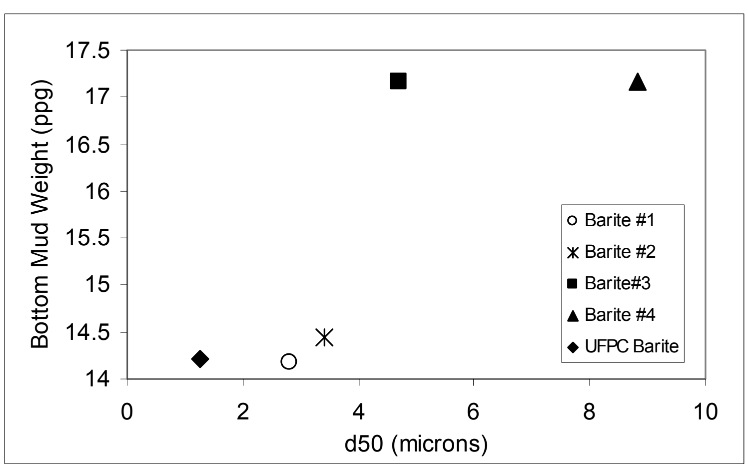

Figure 9 – Static Sag after 40 hours at 250°F