# BENEFITS OF OPTIMIZING THE HIGH SHEAR DISPERSION PROCESS

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The use of high shear dispersion in investment casting foundries is growing in popularity due to the belief that this method will reduce both the amount of time required to make a slurry and the cream-in time as compared to prop mixers or rotating tanks. However, without properly setting up the high shear dispersion process, variability in shell properties can be experienced.

Optimal dispersion guidelines for high shear dispersers have been outlined by Morehouse-Cowles in the Modern Dispersion Technology – A Primer in Dispersers handbook including dispersion speeds, blade size and height. Using this information and a study of dispersion time and slurry properties, it is possible to produce a consistent slurry. Deviation from the guidelines or incomplete slurry mixing can result in varying slurry characteristics.

## Background

Over the past 20 years, the use of high shear dispersers has become more prevalent in investment casting slurry mixing. These dispersers have shown to reduce both the amount of time required to mix a slurry and time until the slurry is available for production use. When using a rotating pot and a Lightnin® mixer, a slurry would mix for up to 24 hours. However, when using a high-speed disperser the mixing time can range from 10 to 60 minutes, depending on tip speed, size of the mixing vessel and viscosity of the slurry. While this reduction in time is advantageous to the process, if the mixing procedures are not properly set up, variations in the shell building process can be introduced.

## Understanding a High Shear Disperser

A high shear disperser has tip speeds in the range of 4,000 to 6,000 FPM. Tip speed can be calculated using the following equation.

$$\text{Tip Speed (FPM)} = \text{Shaft Speed (RPM)} \times 0.262 \times \text{Blade diameter (in)} \qquad \text{(Equation 1)}$$

At these speeds, the impeller imparts high velocity to the slurry creating a turbulent zone of intense flow. The turbulent zone starts at the blade edge and continues 1 to 2 inches beyond. The area outside this zone is laminar and it ensures complete circulation of the entire batch.

A proper vortex visually demonstrates that a turbulent zone exists. The vortex should end where the shaft meets the blade. If the blade is visible, air is being whipped into the slurry. If the vortex is choked, adequate mixing is not occurring and a heat zone is being created in the slurry.

Figure 1 shows a picture of a good vortex.

Figure 2 shows a picture of a choked vortex

## *Disperser set-up parameters:*

- *BLADE DIAMETER*: The diameter of the blade impacts tip speed, however, the blade is limited by the diameter of the vessel.

  Blade diameter = 1/3 x the vessel diameter (Equation 2)

  A larger mixing vessel allows for a larger blade diameter that in turn allows for a higher tip speed. For example, if mixing in a 24” diameter vessel at 1,000 RPM, the blade diameter is 8” and the tip speed would be

  Tip Speed = 1,000 RPM x 0.262 x 8 in = 2,096 FPM

  However, if the same slurry is mixed in a 36” diameter vessel, the blade diameter could be increased to 12” and the tip speed would be

  Tip Speed = 1,000 RPM x 0.262 x 12 in = 3,144 FPM

So, if mixing in a 24” diameter vessel, the shaft rotation speed would need to be 1500 RPM to achieve a tip speed of 3,144 FPM.

Use of a blade too small for the vessel will result in settling of the flour in addition to longer mix times. Use of a blade too large will result in air entrapment and poor product movement within the vessel.

- *BLADE HEIGHT*: Optimal mixing is reached when the blade is ½ to 1 blade diameter off the bottom of the mixing vessel and the liquid height is 1 blade diameter above the blade prior to adding the flour. Therefore the liquid depth should be approximately two blade diameters for optimal dispersion.

**Blade types**

High shear blades are the most common types of blades used in dispersion applications. However, these blades are made of stainless steel that are not resistant to abrasive materials and as a result, are not a good choice for investment casting slurries. Poly-peller blades are designed for use with abrasive materials and will last much longer than the metal blades. Due to the higher surface area of the poly-peller blade and thus higher horsepower requirements, a smaller diameter poly-peller should be used than the high shear blades while maintaining the same disperser speed.

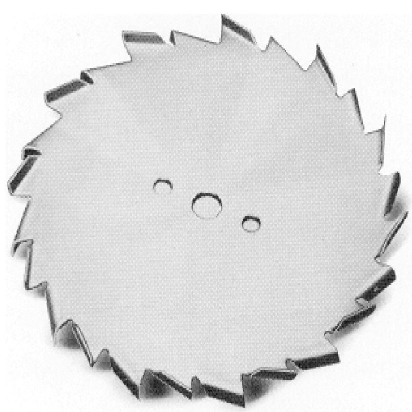

**Figure 3 - High Shear Blade**


**Figure 4 - Poly-Peller Blade**

When using a poly-peller blade, follow the example above and determine the required blade diameter (1/3 the diameter of the mixing vessel) and use Equation 1 to calculate the tip speed.

Tip Speed (FPM) = Shaft Speed (RPM) x 0.262 x Blade diameter (in)

Then install the poly-peller on the disperser using a 2" smaller blade if the blade diameter is 10 inches or above or a 1" smaller blade if the blade diameter is less than 10 inches.

**Component Considerations**

Colloidal silica, a water based chemical, is stable at room temperature, and for short periods of time, it can be stable near freezing (32 °F) or boiling (212 °F). However, when colloidal silica is mixed in a slurry, damage can occur to the sol when the temperature is elevated above 110 °F for extended periods of time. Nalco recommends maintaining a slurry temperature no higher than 100°F.

When high shear dispersion was first introduced into this industry, some concern was raised about degrading the polymer chains if the polymer was added to the slurry liquids and high shear mixed with the rest of the ingredients. In speaking with various polymer manufacturers, high shear dispersion of concentrated polymers could be an issue. However, diluting the polymer with the colloidal silica and water will eliminate this problem.

Latex polymers are emulsions and more efficiently disperse in a water/silica sol than in a high solids slurry. Research has shown that mixing the polymer with the colloidal silica and water prior to adding any flour will yield higher strengths, flexibility and adhesion than if added after the flour is introduced.

The addition of wetting agent and antifoam can be difficult, as neither additive will readily disperse in the liquids. Adding to a partially built slurry seems to yield the best results. By adding them to slurry as it begins to increase in viscosity, the ingredients will thoroughly disperse as the powders are added. Wetting agent will assist in powder dispersion while the antifoam will prevent air entrainment as the powders are added and defoam the air that gets entrained.

**Flour addition time**

A common misconception with the high shear disperser is the flour can be added rapidly into the slurry. The flour needs to be metered into the slurry to prevent the formation of clumps in the slurry. These clumps take time to disperse and can result in longer cream-in times. A common rule of thumb is to add one 55-pound bag on average every 45 to 60 seconds. This may vary as the initial flour is added, but as the slurry begins to thicken up, it is critical to slow down the addition process.

**Slurry Properties**

A question often asked is how do we know when a slurry is creamed-out. The students at the ICI Training Certification Course in Pittsburg, Kansas were taught that a slurry is creamed out if the viscosity of the slurry doesn't change more than one second in two consecutive hourly readings. However, temperature plays a role in the mixing process and relying on viscosity readings to identify if the slurry is creamed-in could result in erroneous results as the increased temperature could allow the slurry to flow faster through the viscosity cup and the higher temperature may cause water to evaporate at a faster rate. In addition, when working with high shear dispersers, mix time is reduced from hours to minutes and foundries may not wait for two consecutive hourly readings prior to introducing the slurry into production. As a result, plate weights are used as another test to compare the slurries after mixing and during the cream-out period. When using the plate weight test, the plate was dipped in the slurry, drained for 30 seconds and then weighed.

The following graphs show the viscosity of a high shear mixed slurry after being transferred to a rotating tank. It should be noted that this slurry was mixed below the optimal tip speed for high shear dispersion (2075 FPM). The viscosity doesn't vary more than one second over a period of five hours.

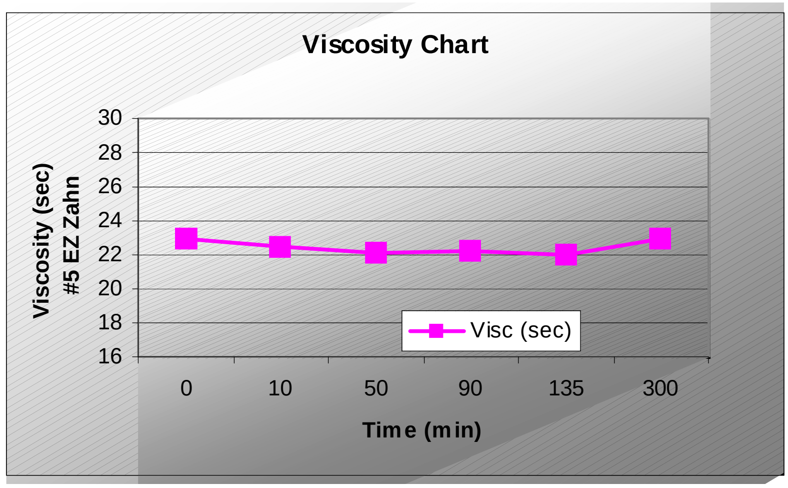


Table 1 - Viscosity Chart for High Speed Mixed Slurry

However, when the plate weight is added to the chart, it shows that while the viscosity appears to be relatively steady, the plate weights are continuing to change during the first 90 minutes after mixing.

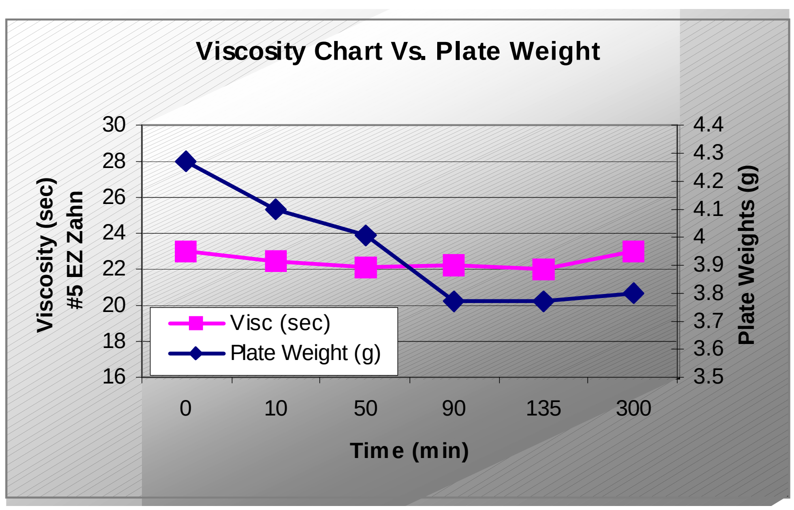


Table 2 - Viscosity vs. Plate Weight Chart

Using both of these metrics can help identify when a slurry is creamed-out and ready to be put into production.

## Mix Time

Mix time, which has a large impact on slurry properties, is the last variable to optimize. It is impacted by the speed of the disperser, the vortex generated by the disperser and the mixing vessel. By using viscosity and plate weights, the ideal mix time can be established.

## RESULTS

### Mix Time Determination

The following shows the slurry properties when a back-up slurry was mixed with a shaft speed of 800 RPM (tip speed of 2934 FPM). Readings were taken at five-minute intervals during high shear dispersion to allow for comparison of the slurry properties. Viscosity was measured with a #5 EZ cup.

| 800 RPM | | | |
|---|---|---|---|
| Time (min) | Temp (°F) | Visc. (sec) | Plate Weights (g) |
| 5 | 76 | Thick | 8.76 |
| 10 | 77 | 152 | 8.55 |
| 15 | 79 | 132 | 8.38 |
| 20 | 82 | 100 | 8.16 |
| 25 | 85 | 64.4 | 7.87 |
| 30 | 87 | 64.6 | 7.87 |

Table 3 - Slurry Results for 800 RPM Mixing Speed

This test was then repeated using the same formula but increasing the shaft speed of the disperser to 900 RPM and the tip speed to 3301 FPM.

| 900 RPM | | | |
|---|---|---|---|
| Time (min) | Temp (°F) | Visc. (sec) | Plate Weights (g) |
| 5 | 79 | Thick | 8.67 |
| 10 | 83 | 98.8 | 8.37 |
| 15 | 86 | 68.2 | 7.95 |
| 20 | 90 | 52.4 | 7.71 |
| 25 | 94 | 48.2 | 7.60 |
| 30 | 98 | 43.4 | 7.46 |

Table 4 - Slurry Results for 900 RPM Mixing Speed

At 800 RPM, both data points of 25 and 30 minutes yield the same viscosity and plate weight. However, when the disperser is sped up to 900 RPM, the slurry yields a much lower viscosity and plate weight after 20 minutes of mixing.

This test was then repeated using the same formula but increasing the shaft speed and tip speed of the disperser to 1000 RPM and 3668 FPM, respectively. The data below shows that additional dispersion speed will yield an even greater drop in viscosity.

| 1000 RPM | | | |
|---|---|---|---|
| Time (min) | Temp (°F) | Visc. (sec) | Plate Weights (g) |
| 5 | 75 | Thick | 8.98 |
| 10 | 82 | 82.2 | 8.32 |
| 15 | 87 | 68.2 | 8.02 |
| 20 | 94 | 54.8 | 7.78 |
| 25 | 98 | 40.8 | 7.48 |
| 30 | 101 | 38.6 | 7.49 |

Table 5 - Slurry Results for 1000 RPM Mixing Speed

**Slurry Properties Differences Related to Mix Time**

In an effort to understand the impact that dispersion speed has on the slurry properties, a test was conducted using the same slurry back-up formula, varying the dispersion time and speed. The Best Case parameters were 1260 RPM (3961 FPM) for 40 minutes while the Worst Case parameters were 435 RPM (1268 FPM) for 10 minutes. During high shear dispersion, the Best Case slurry reached a temperature of 85°F while the Worst Case slurry reached a temperature of 71°F. Once the slurries were mixed in the high shear disperser, they were transferred into a rotating tank.

The following charts show the difference in the slurry properties over the period of 7 hours after transfer into a rotating tank. Both charts show that the slurry properties of the worst-case slurry continue to change over the 7 hours that the material was mixed. The best-case slurry properties show minimal change over the same time period.

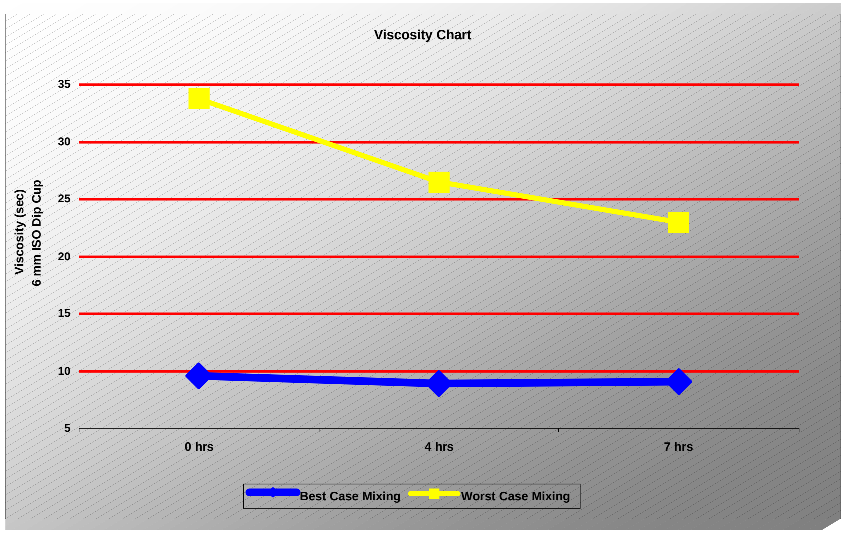


Figure 5 - Viscosity Chart of Best Case vs. Worst Case Mixing

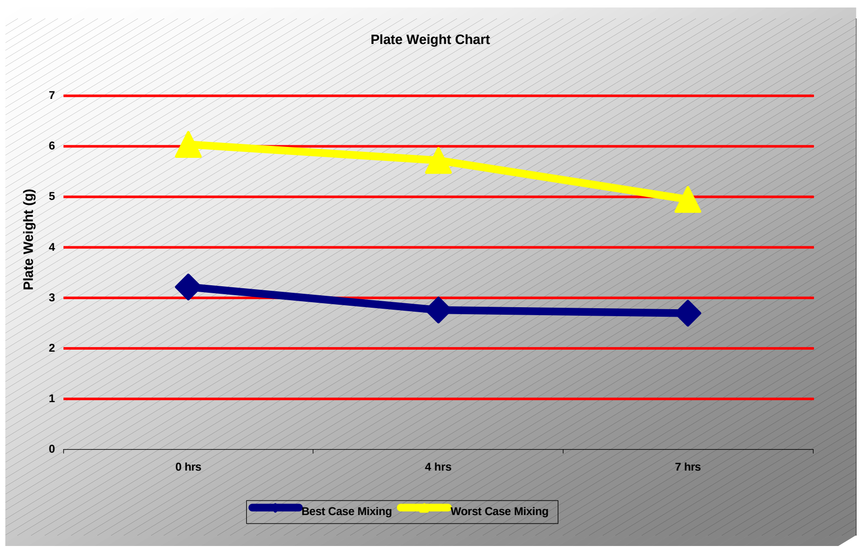


Figure 6 - Plate Weight Chart of Best Case vs. Worst Case Mixing

After the two slurries were allowed to equilibrate for four hours, MOR bars were dipped with 4 back-ups and a seal. The viscosities for the Best-Case and Worst-Case slurries were 9 seconds and 23 seconds, respectively using a 6mm ISO DIP cup. The data shows that the slurry with the lower viscosity yielded a higher MOR while they were approximately one-third thinner. Permeability ball samples were made for the two slurries, however, the Worst Case balls were full of pinhole leaks and as a result, the relative flow rate was in excess of 100% at 0.5 psi.

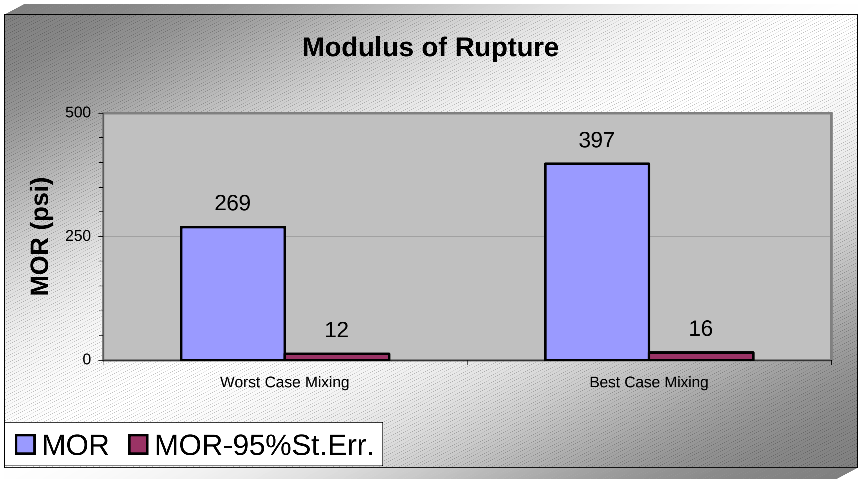


Figure 7 - MOR Results of Best Case vs. Worst Case Mixing

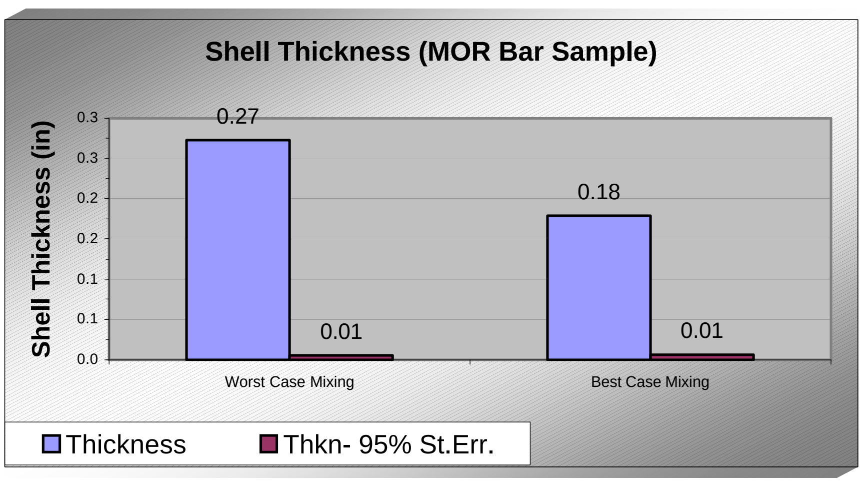


Figure 8 - Shell Thickness for Best Case vs. Worst Case Mixing

### Different Slurries Adjusted to Same Viscosity

Understanding that most foundries would not run slurries with such varying mixing properties, further testing was completed with two slurries with slight mixing variations. However, after the slurries were equilibrated, the two slurries were adjusted to the same viscosity. The first slurry was mixed following the standard mix process of 30 minutes at 875 RPM. The second slurry was mixed for 30 minutes at 1250 RPM. After four hours in the rotating tank, Slurry #1 yielded a viscosity of 15.8 seconds and slurry #2 yield 12.7 seconds using a 6mm ISO DIP cup. Slurry #1 was thinned down to 12.7 seconds using the same ratio of binder, polymer & water as the initial formula. Using a shell system of 4 back-ups and a seal, the lab analysis results show the two slurries have similar MOR and permeability results even though Slurry #1 has 3% more liquids.

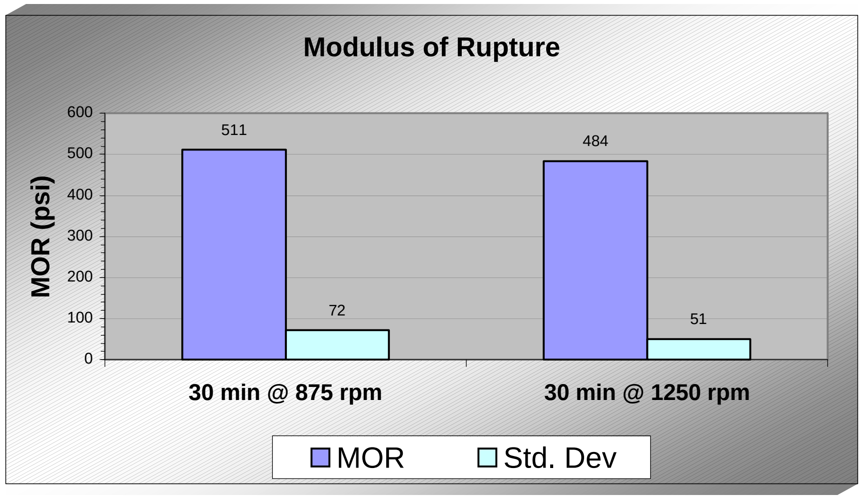


Figure 9 - MOR Comparison of Slurries adjusted to same viscosity

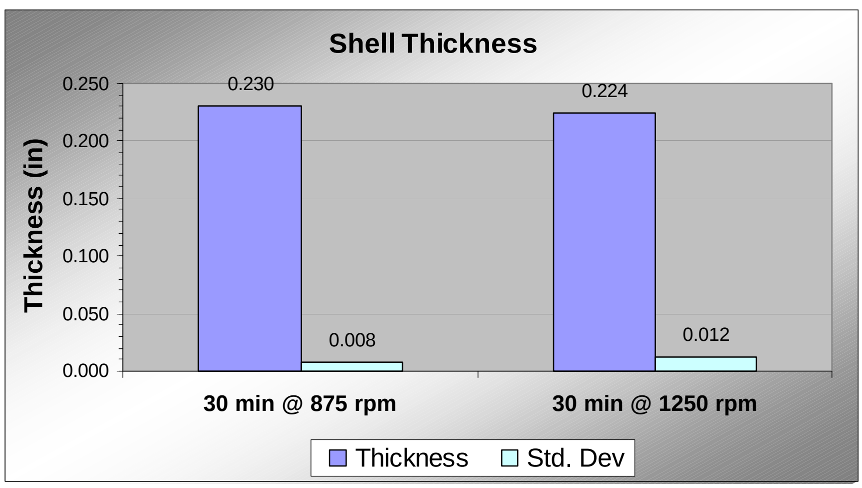


Figure 10 - Shell Thickness Comparison of Slurries adjusted to same viscosity

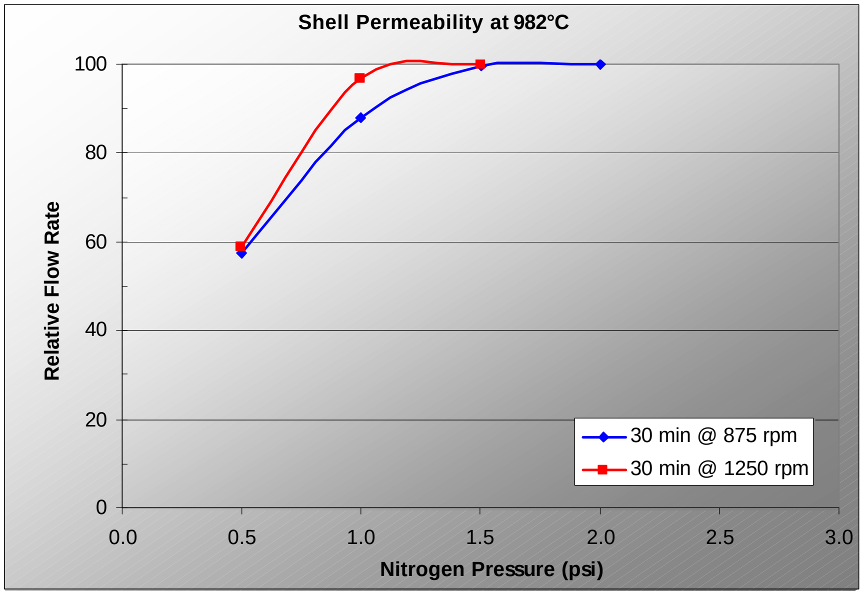


Figure 11 - Permeability Comparison of Slurries adjusted to same viscosity

By optimizing the high shear dispersion process, the amount of liquids in a slurry formula can be reduced while not impacting the performance of the shell. In many cases, this can result in savings in shell material.

## CONCLUSION

The use of high shear dispersion can reduce the amount of time a slurry takes to make and also to cream-out. However, in order to maximize the benefits of the disperser, it is necessary to ensure that robust procedures are in place. In addition, in some cases, by optimizing the procedure, it is possible to realize some cost savings by reducing the liquids in the slurry formulation.

References:

R. Courtain, Modern Dispersion Technology – A Primer in Dispersers, Morehouse-COWLES, 2003.