

Optimizing Oil Well Cementing: Effects of Dispersant and Fluid Loss Additive Concentrations on Thickening Time and Free Fluid Formation

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Optimising cement slurry properties through appropriate additive selection is critical for ensuring successful zonal isolation and preventing costly wellbore failures in oil and gas operations. This research investigated the effects of dispersant and fluid loss additive concentrations on the thickening time and free fluid formation of Class G cement slurry. A systematic two-factor three-level (3^2) factorial design was employed, generating nine experimental runs. Statistical analysis included correlation analysis, ANOVA, and multiple regression modelling. The results revealed that dispersant concentration exhibited the strongest influence on thickening time behaviour, establishing it as the primary control mechanism for cement slurry pumpability. Fluid loss additive concentration demonstrated dual functionality, serving both as an effective filtration control agent and providing secondary influence on thickening time. Significant interaction effects were observed between dispersant and fluid loss additive concentrations ($p = 0.040$), indicating synergistic behaviours. Multiple regression analysis yielded highly predictive models for both response variables, with $R^2 = 0.981$ for thickening time and $R^2 = 0.845$ for free fluid. The developed models provide a systematic framework for cement slurry optimisation in oil well cementing operations, enabling precise targeting of cement slurry properties for improved well integrity and performance. The research demonstrates the effectiveness of factorial experimental design methodology for understanding complex additive interactions in cement slurry systems.

Keywords: Cement, Slurry,Thickenning, Fluid, Loss, Time,Free.

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1. Introduction

Cement slurry thickening time is crucial in oil and gas well construction, defining the operational window for successful cement placement between the casing and formations. Controlling slurry rheological properties, especially viscosity development, influences cementing success and well integrity. Thickening time must balance pumpability during placement and structural development post-placement to prevent fluid migration and maintain zonal isolation. The interaction between fluid loss additives and dispersants in slurry design affects thickening behaviour. Fluid loss additives prevent excessive filtrate loss to formations, preventing premature dehydration. Dispersants reduce viscosity and improve flow by deflocculating cement particles. However, combined use creates synergistic or antagonistic effects on thickening time, leading to unpredictable slurry behaviour under HTHP downhole conditions

Previous research has focused on evaluating individual additive effects on cement slurry properties via trial-and-error lab testing. Studies by Pourafshary et al. (2009), Ershadi et al. (2011), and Petrowiki (2018) documented impacts of admixtures on cement performance. Nelson et al. (1990) classified

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additives for zonal isolation. Recent work examined dispersant effects on cement dispersion and viscosity (Cowan et al., 1993; Bett, 2010). However, these studies used univariate approaches, missing interactive effects between additives in complex downhole environments. Despite contributions, a knowledge gap remains on quantitative relationships between combined additives and thickening time. Current practices lack systematic methods and predictive models for HTHP conditions. Previous studies' lack of experimental design led to inefficiency, extended testing, and suboptimal formulations. Fluid loss additives' dual role in filtration and thickening kinetics is unclear. This study addresses these via systematic experimental design, using response surface methodology to examine additive interactions. Experiments simulate HTHP conditions; thickening time is measured via consistometry. This provides quantitative relationships, enabling optimization of formulations for specific wells, reducing trial-and-error testing. Evaluate effects of fluid loss additives and dispersants on cement slurry thickening time.

Objectives:

1. Design factorial experiments evaluating additive effects on thickening time and free fluid using API procedures.
2. Develop correlations between additive concentrations, thickening time, and free fluid.
3. Study effects of dispersant and fluid loss on thickening time and free fluid.
4. Develop predictive models via regression analysis for thickening time and free fluid.
5. Apply findings for cement slurry optimization in oil well cementing

2. Materials and Methods

Research Design

The study used a quantitative design with a full factorial approach to examine effects of fluid loss additive and dispersant on thickening time and free fluid of Class G cement slurry. A 3^2 full factorial design yielded 9 runs, governed by $N = Lk$ (L =levels, k =factors). Factors: dispersant (0.1-1.0% BWOC) and fluid loss additive (0.1-0.35 gal/sk).

Primary data collection involved lab measurements of cement slurry properties using API standards. Class G cement, water, antifoam, dispersant (Lomar'D), and fluid loss additives were used. Slurries were prepared and blended per API 13B-2 using a Warring blender. Thickening time was tested via consistometer under simulated well conditions. Analysis included descriptive stats, correlation, ANOVA, multiple regression, and surface response analysis. Models were validated using R^2 , RMSE, and residuals to ensure predictive accuracy.

Samples and Sampling Techniques

Samples were Class G cement slurries with varied additives. Materials included cement, water, antifoam, dispersant (Lomar'D), and fluid loss additive. A 3^2 full factorial design sampled combinations of dispersant (0.0%, 0.5%, 1.0% BWOC) and fluid loss additive (0.0, 0.175, 0.35 gal/sk), covering practical concentrations for oil well cementing. Nine experimental runs (R1-R9) covered all combinations of factors and levels. Slurries were prepared per API 13B-2 using a Warring blender. Factorial design enabled evaluation of main and interaction effects. Quality controls included standardized mixing, randomization, and API testing. Samples were tested for thickening time, free fluid, fluid loss, and rheology

Sources of Data

Both primary and secondary data were used. Primary data came from lab measurements of thickening time, free fluid, and fluid loss (9 runs, API procedures). Secondary data came from literature, API standards, and reports on cement additives and oil well cementing

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Method of Data Collection/Instrumentation

Cement slurry prep followed API 13B-2 (1998). Cement, water, defoamer, dispersant (naphthalene sulfonate) were weighed/blended using Warring blender. Liquids measured by volume, solids by mass. Blender speed: 4000rpm (add water, solids, cement in 15s), then 12000rpm for 35s. Repeated for different dispersant concentrations

Cement Slurry Preparation

Table .1: Experimental Design Matrix for 3² Factorial Design

Run	Dispersant Concentration (% BWOC)	Fluid Loss Additive Concentration (gal/sk)
1	0.1	0.1
2	0.1	0.175
3	0.1	0.35
4	0.5	0.1
5	0.5	0.175
6	0.5	0.35
7	1.0	0.1
8	1.0	0.175
9	1.0	0.35

The table shows 9 experimental runs with different combinations of dispersant (0.1%, 0.5%, 1.0% BWOC) and fluid loss additive (0.1, 0.175, 0.35 gal/sk) concentrations. It's a 3x3 grid testing how these two additives affect cement slurry properties (like thickening time and free fluid formation) in oil well cementing

Thickening Time Test

The test measures how long cement slurry remains pumpable under simulated downhole conditions (100°F, 3000 psi). Slurry with varying dispersant concentrations (0%, 0.5%, 1.0% BWOC) was tested using HTHP Consistometer. Test stops when slurry reaches 100 Bc

Free Fluid Testing

The test measures fluid separation from cement slurry after 2 hours, indicating slurry homogeneity. Procedure: Condition slurry at 80°F using atmospheric Consistometer- Transfer to 250ml cylinder, stand for 2 hours- Measure free fluid volume, calculate % of total volume

Free Fluid Equation

$$\text{Free Fluid (\%)} = (\text{ml of fluid} \times 100) / 250$$

This calculates % free fluid in the 250ml sample.

Fluid Loss Testing

Test measures fluid lost to formation under HTHP conditions (80°F, 1000psi ΔP). Procedure: Condition slurry at 80°F for 20min- Transfer to HTHP filter press- Collect fluid loss in 50ml cylinder for 30min

Purpose:

Evaluate effect of additives on fluid loss control- Optimize slurry for downhole conditions

Fluid Loss Equation

$$\text{Fluid Loss at 30min} = (Q_t \times 2 \times 5.477) / \sqrt{T}$$

Q_t = volume collected (ml)

T = time (minutes)

Experimental Design

2 factors (dispersant, fluid loss additive), 3 levels each → 9 runs

Factors:

Dispersant (% BWOC): 0.1 (low), 0.5 (med), 1.0 (high) - Fluid Loss (gal/sk): 0.1 (low), 0.175 (med), 0.35 (high)

Experimental Design Equation

$$N = L^k$$

L = 3 levels,

k = 2 factors

N = $3^2 = 9$ runs

Design Summary:

1. 3x3 factorial design
2. 9 unique treatment combinations (Table 1)
3. Randomized to eliminate bias
4. Response variables: Thickening Time (min), Free Fluid (ml)

Data Analysis Methods

Descriptive stats: Boxplots, normality testing (Shapiro-Wilk),- Correlation analysis: Pearson coefficients, correlation matrix,- ANOVA: Main effects, interaction effects (F-test, p-values). Evaluated effects on: Thickening Time, Free Fluid Formation

Model Development

Multiple Linear Regression model:

$$y = a_0 + a_1x_1 + a_2x_2 + \dots + a_nx_n$$

Relates additive concentrations to:

Thickening Time - Free Fluid Formatio- Will be used to predict and optimize slurry performance

Parameter Estimation

Least Squares Method used to estimate model parameters (a, b)- For linear regression: $Y = a + bx$ - Generates system of equations to solve for a and b

Least Squares Equations

Equations:

$$\sum Y = na + b\sum x$$

$$\sum Yx = a\sum x + b\sum x^2$$

Solutions:

$$b = (n\sum Yx - \sum Y\sum x) / (n\sum x^2 - (\sum x)^2)$$

$$a = (\sum Y - b\sum x) / n$$

3. Results and Discussion

Optimizing Oil Well Cementing

Dispersant Concentration (% BWOC):

Range: 0.0 - 1.0% - Median: 0.50% - Mean: 0.50% (zero skewness) - CV: 86.60%

Fluid Loss Additive (gal/sk):

Range: 0.00 - 0.35 - Median: 0.18 - CV: 86.60% (balanced design)

Thickening Time (min):

Range: 120 - 270 - Median: 186 - Mean: 187.67 (skewness: 0.32) - CV: 26.97%

Free Fluid (ml):

Range: 0.5 - 3.0 - Median: 1.6, - Mean: 1.58 (skewness: 0.35) - CV: 53.48%

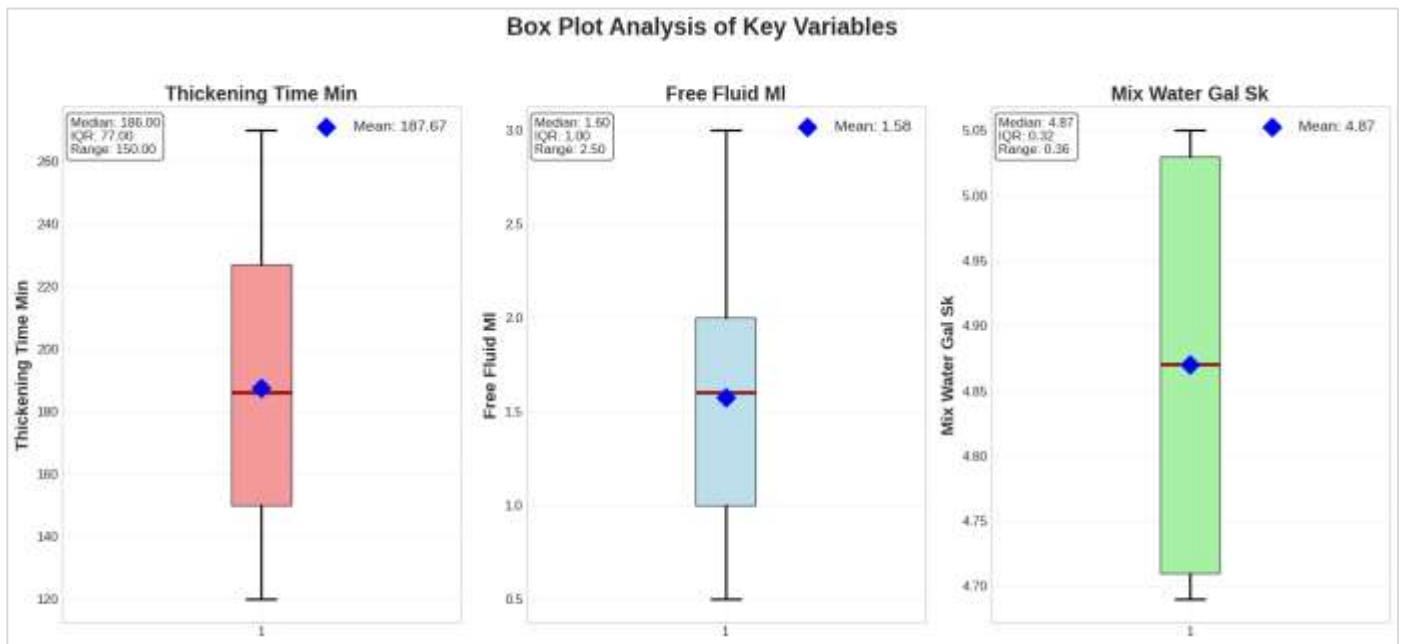


Figure 1: Boxplot showing distribution of cement slurry parameters

Figure 1: Boxplot Summary

Shows distribution of:

1. Dispersant concentration - Fluid loss additive concentration - Thickening time- Free fluid
2. Reveals variability, median, and skewness of parameters

Table 2: Summary statistic of cement slurry parameters

Variable	Mean	Median	Std_Dev	Variance	CV_%
Dispersant BWOC	0.50	0.50	0.43	0.19	86.60
Fluid Loss Additive (gal/sk)	0.18	0.18	0.15	0.02	86.60
Thickening Time (min)	187.67	186.00	50.61	2561.50	26.97
Free Fluid (ml)	1.58	1.60	0.84	0.71	53.48
Mix Water (gal/sk)	4.87	4.87	0.15	0.02	3.03

Dispersant BWOC:

Mean/Median: 0.50% (symmetric) - CV: 86.60% (wide range tested).

Fluid Loss Additive: - Mean/Median: 0.18 gal/sk (symmetric) - CV: 86.60% (wide range tested)

Thickening Time: Mean: 187.67min, Median: 186min - CV: 26.97% (moderate variability)

1. Free Fluid: - Mean: 1.58ml, Median: 1.60ml - CV: 53.48% (moderate variability)
2. Mix Water:- Mean/Median: 4.87 gal/sk (consistent - CV: 3.03% (low variability)

Thickening Time Distribution & Relationships

1. Distribution (Fig 2): Near-normal with slight positive skew (0.32)- Range: 120-270 min, Mean: 187.67 min

2. vs Dispersant (Fig 3): - Positive correlation - 0.0% → 1.0% BWOC: ~120min → ~270min
3. vs Fluid Loss Additive (Fig 4.4): - Complex pattern - Low: ~120-150min (0.0-0.1 gal/sk)
 High: ~270min (0.35 gal/sk)

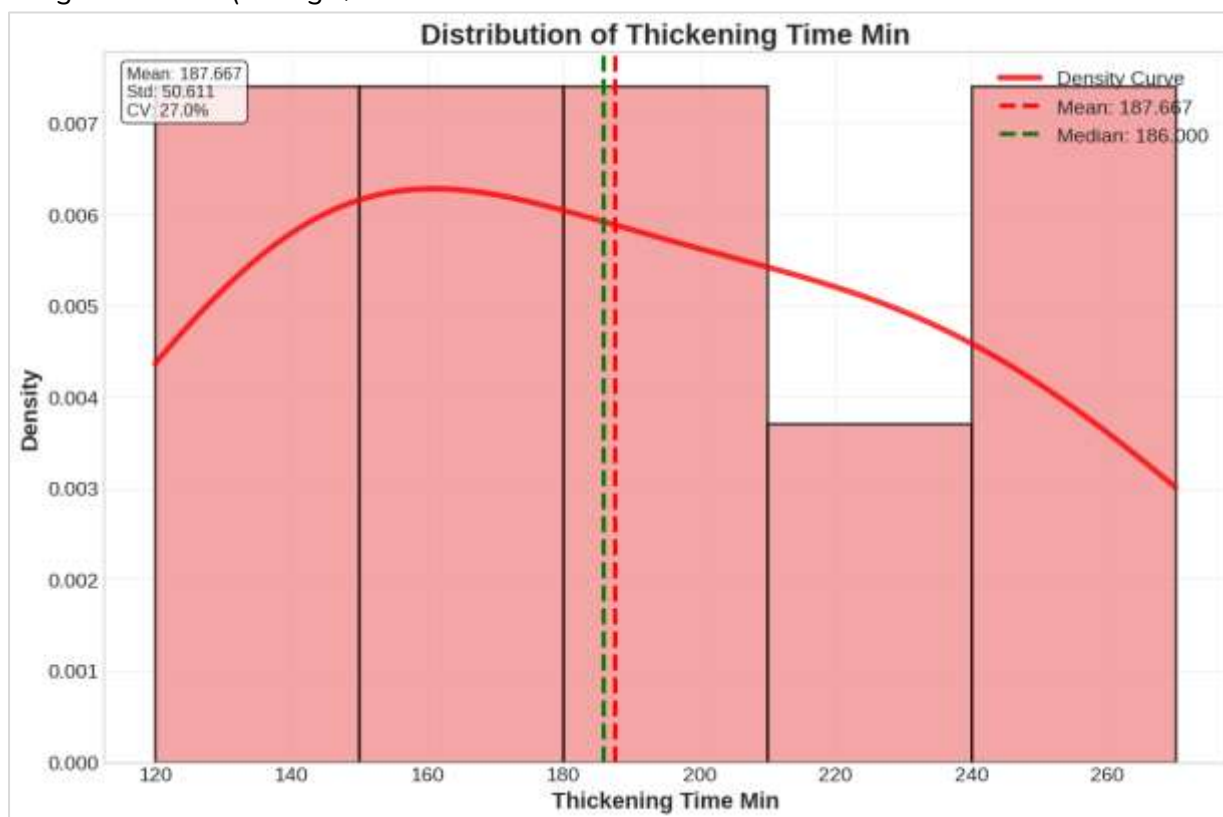


Figure .2: Distribution of thickening time

Table 3: Normality test for response variables

Variable	Shapiro Wilk Statistic	p-value	Is Normal	Interpretation
Thickening Time	0.9588	0.7858	Yes	Normal
Free Fluid	0.9639	0.8379	Yes	Normal

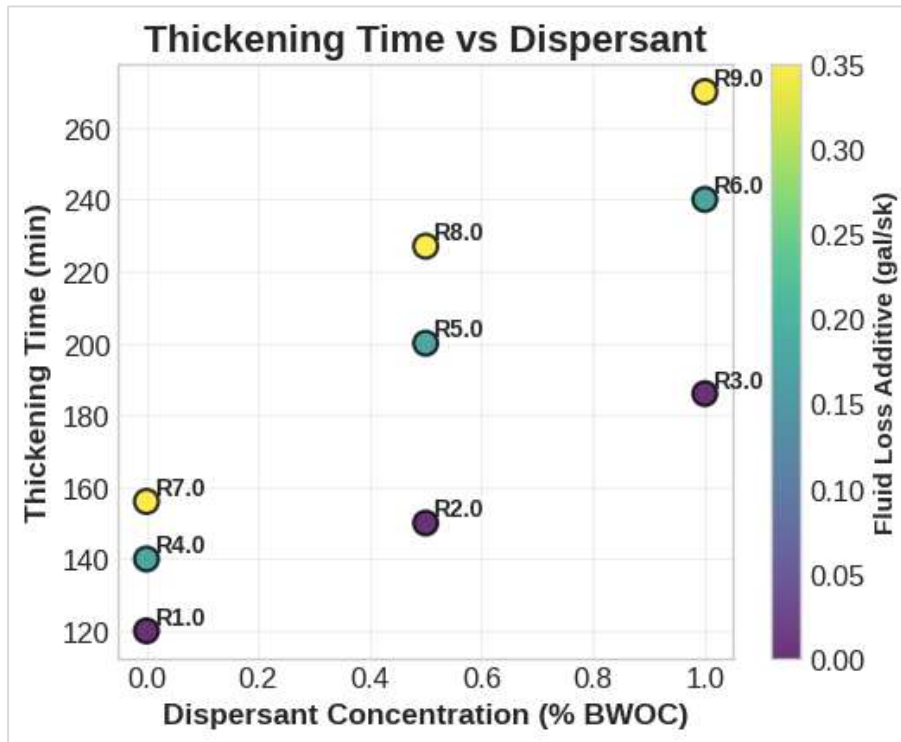


Figure 3: Relationship between thickening time and dispersant concentration

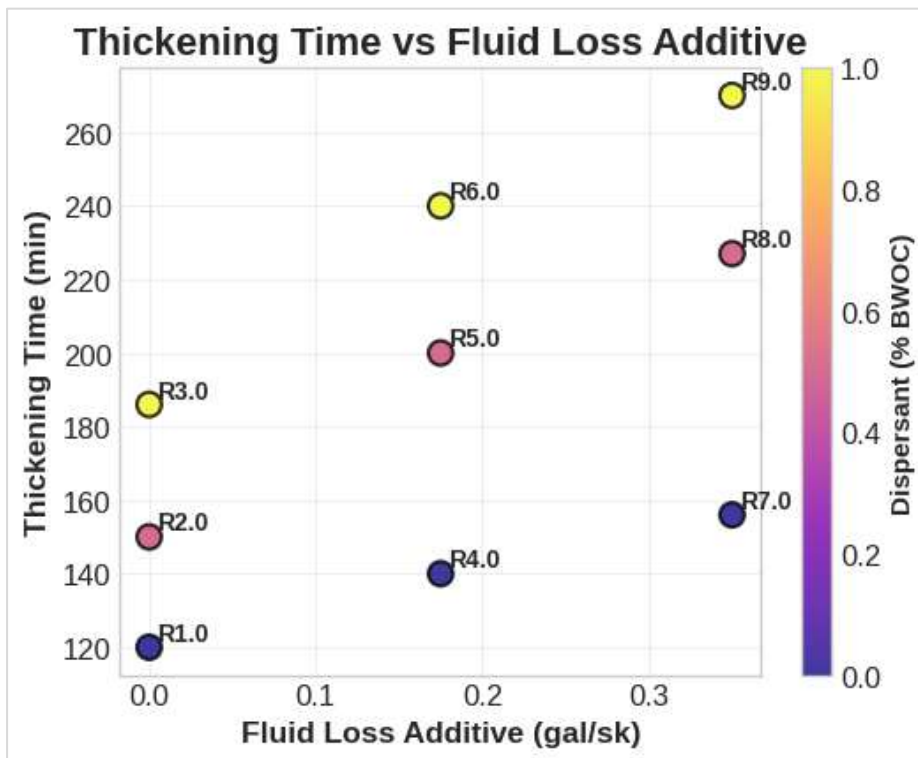


Figure 4: Relationship between thickening time and fluid loss additive

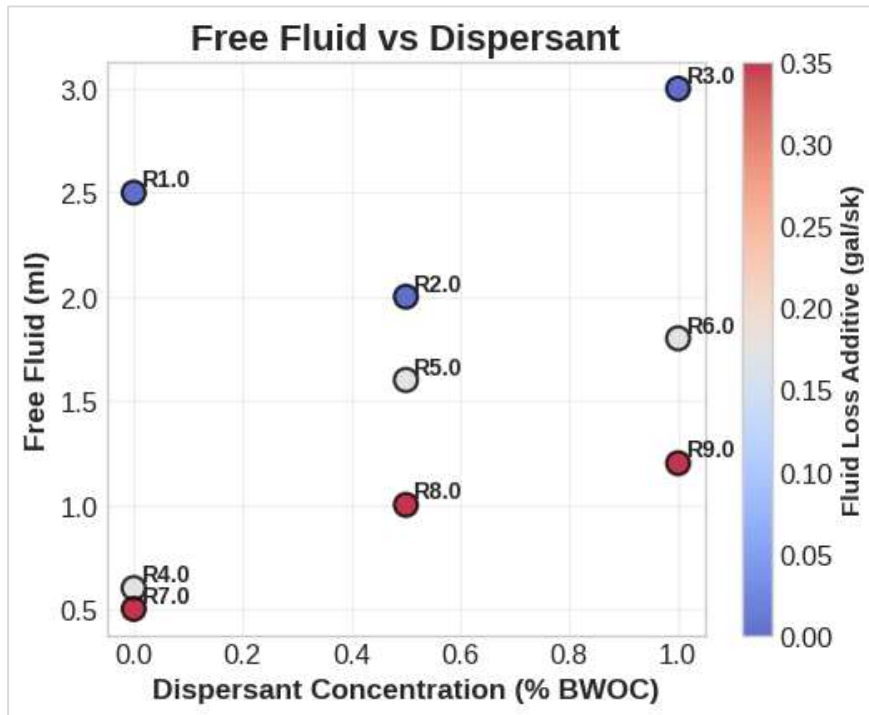


Figure .5: Relationship between free fluid and dispersant concentration

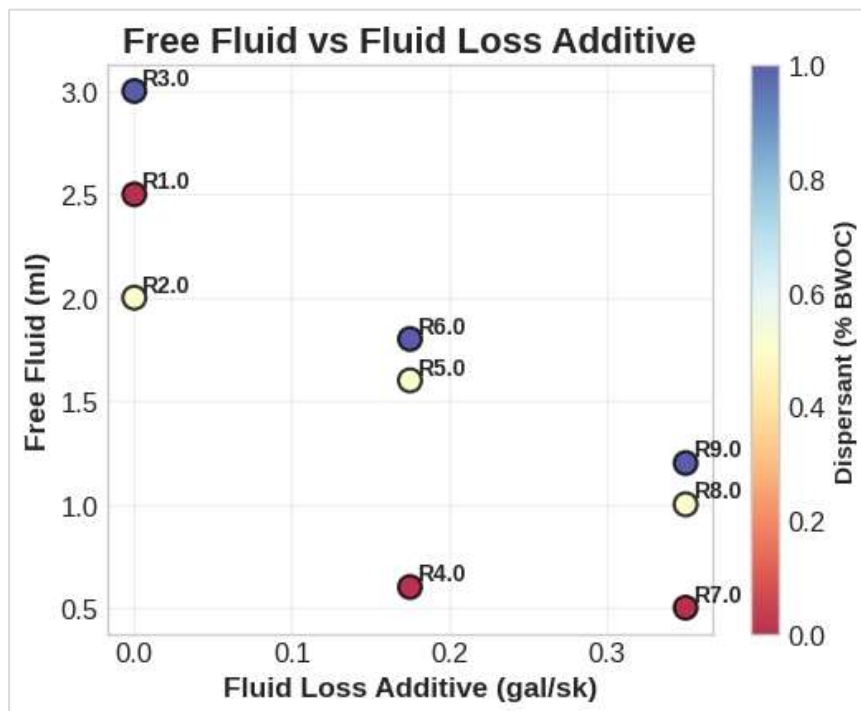


Figure 6: Relationship between free fluid and fluid loss additive

- Fluid loss additives influence cement hydration kinetics, retarding the setting process as evidenced by increased thickening times. This suggests these additives affect not only filtrate loss but also cement particle interactions.
- Normality testing (Shapiro-Wilk) confirms normal distributions for:
- Thickening Time ($p=0.7858$) - Free Fluid ($p=0.8379$)
- Validates use of parametric analyses (regression, ANOVA), ensuring reliable inferences.

Variable Relationships:

Dispersant and Fluid Loss Additive: $r = 0.000$ (orthogonal design)- Dispersant vs Thickening Time: $r = 0.799$ (strong positive) - Fluid Loss Additive vs Thickening Time: $r = 0.562$ (moderate positive) - Dispersant vs Free Fluid: $r = 0.411$ (moderate positive)
 Fluid Loss Additive vs Free Fluid: $r = -0.821$ (strong negative)

Implications:

- a. Dispersant extends thickening time
- b. Fluid Loss Additive controls free fluid & influences setting
- c. Mix water adjustments reflect experimental design

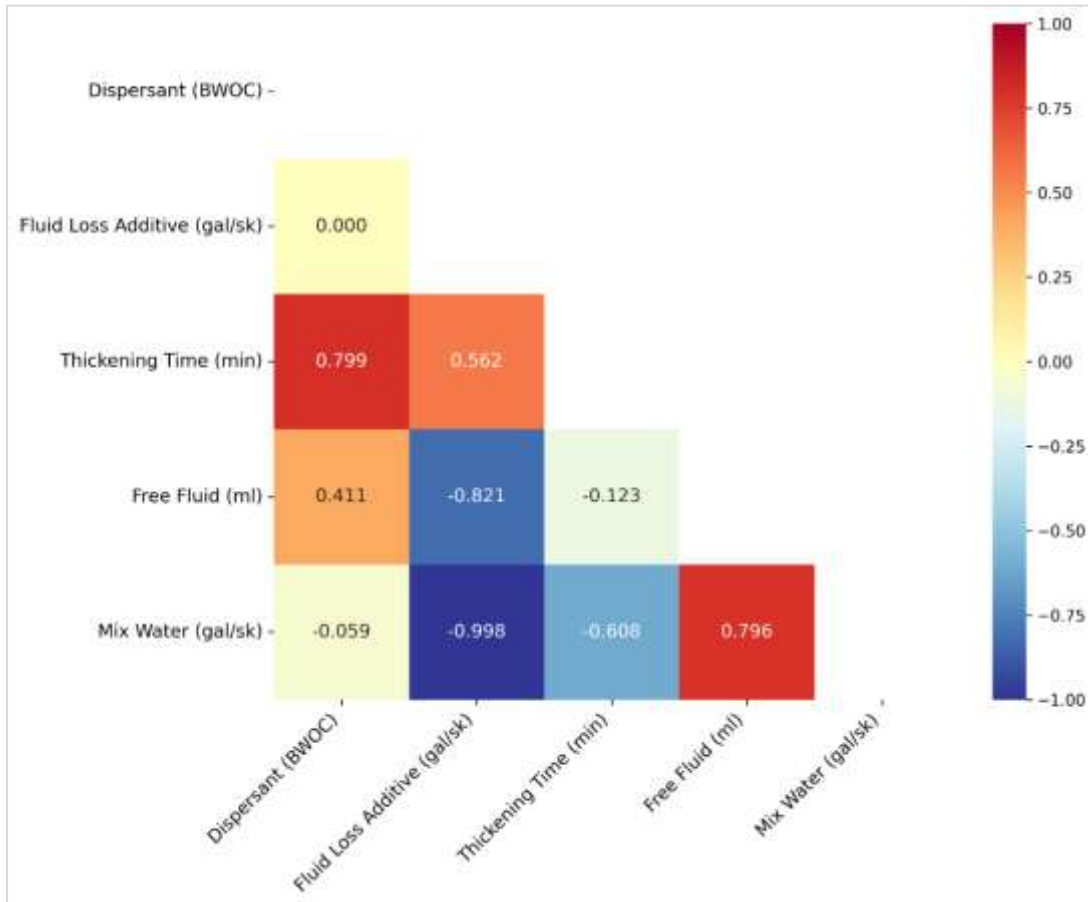


Figure 7: Relationship between cement slurry variables

Table 4: Pearson correlation matrix table for variables relationship

Variables	Dispersant	Fluid Loss Additive	Thickening Time	Free Fluid	Mix Water
Dispersant	1.000				
Fluid Loss Additive	0.000	1.000			
Thickening Time	0.799	0.562	1.000		
Free Fluid	0.411	-0.821	-0.123	1.000	
Mix Water	-0.059	-0.998	-0.608	0.796	1.000

Table 4.: Pearson Correlation Matrix

Shows linear relationships between variables in cement slurry

Values range from -1 (strong negative) to 1 (strong positive)

Key Relationships:

1. Dispersant & Fluid Loss Additive: $r = 0.000$
Orthogonal design; independent variables
2. Dispersant & Thickening Time: $r = 0.799$
Strong positive correlation; dispersant increases thickening time
3. Fluid Loss Additive & Thickening Time: $r = 0.562$
Moderate positive correlation; influences setting
4. Dispersant & Free Fluid: $r = 0.411$
Moderate positive correlation; may increase free fluid
5. Fluid Loss Additive & Free Fluid: $r = -0.821$
Strong negative correlation; reduces free fluid
6. Mix Water relationships:
Reflects experimental adjustments for slurry density

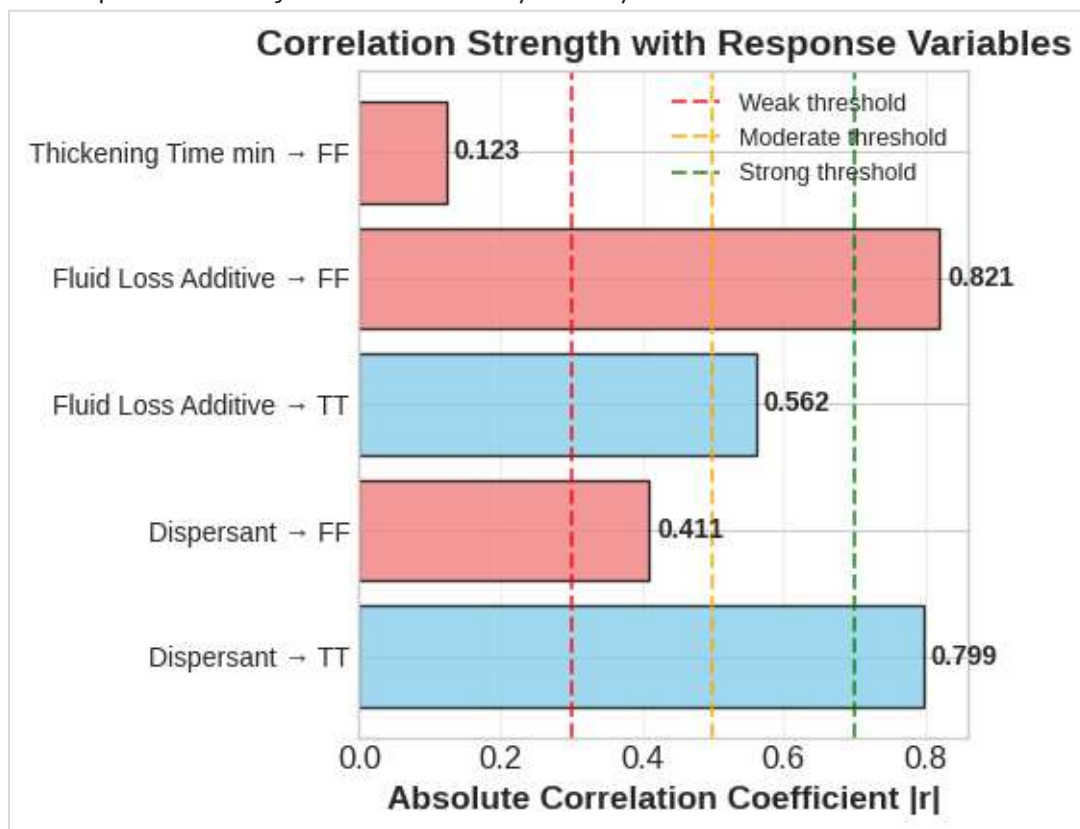


Figure .8 : Strength of independent variables with response variables

Correlation Strengths (Fig 4.8):

- a. Dispersant-Thickening Time: strong ($r=0.799$); primary influence
- b. Fluid Loss Additive-Thickening Time: moderate ($r=0.562$); secondary effect
- c. Fluid Loss Additive-Free Fluid: strong ($r=-0.821$); controls stability
- d. Dispersant-Free Fluid: moderate ($r=0.411$); potential stability concern
- e. Thickening Time-Free Fluid: weak ($r=0.123$); minimal direct link

Implications:

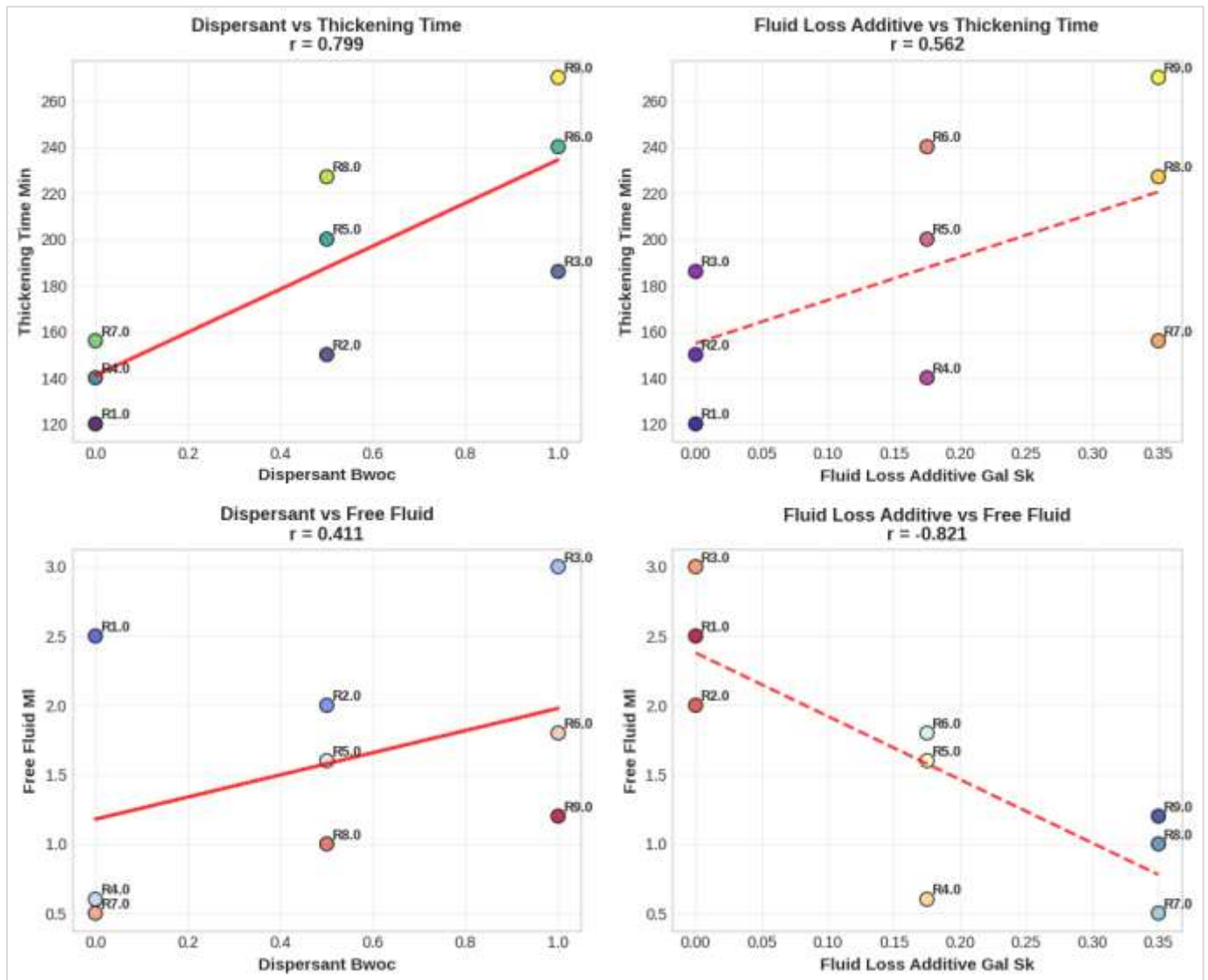
Dispersant dominates thickening time control, - Fluid Loss Additive critical for stability & secondary thickening control, - Balance needed to optimize both parameter

Scatter Plot Analysis (Fig .9):

- a. Dispersant-Thickening Time: strong positive linear trend
- b. Fluid Loss Additive-Thickening Time: moderate positive, non-linear at high concentrations
- c. Dispersant-Free Fluid: moderate positive with scatter; potential stability issues
- d. Fluid Loss Additive-Free Fluid: strong negative linear trend; reliable control

Key Findings:

- a. Thickening Time & Free Fluid: weak correlation ($r=0.123$); somewhat independent
- b. Dispersant dominates thickening time; Fluid Loss Additive controls stability
- c. Trade-offs needed for optimization.



Model Performance (Table 5.):

$R^2 = 0.981$: The model explains 98.1% of thickening time variation, - Adjusted $R^2 = 0.970$: Model is accurate, no overfitting, - RMSE = 8.731min: Error margin is ~4.7% of average thickening time (187.67min), - Durbin-Watson = 2.051: Data points are independent, model assumptions valid

What it means:

- a. Dispersant & Fluid Loss Additive concentrations strongly influence thickening time

- b. Model is reliable for predicting cement slurry behaviour, - Can guide cementing operations with high accuracy

Dispersant's Impact on Thickening Time:

- a. Dominant Factor: Dispersant concentration is the primary influencer of thickening time ($F=37.835$, $p=0.002$)
- b. Linear Relationship: For every 1.0% BWOC increase in dispersant, thickening time increases by ~93.3 minutes
- c. Range of Effect:
 1. 0% BWOC (neat cement): 138.7min (baseline) - 0.5% BWOC: 192.3min (+38.6%)
 2. 1.0% BWOC: 232.0min (+67.3%) - Variability: Confidence intervals widen with increasing dispersant concentration, indicating more uncertainty in predictions at higher doses

Statistical Significance:

p-value of 0.002 indicates extremely high confidence (>99%) that dispersant affects thickening time - F-statistic of 37.835 far exceeds typical significance thresholds

Practical Implications:

- a. Dispersant concentration can be precisely adjusted to target specific thickening times
- b. Linear relationship simplifies predictive modelling and slurry design

4. Conclusion

This study demonstrates that dispersant and fluid loss additive concentrations significantly impact Class G cement slurry performance

Key findings include:

- a. Dispersant concentration is the primary thickening time control factor, with a strong positive correlation ($p=0.002$)
- b. Fluid loss additive serves dual roles: filtration control and secondary thickening time influence
- c. Significant interaction effects exist between additives, requiring combined optimization
- d. Fluid loss additive effectively controls free fluid formation ($r=-0.821$)
- e. Predictive models enable targeted slurry design for field applications

The factorial design approach effectively characterized complex additive interactions, providing tools for optimization. These findings guide cement slurry formulation for improved well integrity and performance.

5. Reference

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