AADE-07-NTCE-15

Enhanced Transfer Efficiency of Bulk Cement and Spacers Reduces Non-Productive Time and Bulk Material Waste

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This paper was prepared for presentation at the 2007 AADE National Technical Conference and Exhibition held at the Wyndam Greenspoint Hotel, Houston, Texas, April 10-12, 2007. This conference was sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author(s) of this work.

Abstract

Rig cementing non-productive time (NPT) and bulk material waste costs can be substantially reduced by a new process that is carried out in the bulk plant to effect a change to the electrostatic characteristics of individual cement grains or other powders. The new process makes bulk cement and other powders easier to refluidize and move pneumatically. Pneumatic transfer of bulk powders such as cement and cement blends with microsilica and pozzolanic materials etc., and spacer component powders containing clays and minerals is a mainstay process vital to material transport, blending, and slurry mixing. While some powdered materials are pneumatically transferred with ease, other materials, such as those with small average particle sizes, are not easily moved. The environment (moisture and temperature) and conditions of transfer (system pressure, tank design, and mode of transport) may also impact transfer efficiency. Poor pneumatic transfer efficiency can result not only in bulk material waste because of incomplete transfer, but also increased rig NPT caused by slower cement and spacer slurry mixing and pumping rates.

This paper presents an analysis of the current bulk transfer process of cements and other powders and introduces a new process for altering particle electrostatic charges by chemically treating typical cements, cement blends, and spacer solids. Optimizing the existing bulk transfer process and adding the new chemical treatment process can dramatically improve pneumatic bulk transfer efficiency by effective fluidization of the materials. A secondary benefit of the improved bulk transfer efficiency is that it can increase slurry pumping rates, thus reducing the rig time required to perform a cementing operation. Case histories are presented from applications in the North Sea, Gulf of Mexico offshore, and Western United States land-based operations.

Introduction

The packing tendency of powder materials is a complex issue and can result from many factors. Mechanisms that have been previously assumed or proposed as being primary causal factors include surface charges, static electricity buildup, moisture content, particle shape, and particle-size distribution, all of which can contribute to agglomerate formation and mass packing.

The chemical composition of a cement powder is, for the most part, complete once the clinker is made in the kiln. While the chemical composition of the cement powder does vary slightly during the grinding process because of temperatures and sometimes the addition of gypsum, its physical characteristics are severely altered during the grinding process.

During grinding, a cement clinker is literally pulled apart, leaving unsatisfied positive and negative charge sites on the surfaces of the particles. The greater the surface area of the resulting cement powder, the greater the degree of potential attraction between particles. These positive and negative surface charges are believed to be responsible for a large degree of the particle-to-particle attraction that subsequently inhibits efficient pneumatic bulk handling. Further, the degree of particle-to-particle electrostatic forces of attraction and repulsion are largely responsible for how well (or poorly) a dry material such as cement handles in a pneumatic transfer system, especially for materials with extremely high surface areas such a ultra-fine cements, fumed silica, barite, etc.

Because of the surface negative charges and the basic (high pH) character of cement material, our investigation centered on using acidic materials to help improve the flow characteristics of particulate materials with similar surface negative charge.

Pneumatic transfer of bulk cement is a mainstay process vital to material transport and slurry mixing. Numerous investigations have been carried out over the years, resulting in improvements to equipment design and occasional blend modifications. While some bulk cements are pneumatically transferred with ease, some cements, such as those with broad particle-size distributions and low average particle sizes, are not so easily moved. Additionally, the environment (temperature, humidity) and conditions of transfer (system pressure, tank conditions, transfer path, tank design) can impact transfer efficiency. While cone-bottomed tanks that have a high angle of repose do not present a severe refluidization problem, horizontal tanks and those with low angles of repose (such as those found on marine transport tanks) may present severe refluidization difficulties. These difficulties are compounded when handling small-particle cement blends and other specialty blended cements.

The purposes of this investigation were to (1) develop a technique to allow correlation between bulk transfer

effectiveness and laboratory modeling, and (2) explore ways to improve bulk transfer under typical conditions such as those found offshore.

Laboratory Test Method

A proprietary procedure was developed and used to determine the flow characteristics of various cements and other powdered materials. This technique, called the powder flowability test (PFT), provides a quantitative method of comparing laboratory and actual pneumatic transfer of particulate materials.

The PFT involves consolidating a sample of cement or other material inside the PFT laboratory device that simulates the mechanical conditions of field storage systems. Then the cement sample in the PFT device is exposed to mechanical conditions that simulate refluidization of powder to determine the material's capability to flow. The PFT results are expressed as the flowability factor (FF) of the powdered material.

To run the PFT, a baseline FF on an untreated sample is first determined. This FF is then used as the basis of comparison for the FF of all subsequently modified and/or treated blend samples. The objective is to not only lower the FF value, but to find one that flattens out as a function of additional treatment. This provides an indication of optimum treatment using flow enhancer treatments, and also allows for comparative predictions of how different combinations of components will behave. Generally, the PFT is repeated five times and the average values are taken as the powdered material's FF. Once the FF of the lab-prepared blended cement or spacer is satisfactory, the PFT does not have to be repeated on job-specific samples or even on samples of similar cement designs.

Full-Scale Verification

Based on the observations made with the PFT technique and the theoretical behavior of charged particles, a new process was developed. This process enhanced the capability of typical pneumatic bulk equipment to refluidize bulk materials compacted in a bulk storage tank. Bulk transfer and PFT testing carried out in south Louisiana confirmed that a concentration of 0.1% flow enhancer (FE) was adequate to reduce waste and bulk cement losses of a Portland Class A: Ultra-fine cement blend to less than 10%, whereas 40% losses had been normal with this particular blend.

A concentration of 0.05% FE significantly improved refluidization, but still resulted in approximately 25% of the blend being left in the tank. The addition of FE also greatly reduced the degree of surging in the bulk equipment, resulting in a much smoother flow of bulk cement for all blends tested. This can be attributed to the ease of de-agglomeration of the cement.

Figure 1 shows the results of the full-scale bulk pneumatic study utilizing the Class A:Ultra-fine blend. This data shows that only 40% of the untreated blend was removed from the bulk tank, while 90% of the blend treated with 0.1% FE was removed.

While the original goal of developing a flow enhancer was to correct bulk flow problems related to bulk losses and severe delivery impairment issues during the job, other attributes become apparent:

- Smoother bulk flow (less surging).
- Smoother density charts.
- Faster mixing rates.
- Fewer plugging problems with mixing heads and lines.

A comparative example of the improved performance of FE-treated cement vs. untreated cement on identical jobs is shown in **Figure 2**. Further, these attributes have been reported several times by offshore operators, including mixing speeds up to double that of untreated blends.

Laboratory investigations were conducted with various other cement blends to determine the optimum concentration of FE for the various blends utilizing the PFT. The systems tested were as follows:

- Blend 1: API Class C cement + fumed silica + pozzolan.
- Blend 2: Ultra-fine cement + ultra-fine pozzolan + 35% crystalline silica + additives.
- Blend 3: API Class C cement + ultra-fine cement + additives.
- Blend 4: API Class C cement + 35% crystalline silica + 20% fumed silica.

Figure 3 illustrates PFT results that correlated to vastly improved bulk transfer and reduced cement waste when the FF value dropped below about 15, indicating that adequate treatment with the FF had been achieved.

Effects on Bulk Cement and Slurries

Because the chemical and grind characteristics of all cements are different, the PFT data from one brand or type to another may indicate slight changes in FE concentrations for optimal bulk flow characteristics. **Table 1** provides some examples of various types of cements and other bulk additives.

Testing was also conducted to determine whether the addition of FE had any effects on slurry performance. Results of this testing for two different systems are shown in **Table 2**. This laboratory testing shows that the FE had negligible effects on slurry thickening times, static gel strength development (transition times), fluid loss, free water and compressive strength development. The slurry performance data presented is considered to be within experimental error.

Case History – US Gulf of Mexico

The use of specialty cement blends for the elimination of shallow water flow (SWF) hazards is extensively documented in the oil and gas industry.[1-2] However, some of these specialty blends are prone to severe packing and difficulty in refluidization in both marine transport vessels and rig bulk tanks. This issue results in wasted bulk cement, at times as much as 40%, and necessitates increased cement volumes on the rig to perform a cement job. The introduction of the FE to these blends reduced bulk cement losses from the reported

average 40% to about 9%.

An operator working in the deepwater region of the US Gulf of Mexico regularly used specialty blended cements to combat SWF hazards. While excessive volumes of waste cement were expected when using specialty blends, the operator wanted to reduce this cost if possible. A typical well was chosen for introducing the FE treatment to determine its effectiveness.

The annular volume of cement slurry for this job required 3,000 sacks of bulk-blended SWF cement. Past experience with this particular blend without the FE treatment indicated that the volume to be loaded on the rig for this job should be approximately 4,200 sacks, so that is what the operator loaded on the rig for the first job. To document the performance of the FE, bulk cement losses were carefully monitored from the bulk plant to the actual mixing of the cement job. A total of seven marine transport tanks and four rig tanks were used for this job. Of the approximately 320 sacks of cement blend lost during this single-job test, approximately 180 sacks were found to be left in the bulk tanks on the marine vessels and on the rig. The remaining 140 sacks (approximately) of cement were apparently lost in the loading and transfer and venting of the materials. A portion of that blend remaining in the rig tanks was actually recovered because the same blend was used on the next job. Not only did the FE reduce bulk cement waste, but additional savings were realized due to one less boat run required for each job, as well as much less time required for transferring blend from the boats to the rig and for cleaning tanks afterwards.

Once this operator saw the benefits of the FE treatment process for this more difficult blend, a second study was requested but this time using only neat API Class H cement. The same material tracking methods used for the SWF blend was applied over an entire well. Records indicated that non-SWF blends averaged 12% losses. For the remaining cementing jobs on this particular well (consisting of four casing strings, two kickoff plugs, and five abandonment plugs), the cement blend was treated with the FE and included a defoamer. All other additives were liquid and added on-the-fly as needed for the requirements of each job. Of the 6,200 sacks of FE-treated cement placed on the rig for these eleven cementing jobs, 5,200 sacks were pumped and 675 sacks were remaining on the rig at the conclusion of the project. This equates to 6.25% bulk cement losses experienced for these 11 cement jobs. The new process cut the operators bulk cement losses in half on this particular well.

Case History – Norway

To establish a baseline, a major operator offshore Norway carefully recorded waste cement for 6 months. Total cement waste of 16.1% was reported during this period. Out of the 16.1% total cement waste, 8.2 % was lost in transfers from delivery boats to the rig storage tanks and 7.9% lost in transfers from the rig tanks to the rig's cement mixing unit. For a second 6-month evaluation period, the use of FE-treated cements was started on one rig. By the end of this time period the treatments were providing significant reductions in cement waste, rig NPT, and cement job shutdowns caused by poor bulk flow. The treatment success has since continued and is summarized in **Table 3,** showing only the job-related loss reductions.

This North Sea rig study of 41 cement jobs demonstrated that FE-treated cements could successfully improve rig cementing operations by maintaining consistent bulk flow rates without any shutdowns to unplug the bulk lines, reduce rig NPT by mixing up to 50% faster (50% for lead and 20% for tail slurries), and decrease cement waste by 77% (7.9% in 20 jobs vs. 1.8% in 21 jobs). In addition, the FE cement treatments benefited rig operations by consistently reducing the time periods to load and unload delivery boats by a minimum of 15 to 20%. In some cases, transfer times were decreased up to 53%, depending on conditions such as the performance of the rig and boat bulk handling equipment and the type of cement composition.

Application of FE-treated cements has become a standard practice in Norway for several operators, with approximately 2,000 jobs having been performed to date. The tracking of cement waste from FE-treated vs. untreated cements continues to show that FE treatments more than pay for themselves even when performance may vary depending on conditions, including changes in the design of cement compositions and bulk cement handling equipment configurations. **Table 4** provides one Norwegian operator's cement cumulative 12-month usage and waste for all cement designs with and without FE treatments.

Based on the results in Table 4, the operator estimated that an additional 437 MT of cement could have been saved with 100% implementation of FE treatments in all cements used during the 12-month period. Data on actual cost savings by FE treatments for operators in Norway have been analyzed to estimate a potential yearly cost savings (**Table 5**) for a one rig operation with the following typical parameters:

- 102 cement jobs/year.
- 1705 MT total cement used and FE treated.
- 79% less cement waste (latest 12 month data 6.22% vs. 1.30%).
- Rig cost 2,000,000 NOK per day.
- Boat cost 95,000 NOK per day.
- FE treatment in all cement jobs:
    - Saves average 15 minutes of rig NPT per job by higher mixing rates.
    - 25% faster transfer rates saves boat time for other uses.
- FE treatment cost includes FE material, equipment and service.

Case History – Cementing Spacer

Operations for an operator in California were experiencing a problem mixing a bulk-blended, barite-weighted cement spacer because of poor bulk flow from the delivery tank to the mixing unit. The location logistics created extremely long distances between the bulk tanks and mixing equipment. The job size and location logistics also made the

possibility of mixing the spacer from sacked materials, or bringing in premixed spacer slurry impossible.

The spacer system was bulk blended in a bulk truck and driven to location to be mixed on the fly through the recirculating mixer. When mixing the spacer the operators could not get it to proper weight and the dry blend would not transfer smoothly. Not only did mixing go poorly, but considerable spacer blend was lost in the transfer system. There were some issues that could have exacerbated the problem on the first application: (a) the location was 100 miles away and the road was quite bumpy, which may have packed the material in the coned bottom of the bulk truck, and (b) the blended material was transferred on location through extra-long hoses needed to reach the cement mixing unit from the distant point that the cement delivery truck had to be spotted.

The bulk-flow problems experienced on the first job were avoided on the next job by adding 0.12% FE by total weight of the spacer blend. The operators said the treated product "transferred and mixed like silk," even with the bulk transfer equipment being identical to the previous job. The FE treatment in the spacer blend solved the problem, i.e., saved rig NPT and prevented wasted spacer blend.

Since the first spacer blend was FE-treated in California and successful under very difficult conditions, many other well cementing applications now apply the treatment and successfully avoid spacer-blend transfer problems.

Global Benefits

Energy feeds cement manufacturing, which in turn is necessary to feed energy production via fossil fuels ultimately produced through cemented wellbores. Sustainability and economic health of this closed cycle are therefore dependent upon maximizing efficiencies, and part of that is to minimize the cement waste.

Since commercial use of the FE started in 1998, over 720,000 tons of cement has been treated with this process for well-construction. Applying a conservative average waste reduction of 6% indicates a waste reduction of 42,000 tons as compared to untreated cement powder. For some specialty blends such as those containing microfine cements, waste reductions in excess of 20% have been recorded.

However, there is more to the picture than simply a savings in cement powder. While the cement industry's collective energy use and emissions are dwarfed by those of thermal power plants, and by those of motor vehicles for nitrous oxides and CO_2, the industry is still studying and implementing ways to improve manufacturing economics and reduce emissions. In addition to simple waste reduction of cement powder during pneumatic transfer and at the point of use, conservation of Portland cement has implications in terms of overall energy savings and reduction of carbon dioxide emissions. Hendriks *et. al.* report that the energy consumption by the cement industry is estimated at almost 5% of the total global industrial energy consumption, and likewise results in approximately 5% to the total carbon dioxide emissions.[3] Griffin reports that oil- and gas-well construction accounts for only 2 to 3% of global cement consumption.[4]

For every pound of Portland cement manufactured, depending on which of the five processes is used and the efficiency of the manufacturing plant, approximately 2,100 BTU of energy is required. This estimate does not include conveying and shipping after-the-fact. Further, the global average of carbon dioxide emissions resulting from a combination of fuel consumption and the calcination process during clinker production is 0.81 tons per ton of cement produced.[3] Applying these factors to the previously-stated waste reduction of 42,000 tons of cement provides an estimated energy savings of 17.6 $x10^{10}$ BTU, and the prevention of 34,000 tons of CO_2 emissions. This treated volume of 720,000 tons over approximately 6 years accounted for only a very small fraction of the total global cement usage and associated energy and emissions by the well-construction industry. However, this shows that there are still significant gains to be realized with expanded use of flow enhancement technology. Please bear in mind that, while these factors can vary considerably (as much as 20%), the authors have chosen to apply conservative values in this paper. Actual savings may be considerably more in some areas.

Conclusions

1. A flow enhancer process applied in cement bulk plants changes electrostatic characteristics of individual cement grains. This helps make cements and other powders easier to fluidize and move by pneumatic systems.
2. A laboratory test has been developed to quantify a flowability factor. This helps correlate actual pneumatic bulk transfer effectiveness with laboratory modeling.
3. Cements treated with the flow enhancer are less likely to hang up in bulk tanks and equipment. Cement losses and waste can thus be greatly reduced.
4. Flow-enhanced cements are more easily moved on the jobsite and help reduce rig non-productive time.

Acknowledgments

The authors thank Halliburton management for permission to present this paper. Halliburton colleagues who helped the authors develop and field-prove the FE treatment process include B.R. Reddy, Russel Fitzgerald, Gunnar Lende, Bob Martin, and Mark Haire. Thanks also to numerous field operations personnel that supported this project with their invaluable suggestions.

Nomenclature

psi = Pounds per square inch (cement strength)
lb/gal = Pounds per gallon (cement slurry density)
BPM = Barrels per minute (slurry mixing and pump rate)
MT = Metric tonnes (1 MT = 1.102311 short tons)
NOK = Norwegian Krone (1 NOK ≈ 0.16 US dollars)
UCA = Ultrasonic cement analyzer

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Table 1: FE Additive Use in Various Materials

Material	FF Before Treatment	% FE Additive	FF After Treatment
Class G – source I	25	0.09	10
Class G – source II	30	0.09	10
Class H	26	0.08	11.4
Class A - source I	16.7	0.07	7.3
Class A - source II	20.6	0.05	12.4
Fumed Silica	19	0.13	7
Barite	26	0.10	7

Table 2: Effect of FE on Slurry Performance

	Slurry 1		Slurry 2	
FE Treatment	NONE	0.15%	NONE	0.3%
Thickening Time (hr:min) at Temp. (°F)	1:46 at 120°F	1:52 at 120°F	2:51 at 110°F	2:46 at 110°F
Free Water (%)	0	0	0	0
API Fluid Loss (cc/30 min)	505	449	—	—
UCA Compressive Strength Time to 500 psi (hr:min) at Temp. (°F)	2:48 at 140°F	3:01 at 140°F	7:47 at 130°F	8:33 at 130°F
12-hour Compressive Strength (psi)	2680	2820	875	775
24-hour Compressive Strength (psi)	3025	3160	1230	1260

Slurry 1: Class C Cement + 35% crystalline silica + 20% fumed silica, mixed at 13.8 lb/gal with 11.6 gal/sk water.
Slurry 2: Class C Cement + pozzolan + fumed silica + additives, mixed at 11.5 lb/gal with 13.3 gal/sk water.

Table 3: Rig Study of Bulk Cement Flow Enhancement and Waste Minimization

FE-Treated	Jobs	Bulk Flow	Mixing Interruptions	Mixing Rates, bpm	Average Cement Waste
NO	20	Erratic	~ 5 per job	4.5–5.0	7.9%
YES	21	Steady	None	6.9–7.5	1.8%

Table 4: 12-Month Rolling Usage Data

General Blend Description	Usage, MT	Treated	Waste, MT (%)
API Class G + 35% crystalline silica	3458	NO	436 (12.61%)
	4081	YES	133 (3.25%)
All other blends combined	4757	NO	451 (9.48%)
	10779	YES	327 (3.03%)

Table 5: Potential Annual Cost Savings by FE Treatment Process for One Rig

Parameter	NOK/Year
Bulk cement waste reduction	107,961
Rig time saved	2,125,000
Boat time saved	23,750
Subtotal savings *(improved HSE not included)*	**2,256,711**
Additional cost for FE treatments	(596,750)
Total Cost Savings Potential per Rig	**1,659,961**

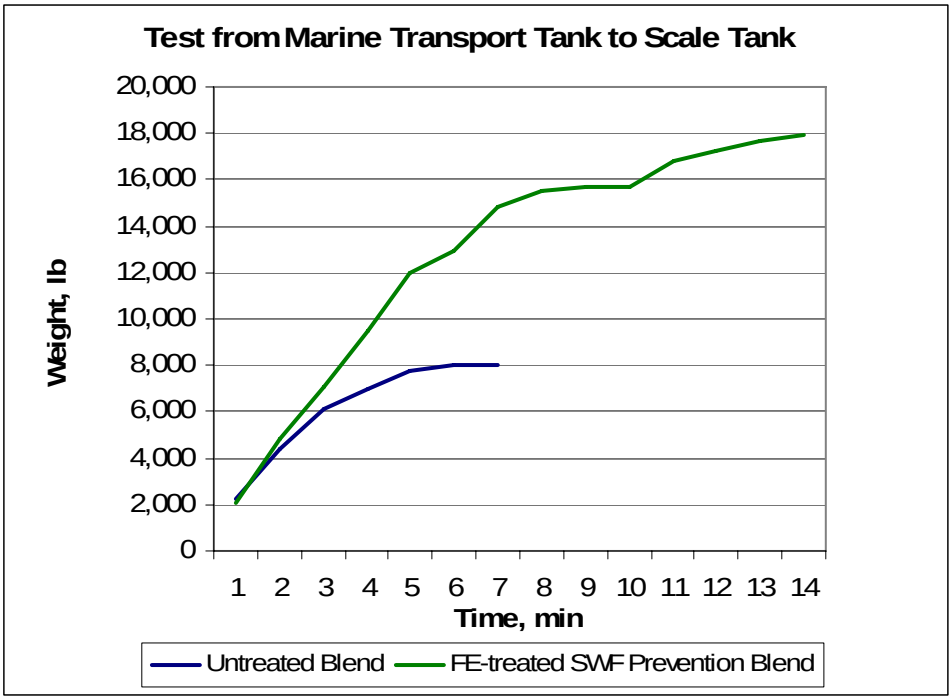


Figure 1: Bulk transfer rates with and without flow enhancer (FE).

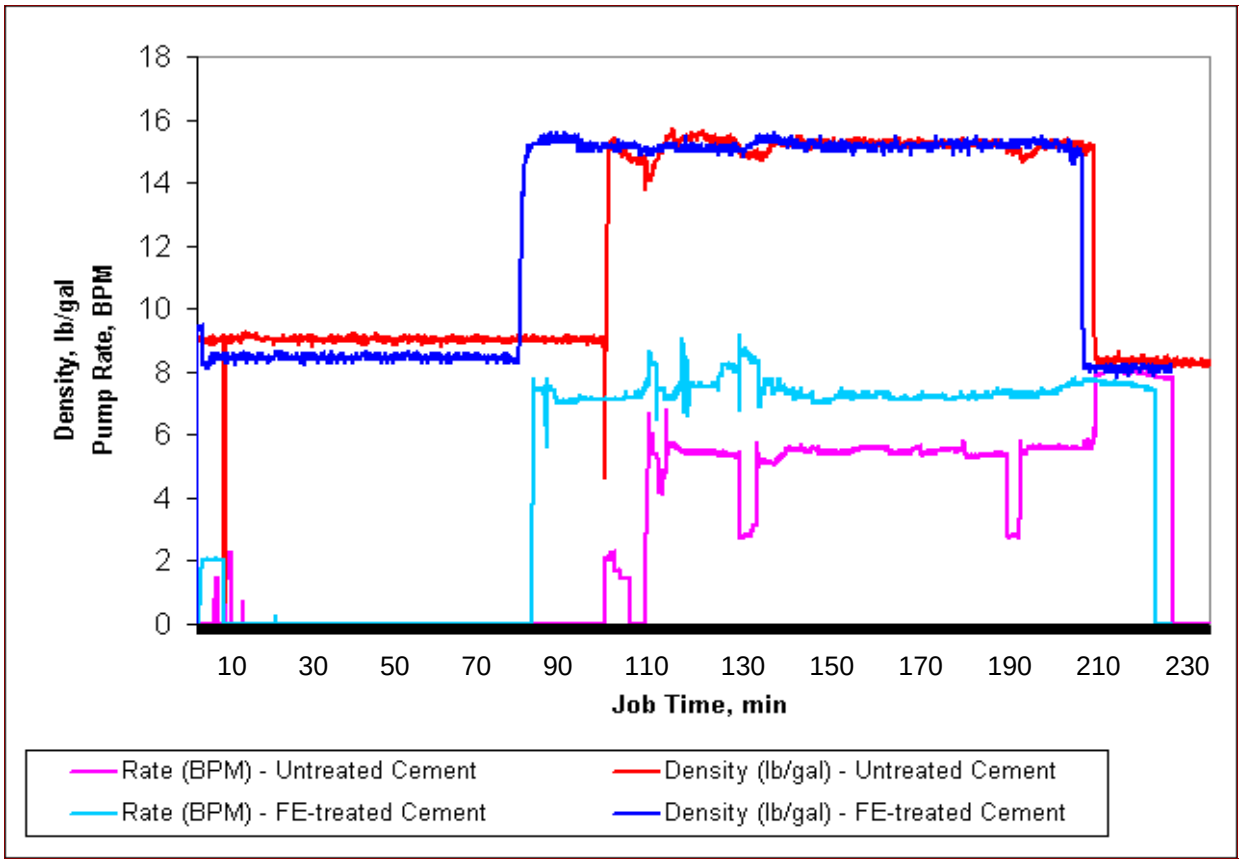


Figure 2: SWF-prevention cement jobs comparison of FE-treated vs. untreated cement blend.

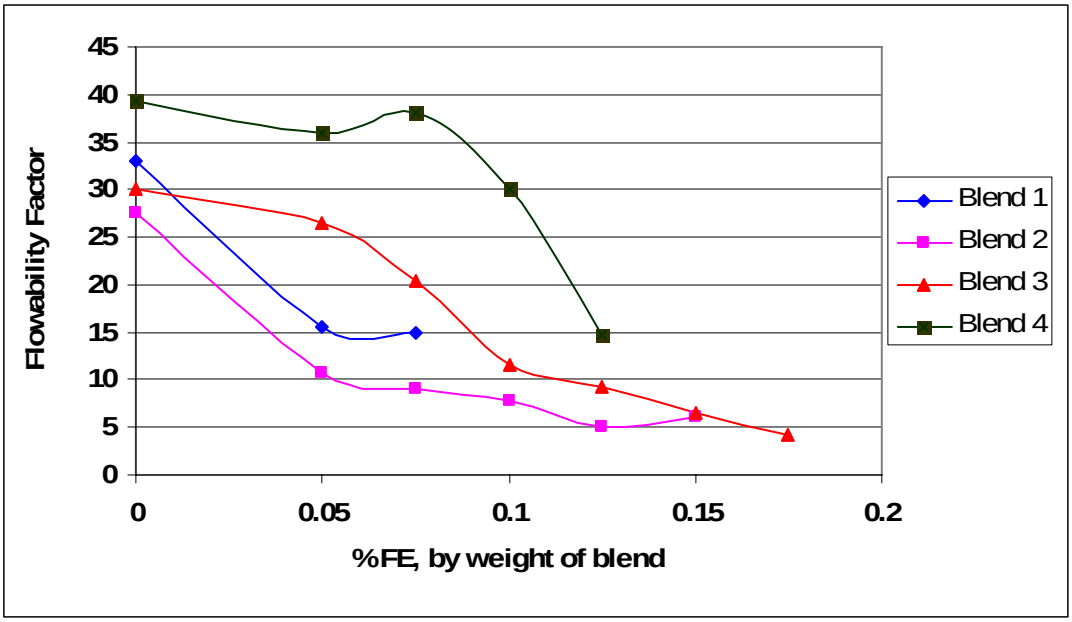


Figure 3: Impact of % FE concentration on the flowability factor for various blends.