Newly Developed Anti-Caking Agents and Physical Influences on Salt Caking

Robert Geiger, Steffen Ball, Geoffrey Brown and Daniel K. Pannell
Compass Minerals, 9900 West 109th St, Overland Park, KS 66210, USA
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Abstract

The tendency for salt to cake or clump during storage or transportation has been a recurring problem for the salt industry. Salt caking is due to the aggregation of individual salt grains into larger, hardened conglomerates. This occurs due to the hygroscopic nature of salt which readily attracts moisture from the surrounding atmosphere. This results in the outer surfaces of the salt grains to moisten, and bond to adjacent granules when the salt water evaporates. These conglomerates may result in salt that cannot be easily poured from a container or spread about a road surface for deicing purposes. Historically the industry has applied an additive to prevent caking called sodium ferrocyanide in the 50 to 150 ppm range for deicing salt and limited to 13 ppm for food and animal feed salt. Long-term studies on the environmental impact of YPS are lacking and questions concerning its impact continue to recur. These questions suggest a need to develop anti-caking alternatives to sodium ferrocyanide.

This study utilized a method of quantifying the caking of salt with a variety of newly developed anti-caking agents. Additionally this study examined the impacts of moisture content, grain size, and packaging on the degree of caking. This paper compares the performance of these anti-caking agents simulating conditions that are typically encountered by salt over a one year period. The impacts of various physical influences on caking were also examined and are presented within this paper.

Introduction

When sodium chloride (salt) is stored or transported, caking or clumping often occurs. Caking is the amalgamation of individual salt grains into a larger salt conglomerate which is primarily due to the hydroscopic nature of the material. Salt will attract water to its surface creating concentrated brine and when upon evaporation of this brine will result in microcrystalline growth and solid bridging that will bind the grains together (1,2). This caking produces many challenges to the industry from large scale transport and storage to small scale cartons and bags. The resulting large clumps can dramatically limit the flowability of the salt resulting in difficulty in spreading the salt for deicing purposes. The industry has addressed this challenge by including an anti-caking additive known as sodium ferrocyanide (YPS or Yellow Prussiate of Soda) which prevents or reduces the ability of salt to become caked. Although YPS is a very effective anti-caking agent, questions continue to arise concerning its environmental impact (3,4). In addition to apprehension

 geigerr@compassminerals.com phone 9133272402

about environmental impact, YPS has a characteristic property of crystal creep, which causes the crystal migration of salt and YPS crystals through small ventilation holes in bags and cartons. These phenomena results in unsightly and messy product packaging.

Though YPS remains the ‘gold standard’ for salt anti-caking, there exists a need for a new alternative for packaged products and areas where environmental concerns become prominent.

This study was designed to test two newly developed anti-caking agents (designated in this paper as CMP1 and CMP2) in a real world scenario that would replicate the conditions that a bagged salt product would encounter over a one-year period. Additionally, this study examined other physical influences like grain size, bag size and moisture content that could affect how the material clumps over this time period by employing a quantitative approach to evaluating salt caking.

Methods

To perform this study in a real world setting, a packaging facility in Chicago, Illinois, was selected to package and store bags of salt. Salt was packaged in UV-resistant bags that hold 25 and 50 lb.s. To accelerate the rate of caking and determine the impact of moisture on caking, the salt was treated with two different moisture levels, 0.5% and 0.9%. The salt was bagged with both fine and coarse grained material to determine how grain size impacts salt caking. Fine grained salt refers to a grain size that is on average 2 mm (10 mesh) in size, while coarse grained salt is an average of 3.34 mm (6.36 mesh). Each of these variables was examined with each additive that was being tested (Table 1). Previous laboratory experimentation indicated that an effective concentration would be in the 25 ppm range and thus such was targeted for each bag and additive type.

For comparison purposes, sets of samples were also prepared with no anti-caking agents and with 25 ppm of YPS. Table 1 below summarizes the different sample sets. 25 bags of each sample type was produced and palletized. The pallets were covered with a plastic shroud and plastic wrapped then stored outside for the duration of the experiment.

Table 1. Each sample type bagged during the 1 year trial.

	Control	Industrial Standard	Proprietary Blend 1	Proprietary Blend 2
0.5% Moisture Fine Grained 25 lb. Bag	Untreated	YPS	CMP1	CMP2
0.5% Moisture Fine Grained 50 lb. Bag	Untreated	YPS	CMP1	CMP2
0.9% Moisture Fine Grained 25 lb. Bag	Untreated	YPS	CMP1	CMP2
0.9% Moisture Fine Grained 50 lb. Bag	Untreated	YPS	CMP1	CMP2
0.5% Moisture Coarse Grained	Untreated	YPS	CMP1	CMP2

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25 lb. Bag				
0.5% Moisture Coarse Grained 50 lb. Bag	Untreated	YPS	CMP1	CMP2
0.9% Moisture Coarse Grained 25 lb. Bag	Untreated	YPS	CMP1	CMP2
0.9% Moisture Coarse Grained 50 lb. Bag	Untreated	YPS	CMP1	CMP2

Approximately every three months over the course of a year, a bag from each pallet was collected and assessed to determine the amount of caking. Each collected bag was weighed and dropped from a height of 3 ft. The bags were then opened and the clumps were separated from the free-flowing material using a screen. Upon collection of clumps, they were placed upon a screen and agitated by a vibrating motor for 30 secs. By dropping the bags and agitating the clumps, loosely caked material would readily separate, allowing for the measurement of only severely caked material. The weights of the clumps were then measured and the percent of caked material could be calculated. Previous studies have employed qualitative methods of evaluating the degree of caking. For this study a method capable of quantifying the degree of caking was developed and utilized. This method allows a more thorough evaluation of the newly developed anti-caking additives.

Results and Discussion

Impact of Additives on Caking

Untreated samples showed significant caking throughout the duration of the trial and were used as a control for this study (Figure 1). The significant caking in the untreated salt verified that the conditions were adequate for caking to occur and allowed for proper evaluation of the effectiveness of the anti-caking additives.

geigerr@compassminerals.com phone 9133272402

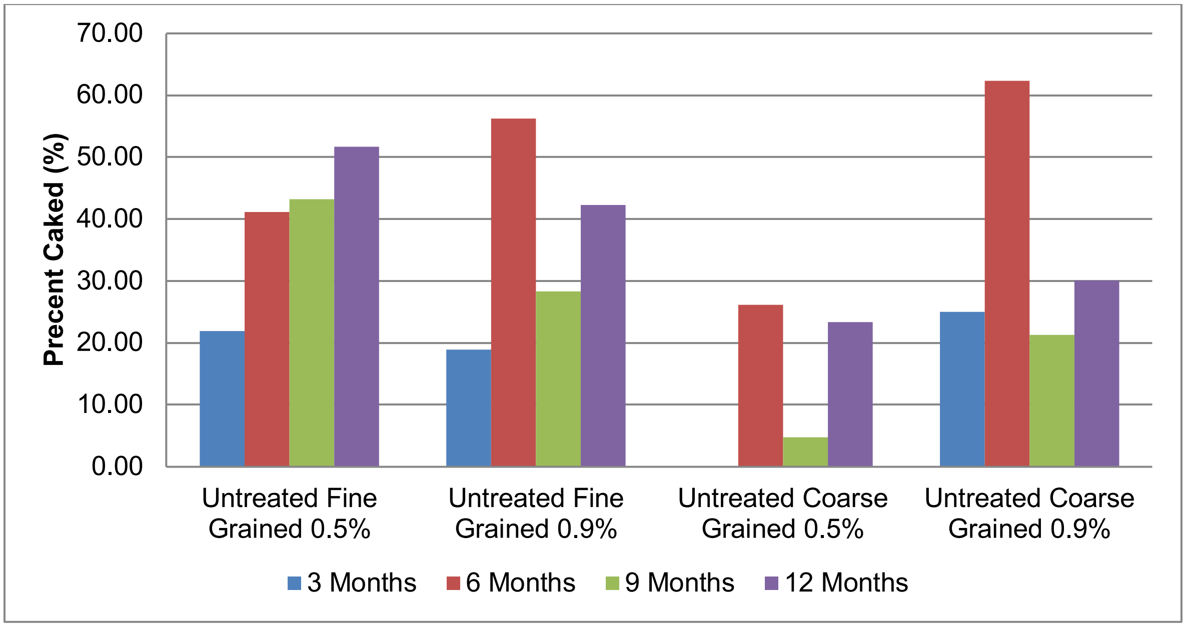

Figure 1. Percent of caked material of untreated salt samples

The YPS-treated salt worked as expected with very minimal to no caking observed in the majority of bags (Figure 2). YPS was used in this experiment in order to compare the newly developed anti-caking agents with what is considered to be the industry standard.

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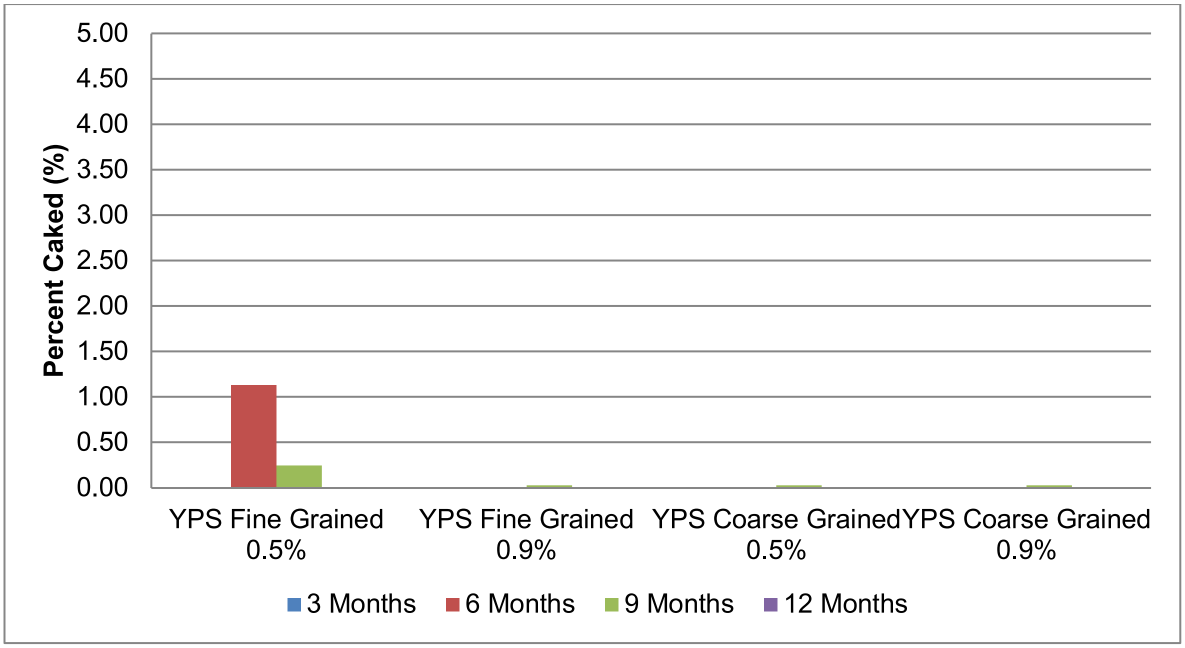

Figure 2. Percent of caked material of YPS-treated salt samples

The CMP1 additive reduced caking in the salt bags compared to untreated samples, but did not reduce caking to the extent of YPS (Figure 3). The total average reduction in caking with the CMP1 additive was 55.47% as compared with untreated salt.

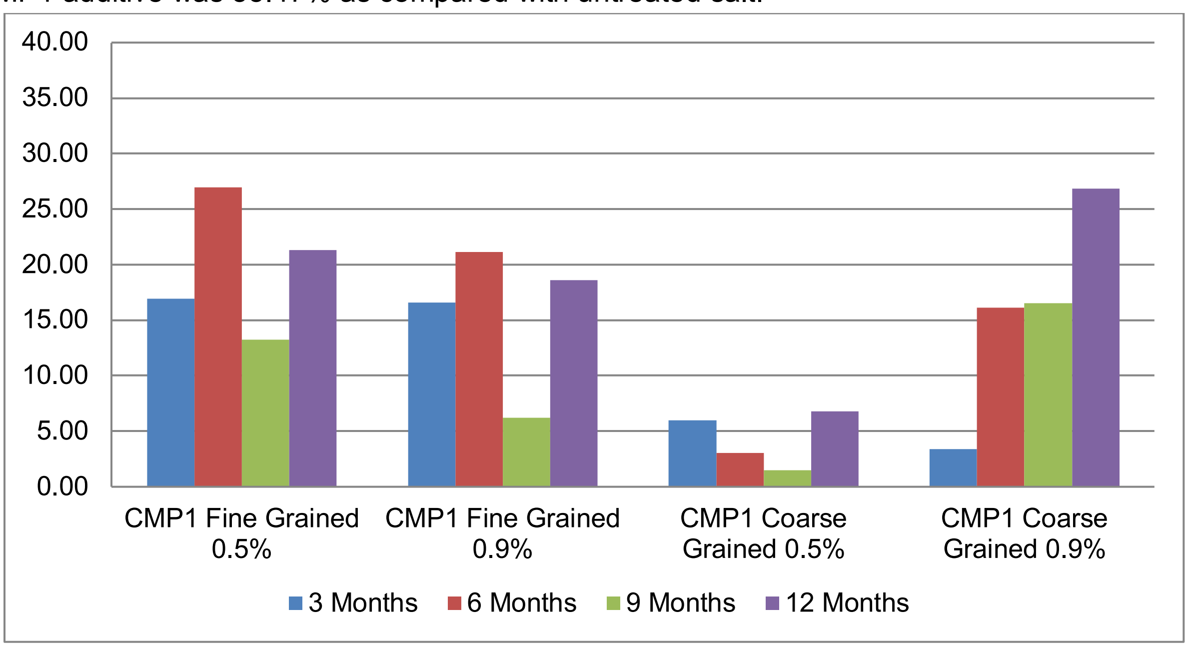

Figure 3. Percent of caked material of CMP1 treated salt samples

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The CMP2 additive reduced caking in a similar manner as the CMP1 blend but had a slightly better performance (Figure 4). The total average reduction in caking was 59.70% as compared with untreated salt.

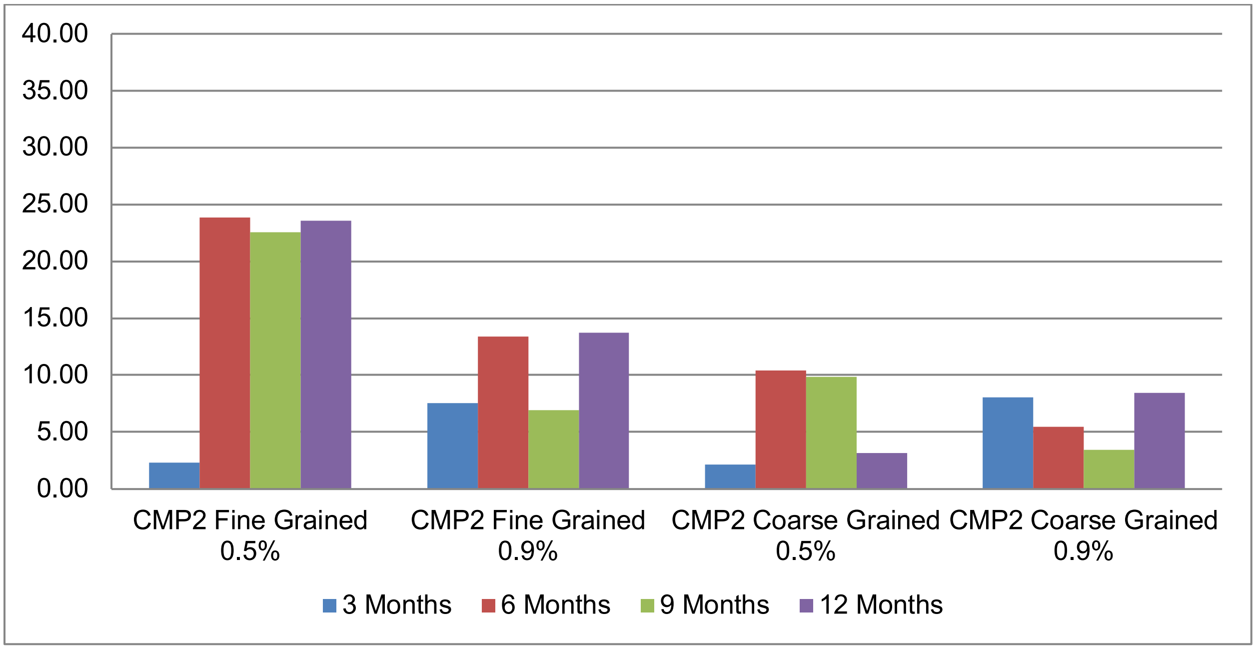

Figure 4. Percent of caked material of CMP2 treated salt.

Figure 5 shows the cumulative average of the degree of caking for each additive during the year-long trial. This demonstrates that YPS effectively reduced almost all caking and the CMP1 and CMP2 blends significantly reduced caking.

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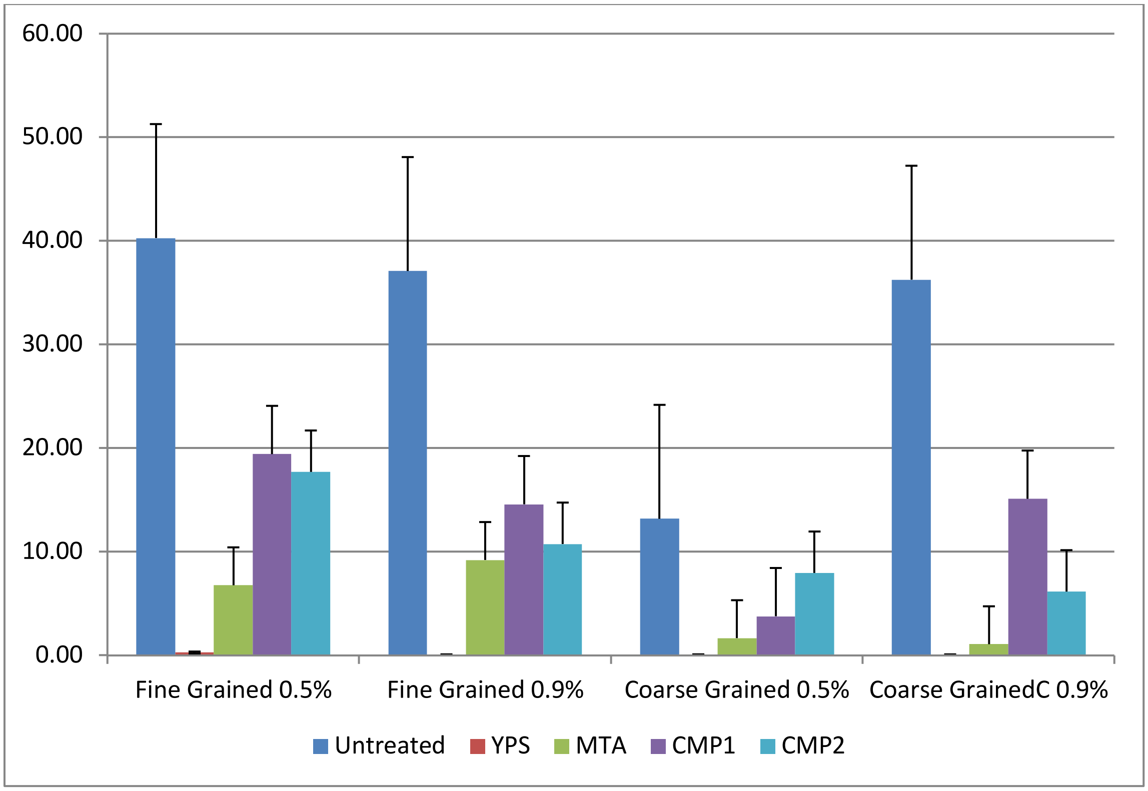

Figure 5. Cumulative average of the percent caking of all additives over the year trial.

Surprisingly caking did not occur linearly with time but instead most bags reach peak caking at the six month evaluation, and then consistently had reduced caking at the nine month interval. The 12 month evaluation saw caking levels rise again to close to the six month evaluation. It is unclear as to what may have caused these fluctuations but it is hypothesized that the extreme temperature fluctuation that occurs in the Chicago area could be an influencing factor.

Physical Influences on Caking

Salt was bagged at moisture levels of 0.5% and 0.9% moisture. Surprisingly the impact of moisture content was most pronounced with the untreated salt and had little impact on the salt treated with anti-caking additives (Figure 6). This is thought to be due to the process on which anti-caking additives function. Caking is directly related to how moisture interacts with salt, anti-caking agents work by altering the water-salt interaction, thereby reducing the impact that moisture has upon caking.

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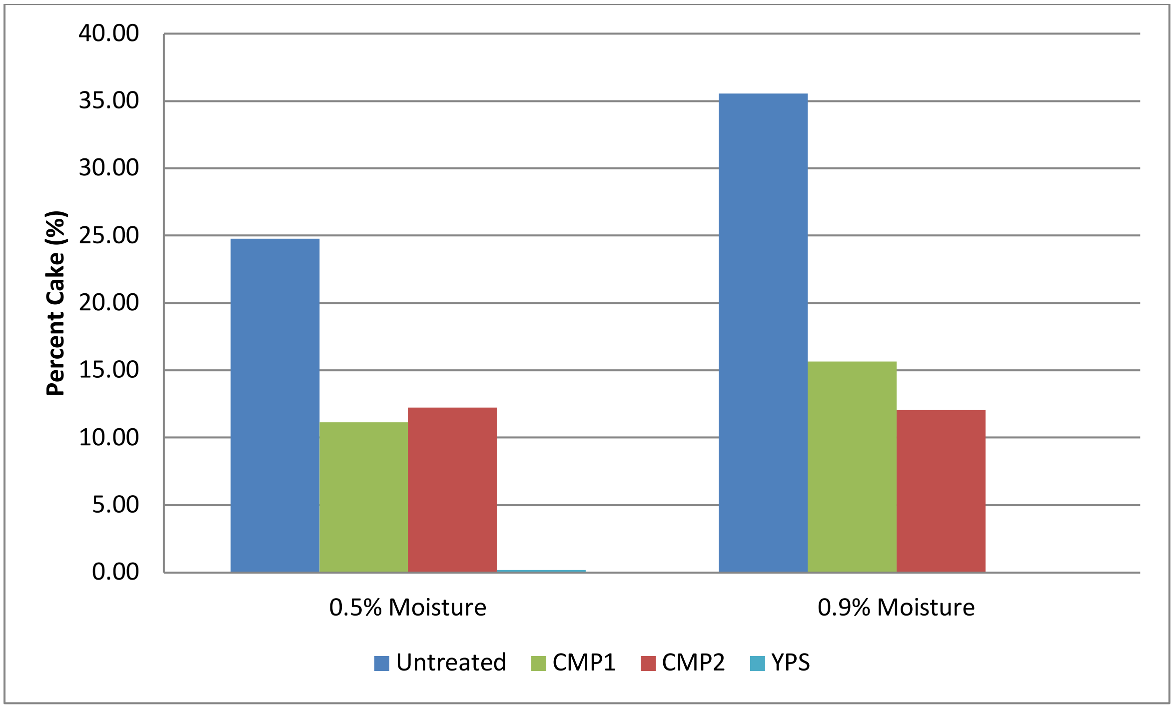

Figure 6. Impact of 0.5% vs 0.9% moisture on caking of bagged samples.

Salt was bagged in 25 and 50 lb. bags, and were compared in terms of the percent of caked salt (Figure 7). The 25 lb. bags were observed to have consistently higher levels of caking from 3-5%. It is unclear as to the reason why 25 lb. bags result in more caking, but it is thought that physical shape of the bag plays a role. It was observed that caked material was often present in the corners of the bags as they tapered and the ratio of space occupied by the tapered corners is larger in the 25 lb. verses the 50 lb. bags.

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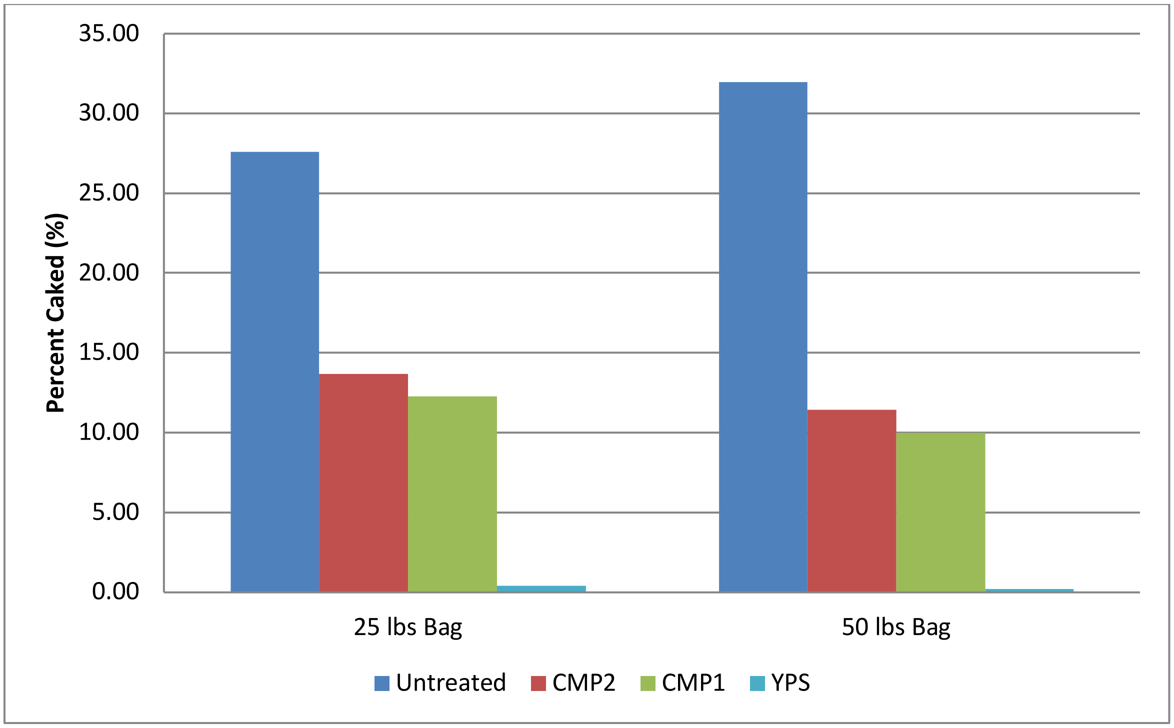

Figure 7. Impact of bag size on salt caking in 25 lb. and 50 lb. bags.

The grain size of the salt appeared to be the largest influencing physical factor in the caking of salt. The finer-grained salt had significantly more caking then the coarse-grained salt (Figure 8). This is thought to be due to the amount of surface area of individual salt grains that are in contact with other grains. The larger grain size would have a higher portion of pore space between the grains limiting the amount of welding that can occur between them.

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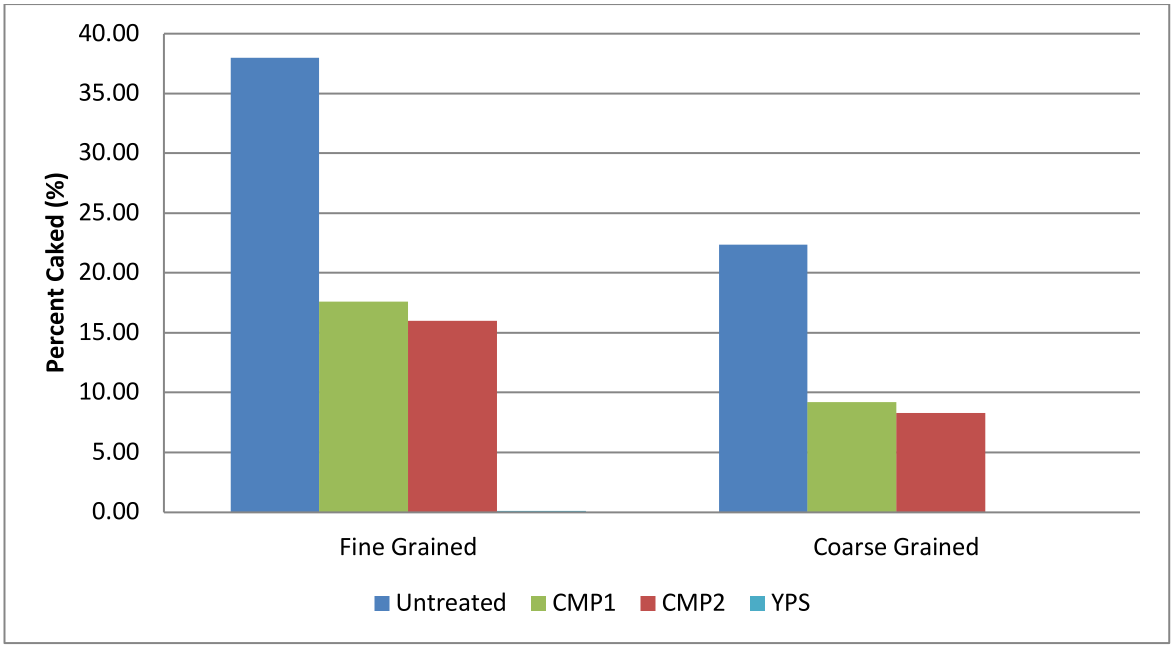

Figure 8. Impact of grain size on salt caking

Crystal Creep

Throughout the trial, the bags were examined to determine if crystal creep was occurring on the outside of the bags. Many of the YPS treated salt pallets had noticeable blue and yellow crystal development on the bag and pallets (Figure 9). This produced a messy and undesirable appearance. The untreated, CMP1 and CMP2 additives showed no signs of crystal creep throughout the length of the trial.

Figure 9. Messy and undesirable blue and yellow crystal creep from the YPS treated salt.

 geigerr@compassminerals.com phone 9133272402

Conclusion

The challenge of salt caking has been a reoccurring issue within the salt industry. Caked material results in reduced flowability, which negatively impacts how salt will dispense from a carton or a salt spreading truck. The industry has responded to these challenges by employing the use of anti-caking agents such as YPS. Although YPS is a very effective anti-caking additive there are associated environmental concerns. Additionally, YPS in salt is prone to crystal creep which negatively impacts the packaging aesthetics.

In response, the industry has identified a need to develop new, environmentally friendly anti-caking agents that do not negatively impact packaging aesthetics. The focus of this research was to test two newly developed anti-caking agents in a real world scenario that would include a large number of variables to better understand caking and how anti-caking agents work within these systems. Both newly developed anti-caking agents showed a significant reduction in caking when added to salt bags. More specifically the CMP1 additive showed a 55.47% total reduction and CMP2 59.70% total reduction in caking. The other variables demonstrated that there are many factors that ultimately influence caking of salt:

1. Moisture Content – The amount of caking in the salt increased with moisture in untreated salt but moisture did not affect treated salt.
2. Bag Size – 25 lb. bags were observed to have a greater degree of caking than the 50 lb. bags.
3. Grain Size – Coarser grained material was observed to have less caking than fine grained material. This was found to be the largest external factor that contributes to caking investigated in this study.
4. Climate fluctuations are thought to be related to the fluctuation in caking observed during the one-year trial.

Considering the numerous factors that salt will encounter between production, packaging and final use, this study makes an initial venture into quantifying the variables that produce caking in salt. Although limited in scope, this real world study has demonstrated that the two newly developed anti-caking agents CMP1 and CMP 2 hold promise and could potentially find practical use in applications where the drawbacks of YPS prevent its application.

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geigerr@compassminerals.com phone 9133272402