

An Experimental Study of Moisture Content for a Feed Mill Wet Bin

by

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Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in the

Mechanical Engineering

Program

YOUNGSTOWN STATE UNIVERSITY

August 2017

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ABSTRACT

As the world's population continues to grow, the demand for grain continues to increase. To keep up with this demand, proper drying and storage of grain is critical. Increasing the efficiency of these systems has been investigated, but there has been very little focus on the phenomena that occur inside a wet bin. If a profile could be created that would accurately predict the moisture content of grain as it leaves a wet bin and enters a grain dryer, there could be a significant increase in the optimization of grain dryer settings. This optimization might be able to eliminate over or under drying issues, and could save money throughout the process. This research investigated what effect a hopper bottom wet bin has on the moisture content of corn as it leaves the wet bin. The dominating phenomena that were seen were mixing and diffusion to air. Combining these results, gave a profile that accurately predicted the test setup's output moisture content. This research also considered the possibility of using a computational fluid dynamic (CFD) model to create this profile. The results from the CFD model were preliminary but showed great potential to generate an accurate profile.

ACKNOWLEDGEMENTS

The author would first like to thank her family for all of their support during this process. The long hours spent away from her children were hard, but her parents and in-laws were a tremendous help during this journey. The author would like to add a special thanks to her amazing husband. He not only helped support her through this whole process, but has always been a great source of inspiration. Without her husband's love of farming, the author would never have thought to pursue research into the agricultural industry.

The author would also like to thank her advisor, Dr. Choo, for being so understanding of her non-traditional circumstances. Dr. Choo and the other thesis committee members, Dr. Marie and Dr. Solomon, deserve a big thank you for all of the time they spent helping the author to complete her master's degree.

Finally, the author would like to extend a big thank you for all of the help she received with her CFD modeling. Without the help of her professor, Dr. Moldovan, and fellow graduate student, Tim Daugherty, an accurate model would never have been possible.

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CHAPTER 1 INTRODUCTION AND BACKGROUND

1.1 FEED MILLS

Feed mills are plants that take grain and other raw ingredients and process them into animal feed. Each feed mill often generates several different feed blends because each animal has different nutritional requirements. Also, some farmers require special blends. For example, an organic farm would have much different requirements than a non-organic farm. To get all of the different blends, all feed mills follow similar processes. They take the raw ingredients and process them into appropriate sizes through grinding or milling processes. Then the desired weights of each ingredient are measured out and everything is thoroughly mixed together to make a homogenous blend. Some feeds are then pelletized, but some are left loose. Finally it is packaged and ready for sale.

Producing animal feed is a year-round industry, but harvesting the grain that is required to produce animal feed is not. Depending on the weather in any particular area, the harvest season for some grains can be as short as a few weeks or as long as several months. So grain is often stored for several months before it's needed. Harvest season for some farms is also dependent on the availability of equipment or whether or not the field needs to be used for additional crops that year. These limitations cause crops to be harvested too early or too late. Harvesting crops when they are not at their driest can lead to the moisture content being as high as 20 to 30 percent moisture (Gursoy, Choudhary, & Watson, 2013). For the long-term storage, some grains need to be dried to as low as 9

percent moisture (depending on the grain and climate of that part of the world). Drying the grain to the desired moisture content can be a significant cost for many feed mills.

Farmers only have a few options to dry their grain after harvest. When feed mills have their own drying systems, the grain can be sold directly to the feed mills. If not, farmers can sell to grain elevators. Grain elevators dry, store, and re-sell the grain. Both feed mills and grain elevators deduct the cost of drying from the farmer's profits. If the farm is equipped with its own dryer, it can dry and store the grain themselves. Regardless of the setup the process is similar. Figure 1.1-1 shows a diagram of the typical drying process that can be found on a feed mill. After grain is harvested it is delivered directly from the field to the feed mill. Grain is typically delivered in gravity wagons, grain trucks, or grain trailers. Their typical capacities are 250 bushels, 500 bushels, and 1,000 bushels respectively. In some locations, grain can even be delivered via train cars which can deliver up to 1,000 bushels each. After the grain is delivered, it is temporarily held in a wet bin. Since several different farms can be delivering to a single feed mill, the load sizes, moisture contents, and delivery times can vary greatly from day to day. The wet bin is designed to hold grain only long enough to ensure that there will be a continuous stream of grain being sent to the grain dryer. Wet bin designs are chosen based on the layout of the feed mill and the capacity of its grain dryer. Some feed mills use flat bottom bins with side augers and others use gravity fed hopper bottom bins. Once the wet bin has enough grain available to ensure a continuous flow of grain to the grain dryer, the transfer process begins. The design and size of the grain dryer will dictate how

much grain is necessary before the grain dryer can be used. After the grain has been dried to its desired moisture content, it can be stored in grain bins until it is needed.

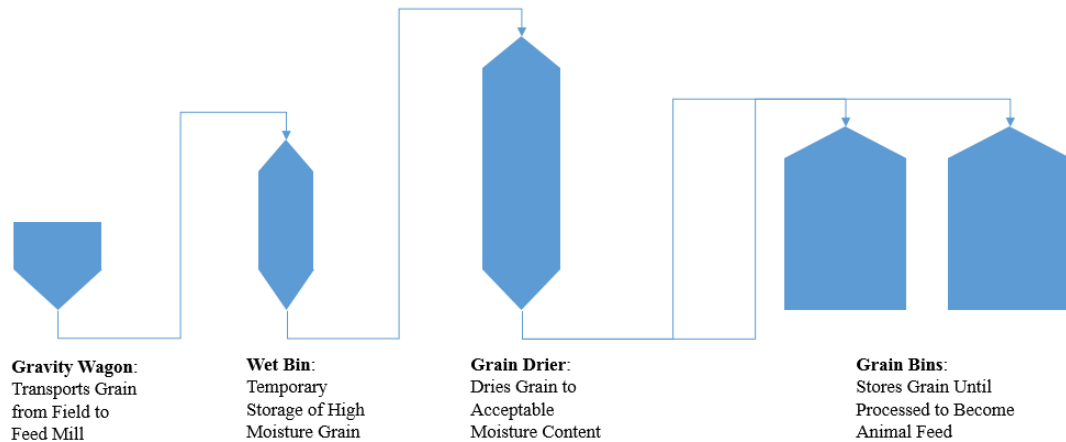


Figure 1.1-1: Typical Steps of the Drying Process at Feed Mills with In-House Drying Systems

1.2 CONTINUOUS FLOW GRAIN DRYERS

Acceptable moisture content is necessary for proper storage of grain. There are several methods available to dry grain. In climates where harvest seasons can be short, grain often gets harvested at much higher moisture content than what is ideal for storage. These high moisture contents require high temperature grain drying to reach the desired moisture for storage. To achieve this, the popularity for high capacity continuous flow grain dryers has continued to increase as the demand for grain increases around the world (Wehrspann, 1998).

There are several types of continuous flow grain dryers: cross flow dryers, counter-flow dryers, and mixed-flow dryers. Figure 1.2-1 and Figure 1.2-2 show examples of typical continuous flow grain dryers. Cross flow dryers can be found in horizontal or vertical designs. In both designs, the grain is gravity feed and the hot air flows perpendicular to the grain flow. In the counter-flow dryers, grain is again gravity feed, but the hot air is forced up through the grain from the bottom of the dryer. Finally, the mixed-flow dryers have multiple drying zones. So, the hot air flows both perpendicular and counter to the grain flow. (Wehrspann, 1998)

There are several advantages and disadvantages to each dryer type, but all continuous flow grain dryers face the same major challenges. The grain needs to be dried to acceptable levels without over drying or damaging the grain. Major grain dryer equipment manufacturers are currently researching the optimization of the drier process and advances are being made (Liu & Bakker-Arkema, 2001), but understanding the moisture content of the grain before it enters the drier can greatly help the process. Sensors that are currently being used in continuous flow grain dryers have several limitations. Build up can occur on the sensors which can affect their readings, and the feedback loops they feed into may not have fast enough response times. Even after the sensors detect an issue, the grain may have moved too far through the process for any changes to be effective. A better understanding of the moisture content of the grain as it flows into the dryer would help combat the sensor's limitations. (Bruce & McFarlane, 1993), (Nellist & Bruce, 1992)



Figure 1.2-1: Typical Vertical Cross-Flow Grain Dryer (Wehrspann, 1998)



Figure 1.2-2: Typical Horizontal Cross-Flow Grain Dryer (Wehrspann, 1998)

1.3 LONG TERM GRAIN STORAGE

There are two major concerns to consider when grain needs stored for several months. The first is the condition of the grain as it leaves the grain dryer and the second is maintaining the grain quality over long periods of time. When grain leaves a grain dryer, the moisture content should be ideal for storage, but often there are over or under drying issues. If grain is dried at too high of a temperature or is dried too quickly, stress cracks can occur. This can severely deteriorate the quality of the grain. If the grain is under dried, it may need to be sent through the drying process again. With typical feed mill setups, this would be a very difficult task. The grain would need to be manually rerouted, which would add unneeded time and cost to the process. If the high moisture content is not corrected before the grain is added to long term storage, spoilage can occur quickly. At large scale feed mills this could lead to the loss of thousands of bushels of grain. These potential issues require a robust drying system to ensure that a grain's moisture content is ideal for storage.

The second major concern seen in long-term grain storage is ensuring that the quality of the grain does not deteriorate. There has been a lot of research regarding this issue, but there is still not a one size fits all solution that works for all climates and all storage conditions. Studies have shown that after 2-3 months grain at the outer surface of a grain bin can be 10-40°F lower than grain at the center (Laws, 2008). This temperature gradient can lead to thick layers of mold forming at the top of bins. It also leads to ideal conditions for insect breeding. These insects can then eat the grain and reduce its quality

quickly. To combat this temperature increase at the center of grain bins, aeration systems are often used. Aeration systems force air through the grain to ensure that the temperature is low and uniform. When these systems are partnered with temperature monitoring technology, intermittent cooling can be done. This is much cheaper and more efficient than continuously running an aeration system. An example of an aeration system's effectiveness is seen in the storage of corn. When an aeration system is not in place, an ideal moisture content for shelled corn storage is 13 percent, and its quality typically begins to show significant deterioration after only six months. When an aeration system is in place, the corn only needs to be dried to 15.5 percent and the quality can be maintained for much longer (Laws, 2008)

1.4 PURPOSE AND SCOPE

The purpose of this research is to understand the phenomena that effect the moisture content of grain as it leaves a hopper bottom wet bin and enters a grain drier. There has been very little research done on these phenomena. Research into the grain drying and storage process has focused primarily on the stresses in grain bins, technology advances in in-line grain dryer sensors, or issues that occur during grain storage. With a better understanding of the moisture content of grain as it enters a grain dryer, there is a potential to have a significant impact on the efficiency of the dryer. There is no current industry standard for parameter optimization of a grain dryer. Most feed mills, grain elevators, and farmers use past practice to establish parameter settings. If a profile could be created that could accurately predict the moisture content of grain as it leaves a wet

bin, dryer parameter settings would no longer need to be determined through trial and error.

The scope of this research was limited to a small scale dryer setup. The larger the process setup, the easier it would be for the process to absorb losses due to inefficiency in the drying process. Therefore, changes to practices at small scale setups could have a much greater overall impact. The research investigated a setup with a 12 ft. diameter hopper bottom wet bin with a capacity of approximately 1,500 bushels. All of the load sizes were limited to standard gravity wagon size, 250 bushels. The trials investigated a range of moisture contents between 10 and 30 percent.

CHAPTER 2 EXPERIMENTAL APPROACH

2.1 EQUIPMENT LIST

The test setup was scaled from equipment that could be found at a typical small scale feed mill that had an internal drying process. Below is a list of equipment chosen;

- Wet Bin: Sukup's 12 ft. diameter 45° hopper bottom medium duty bin with 1,492 bushel capacity. Figure 2.1-1 shows size specification.
- Gravity Wagon: J&M's 250-7SB gravity wagon with 250 bushel capacity. Figure 2.1-2 shows size specifications.
- Moisture Tester: Dickey-John's Mini GAC moisture analyzer. Shown in Figure 2.1-3.

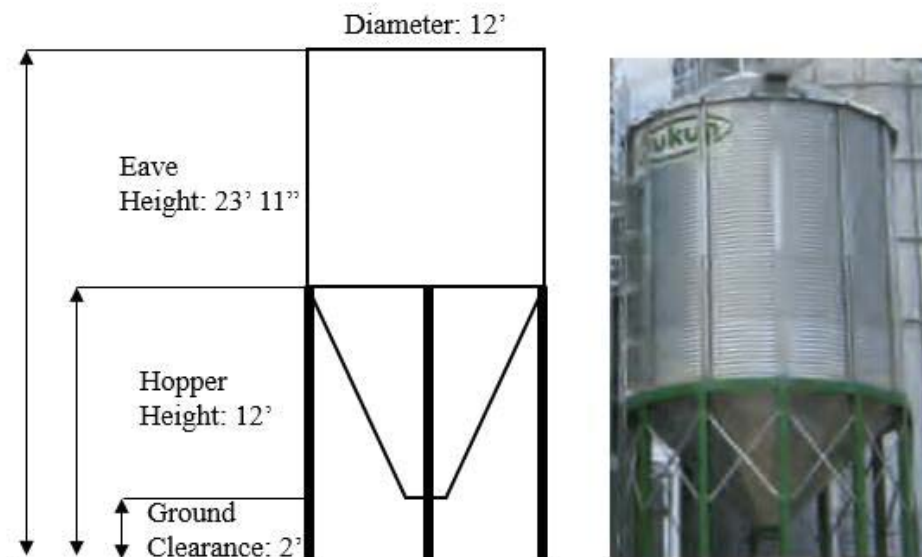


Figure 2.1-1: Sukup's Medium Duty Hopper Bottom Bin Dimensions, 12' diameter, 1492 bushel capacity, (Sukup Grain Bins, 2017)

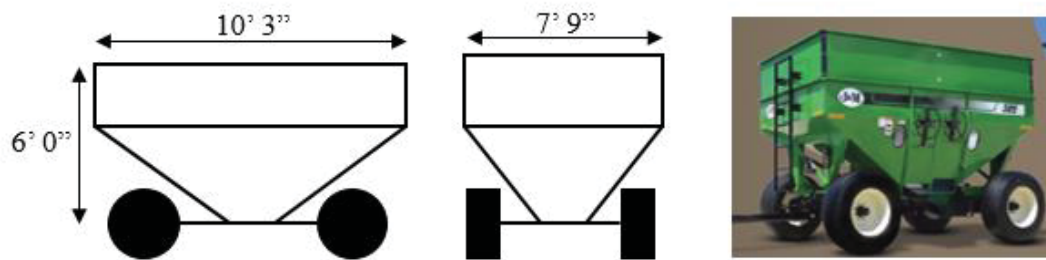


Figure 2.1-2: J&M's 250-7SB Gravity Wagon, 250 bushel capacity, (J&M Gravity Wagons, 2017)



Figure 2.1-3: Dickey-John's Mini GAC Grain Moisture Analyzer, (Mini GAC and Mini GAC Plus Operator's Manual, 2017)

2.2 TEST SETUP

The experimental test setup for this research was a 1/16th scale version of the Sukup's 12' diameter, 1,492 bushel capacity hopper bottom bin, shown in Figure 2.1-2. Although typical grain bin construction is made of aluminum and steel, this test setup used translucent polycarbonate sheets. The plastic did not provide the rigidity that metal provides. To ensure that the plastic kept the proper dimensions, a stiffener was added to the seam and brackets were added for wall stiffening. The dimensions of the experimental scale wet bin can be seen in Figure 2.2-1. Although using plastic did not give an exact replication of the full scale wet bin, it did allow for visual observations of the grain. This was critical because observing grain in a wet bin can be a deadly process. Figure 2.2-2 shows how a person can be completely covered by grain in less than 30 seconds, if the grain is flowing in a grain bin.

Each trial represented three grain loads. Each load size represented a 1/16th scale of J&M's 250-7SB gravity wagon shown in Figure 2.1-2. This gravity wagon's capacity is 250 bushel (8,810 liters). A graduated cylinder was used to accurately measure each 1/16th scale load to 2.15 liters. The grain used in all of the trials was shelled feed corn, which was harvested from the previous year's crop. All of the moisture content results were measured by Dickey-John's mini GAC moisture tester, which only had calibrations for full scale corn. So the corn itself was not scaled for this research.

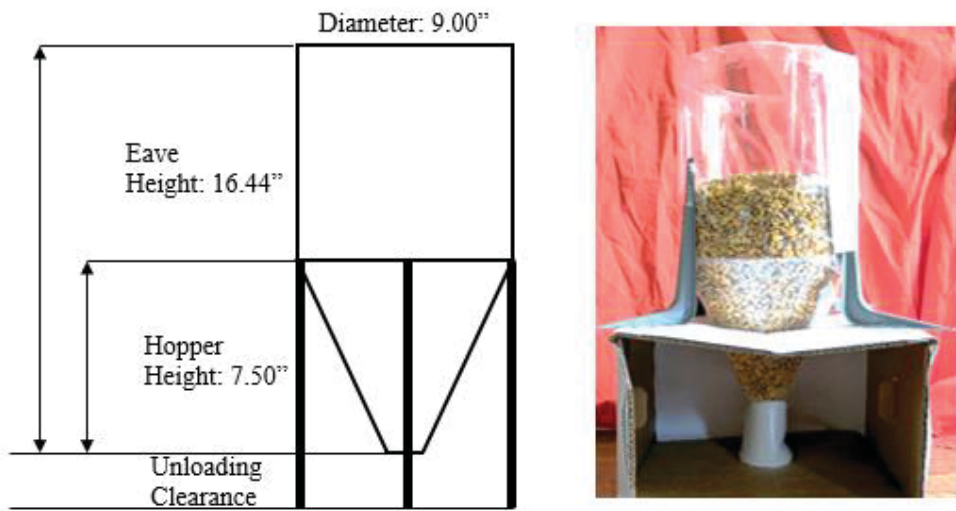


Figure 2.2-1: Experimental Test Setup, Wet Bin

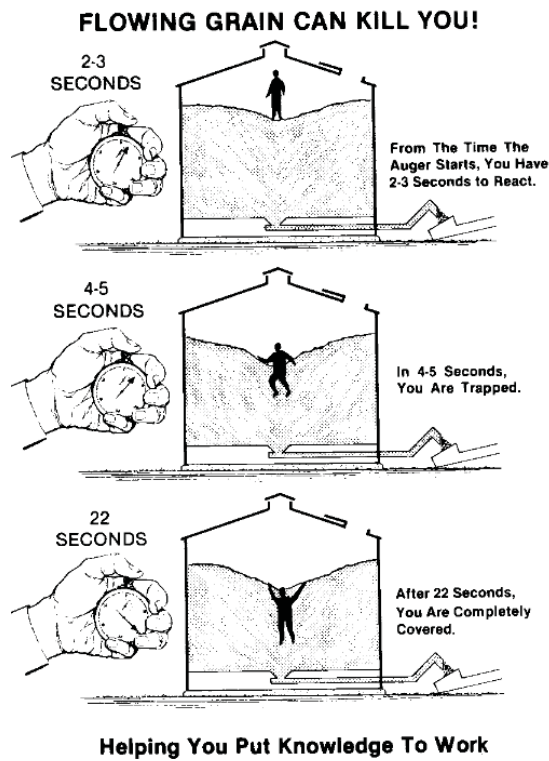


Figure 2.2-2: Cartoon Depicting the Potential Hazards of Being in A Grain Bin When Grain is Flowing (Hellevang, 1983)

2.3 MOSITURE TESTER

The mini GAC moisture tester made by Dickey-John, was used for all of the moisture readings. This grain tester is a hand held unit that can quickly and accurately test the moisture content of a grain sample anywhere, including in the field. Dickey-John has over 450 load calibrations available for download. The mini GAC can be loaded with up to 20 calibrations at a time. For this research, their corn and corn high calibrations were used. This analyzer has an internal scale and temperature reader so the instrument can automatically compensate for sample temperature. It requires approximately 470 mL of grain for each test. The mini GAC can measure moisture content between 5 and 45 percent with an accuracy of 0.2 percent (Mini GAC and Mini GAC Plus Operator's Manual, 2017).

Proper operation of the mini GAC moisture tester requires that the load cell is empty and clean prior to each test. Once the unit is turned on, the grain of interest needs to be selected. An empty cell test then needs to be performed before adding any grain for testing. The provided loader cup then needs to be filled to the minimum fill line and placed on the top of the load cell. The slide is then pulled and the load cell is filled. The loader cup is then used to strike the grain to keep a consistent volume with each test. After pressing enter, the moisture content is measured. Figure 2.3-1 shows these steps. The load cell uses the pre-loaded calibrations to determine the moisture content based on the volume and weight of the grain.



Figure 2.3-1: Mini GAC Moisture Tester Procedure

2.4 MOISTURE CONTENT TEST PROCEDURE

The grain used for this research was shelled feed corn. After harvest, it had been dried and stored. To get the desired moisture content for this research, it needed to be rehydrated. Each trial needed three moisture contents. The lowest moisture content used was the corn in its dried condition, approximately 12 percent, to represent a very dry harvest. The medium moisture content used was approximately 18.5 percent, to represent a typical harvest. To reach this, the corn needed to be hydrated in a bath of water for a minimum of 6 hours. The corn was then laid in a thin layer on absorbent material for at least 30 minutes to remove the surface water. The highest moisture content used was approximately 28 percent, to represent an exceptionally wet harvest. To reach this, the corn needed to be hydrated in a bath of water for a minimum of 20 hours. It was then laid in a thin layer on absorbent material for at least 30 minutes to remove the surface water. (Tirawanichakul, Prachayawarakorn, Varanyanond, & Soponronnarit, 2004)

A low, medium, and high moisture content load was measured for each trial. The volume of each load was 1/16th scale of a 250 bushel capacity gravity wagon, 2.15 liters. The mini GAC moisture analyzer was used to measure the moisture content of each load before it was added to the wet bin. The wet bin was centrally filled from the top by gravity. As the corn was being poured, a visual inspection was done to ensure the corn was piling as expected in the center of the bin. Figure 2.4-1 shows the loads being added to the wet bin.

After the last load was added to the wet bin, the corn was allowed to sit for thirty minutes before being unloaded. This time represented the typical time required to get the grain dryer started at a small scale feed mill. The wet bin was then unloaded in increments. Each increment was only enough corn to fill the mini GAC moisture tester, approximately 470 ml. The moisture content of each unloaded sample was taken and recorded until the bin was empty. Figure 2.4-2 shows the wet bin being emptied.

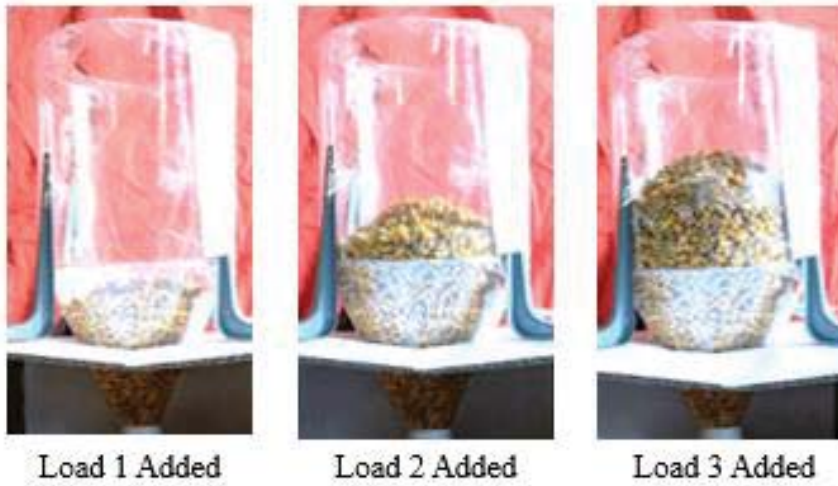


Figure 2.4-1: Filling the Test Setup Wet Bin During the Moisture Content Trials

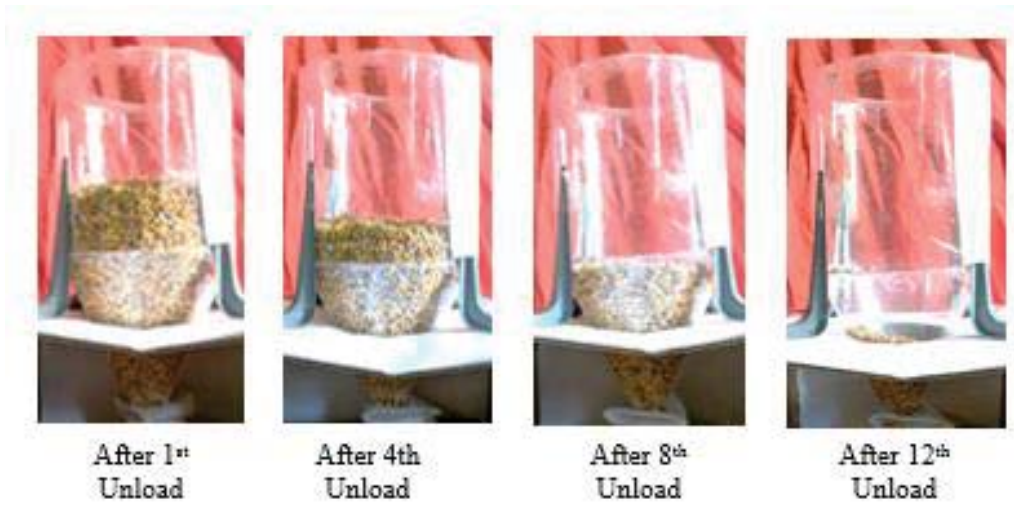


Figure 2.4-2: Unloading the Test Setup Wet Bin During the Moisture Content Trials

2.5 DYE TEST PROCEDURE

The same shelled feed corn that was used during the moisture content trials was dyed. The corn was allowed to soak in water that contained food coloring for 24 hours. The corn was then dried for 2 hours to remove any wet food coloring on the surface of the corn. The load sizes match the sizes used in the moisture content tests, 2.15 liters, which represented a 1/16th scale of a 250 bushel capacity gravity wagon. This test did not have any moisture content results, instead the percentage of each load was being investigated. So each load had been dyed a different color.

During the filling of the wet bin, each load was centrally gravity feed from the top of the bin. During the filling process, a visual inspection was done to ensure that the corn was piling in the same manner that it had during the moisture content trials. Figure 2.4-3 shows the filling process.

After the filling was complete, there was no need for the corn to sit thirty minutes because the effect of diffusion was not being factored into these trials. The unloading of the wet bin was gravity feed from the bottom of the bin. It was done incrementally to match the volume of the moisture content readings. Each increment was approximately 470 ml. The unloading process is shown in Figure 2.4-4. After unloading was complete, each unload increment was separated by color and the number of corn kernels were counted. The percentage of each load that was found in each increment was recorded.



Figure 2.4-3: Filling the Test Setup Wet Bin During the Dye Test

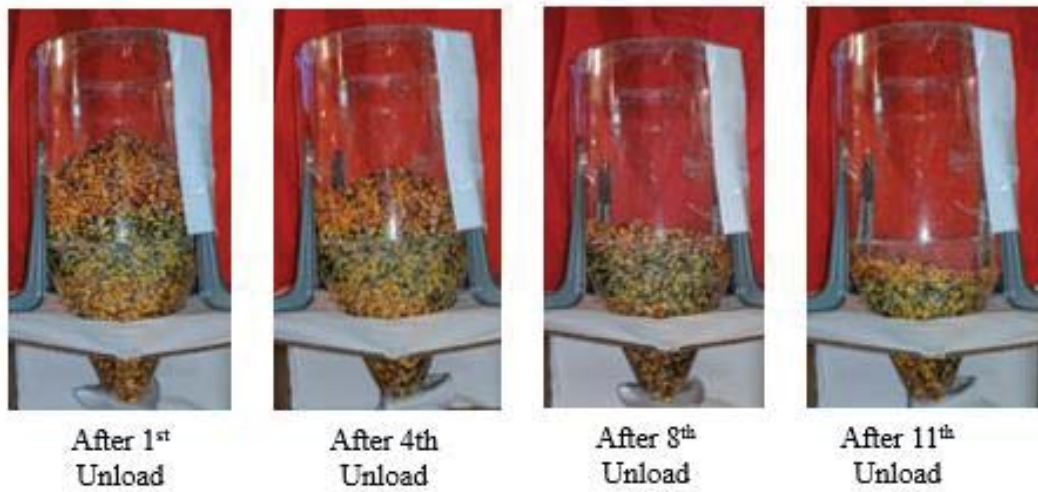


Figure 2.4-4: Unloading the Test Setup Wet Bin During the Dye Test

2.6 SINGLE LOAD DIFFUSION TEST PROCEDURE

The moisture content testing investigated the moisture content after three loads had been added to then unload from a hopper bottom wet bin. Using similar procedures, testing was done on a single load. The test was repeated with the low, medium, and high moisture contents mentioned in section 2.4. The same moisture content values and rehydration procedures were used. After the volume of a single load was measured, 2.15 liters. The moisture content of the load was measured before it was added to the test setup wet bin. It was then centrally gravity fed from the top of the bin. The same thirty minute wait observed in the moisture content test was observed in this single load diffusion test. The test setup was unloaded in increments of approximately 470ml. Each increment's moisture content was tested and an average change in moisture was determined for each of the three tested moisture contents.

CHAPTER 3 NUMERICAL APPROACH

3.1 PROGRAM SELECTION

Creating a numerical model for the phenomena that occurred in a wet bin posed some interesting challenges. Since there was very little research in this field, a broader study into computational fluid dynamic (CFD) modeling of agricultural processes was done. Applicable research focused primarily on the stresses seen in the bin walls during various load conditions. For this research, the numerical model needed to focus primarily on the properties of the grain, instead of the properties of the bin. The research showed that modeling the corn as a fluid instead of a solid was a viable option, and that ANSYS Fluent's volume of fluid model could do that. To create a mesh that could accommodate the test setup's geometry and was compatible with Fluent, ANSYS ICEM was used. The model was setup to replicate the results of the dye test.

3.2 GEOMETRY

The geometry that was used for the CFD model assumed an ideal filling of the dye test. The bin dimensions matched the dimensions of the 1/16th scale test setup, which are shown in Figure 2.2-1. Figure 3.2-1 shows a simulation of the model geometry generated in SolidWorks compared to the experimental test setup after all three loads were added in the dye test. Running 3D geometry can often be very time consuming and may take a lot of computing power. Fluent is capable of analyzing axis symmetric models, and because

the geometry was assumed to be an ideal filling case, it was axis symmetric. The only limitation that Fluent imposed was that the axis of symmetry needed to be along the x-axis. The geometry was then rotated to have the bin's centerline along the x-axis.

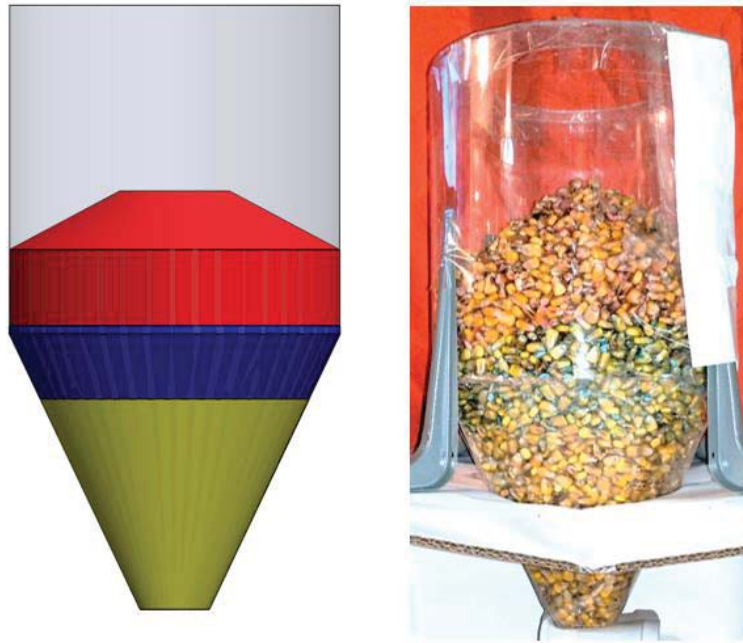


Figure 3.2-1: Left: SolidWorks Rendering of the CFD Model Geometry, Right: Experimental Test Setup After Dye Test Filling Was Complete

3.3 MESH

The mesh was generated in ICEM. To create the 2-D geometry needed for this mesh in ICEM, points need to be generated at all necessary locations, then lines drawn to connect them, and finally surfaces generated from the lines. For this research, the geometry did not just include the bin walls. It also needed to include lines segregating all three loads. After the geometry was correct, a 2-D planer block was added and was split to create a separate block for each load of corn as well as the remaining space filled by air in the bin. The blocks were then associated to the geometry and pre-mesh parameters were applied. All of the different geometries and blocks were then labeled. Figure 3.3-1 shows how each of the loads were separated in the mesh. After the mesh was inspected to ensure it had acceptable elements, it needed to be converted into an unstructured mesh. Boundary conditions were then applied to all of the mesh and geometry components. Since Fluent was used for the simulation, the Fluent solver needed to be coded to the mesh so it could properly import.

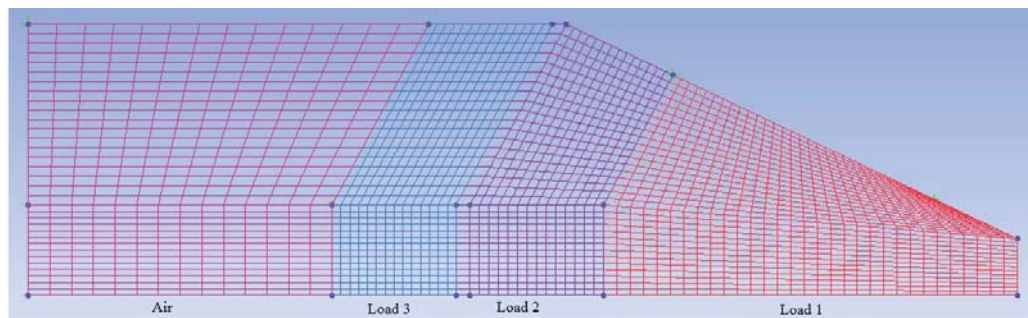


Figure 3.3-1: CFD Model Mesh with Loads Segregated

3.4 SIMULATION PARAMETERS

After importing the mesh into Fluent, the parameters for the simulation were defined. The goal of the simulation was to get the volume fraction of each load as it exited the bottom of the wet bin, so the simulation was setup as transient. The unloading was also done by gravity, so gravity needed to be turned on and defined to be parallel to the axis of symmetry. The models used were viscous-laminar and multiphase-volume of fluid. Four phases were applied to the simulation. The primary phase, Phase 1, was defined as Fluent's default parameters for air and Phase 2, 3 and 4 were defined as a newly created fluid material of "corn".

The corn material was defined as a fluid, not a solid, so its density and viscosity needed to be determined. The density of shelled corn is defined to be 56lb per bushel when the moisture content is at 16 percent. Instead of using this conversion, the density of the corn used in this research was determined experimentally to be an average of 705 kg/m^3 . This was only a 2 percent difference from the calculated density. The viscosity was assumed after the flow behaviors of corn were compared to other know fluids. These observations gave an original viscosity of approximately 100 kg/(ms) . After completing the simulation, the unloading profile was reviewed. It did not match the experimental profiles seen in the dye test. The simulation was then re-run with the viscosity varied between 0.5 kg/(ms) and 500 kg/(ms) , and the profiles examined. It was determined that a viscosity of 10 kg/(ms) gave the most accurate results.

It was necessary to apply boundary conditions that would simulate the experimental dye test. The top of the bin was split into two boundary conditions, inlet-vent and pressure outlet. This allowed for air to move freely in and out of the bin without generating additional pressure or a potential vacuum as the corn unloaded. The outlet of the bin was set as a mass-flow-inlet. The wet bin walls were set as stationary walls with no slip. Finally, the axis of symmetry was defined to be the center line of the wet bin.

A standard initialization was done before the calculations began. The gauge pressure was set to 0 pa, the axial velocity was set at 0.1 m/sec, and the radial velocity was set at 0 m/s. Each load area was set to be 100 percent of their respective phases. The simulation was then run until the wet bin was emptied.

3.5 CONVERGENCE TESTING

During a CFD simulation, the mesh size can affect the accuracy of the desired results. To ensure the results are accurate, a grid convergence test can be performed. The mesh size can be modified in ICEM to generate a mesh with more and less mesh elements. These additional meshes were then run with the same parameters as the original mesh and the results were compared. To determine if the results were accurate, the time it took for each additional load to reach the outlet of the wet bin was compared. The grid convergence test results can be seen in Table 3.5-1.

The time step size can also affect the accuracy of CFD simulation results. So, a time convergence test was also performed. The size of the time step was both increased and decreased and the simulation was re-run using the baseline mesh. To determine if the results were accurate, the time it took for each additional load to reach the outlet of the wet bin was again compared. The time step convergence test results can be seen in Table 3.5-2.

Table 3.5-1: Results of CFD Simulation Grid Convergence Test

	Grid Convergence: Max % Error
Mesh Elements: 1,542	0.99%
Mesh Elements: 2,862	Base
Mesh Elements: 5,180	0.00%

Table 3.5-2: Results of CFD Simulation Time Convergence Test

	Time Convergence: Max % Error
Time Step: 0.0003 sec.	0.49%
Time Step: 0.0005 sec.	Base
Time Step: 0.00075 sec.	0.94%

CHAPTER 4 RESULTS AND DISCUSSION

4.1 MOISTURE CONTENT TEST RESULTS

There were four different loading cases reviewed in this research. Each case varied the filling order of the different moisture content loads. The detail of the order of each case is shown in Table 4.1-1. The moisture content data collected during the unloading of each trial is shown in Figure 4.1-1 to Figure 4.1-4. The figures have the trials grouped by case. For reference, each figure shows the moisture content and order of each load during the filling process for that case.

Multiple trials were performed for each load case. There were some outliers seen in the test results. For example, trial 6 which tested case 2 has an outlier at unload increment #2. Even with the outliers, it appears that the profile seen from each case was consistent.

The two simplest profiles that can be assumed for the moisture content of the grain as it leaves a hopper bottom wet bin, would be either a fully segregated profile or a fully homogenous profile. If the fully segregated profile was true, the results from the moisture content tests would all overlay the grey moisture content reference lines on each graph. If the fully homogenous profile was true, the results would all equal the average moisture content of 19.5 percent, regardless of the case being tested. It can easily be seen in the graphs, that neither of these profiles are accurate. If either of these profiles were assumed at a feed mill, there would be both over dried and under dried corn entering the

long-term storage grain bins. To determine an accurate profile that can be used for the prediction of the moisture content as it exits the wet bin, additional investigation needed to be done.

Table 4.1-1: Moisture Content Detail of Each Filling Load for All Cases

	Load 1	Load 2	Load 3
Case 1	Low: ~12% m.c.	Medium: ~18.5% m.c.	High: ~28% m.c.
Case 2	Low: ~12% m.c.	High: ~28% m.c.	Medium: ~18.5% m.c.
Case 3	High: ~28% m.c.	Medium: ~18.5% m.c.	Low: ~12% m.c.
Case 4	Medium: ~18.5% m.c.	Low: ~12% m.c.	High: ~28% m.c.

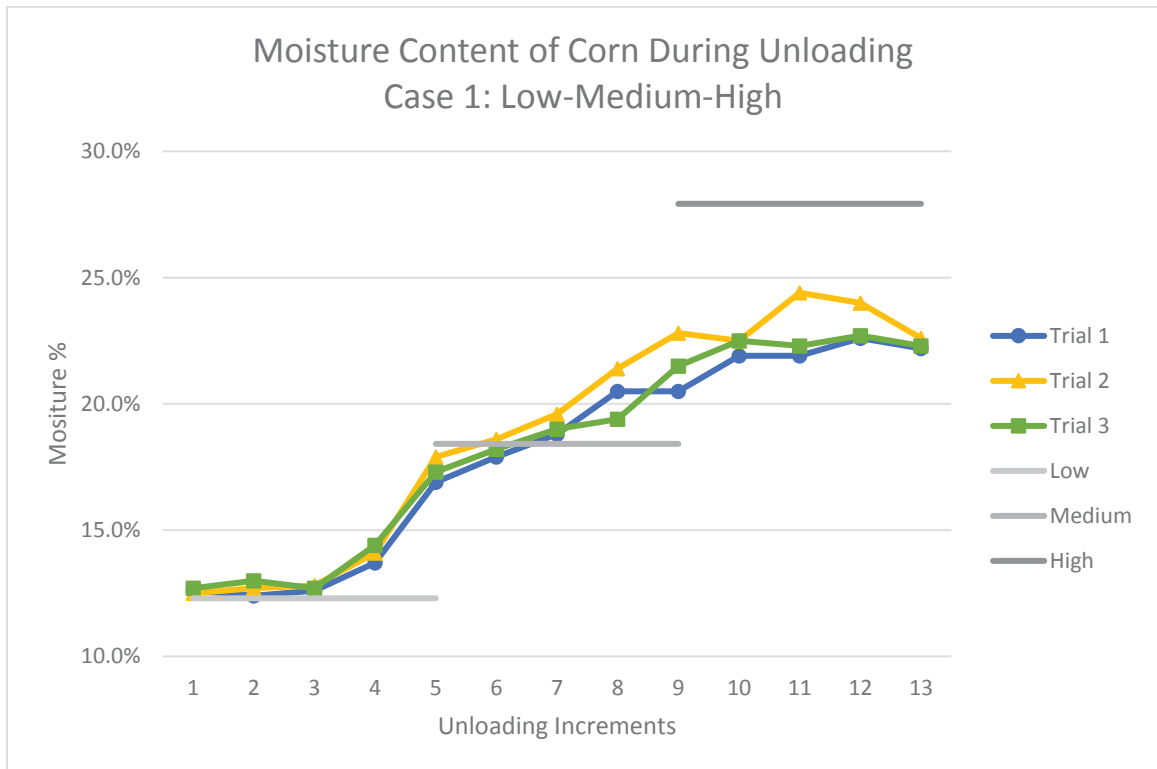


Figure 4.1-1: Moisture Content Readings for Case 1: Load 1-Low Moisture Content, Load 2-Medium Moisture Content, and Load 3-High Moisture Content

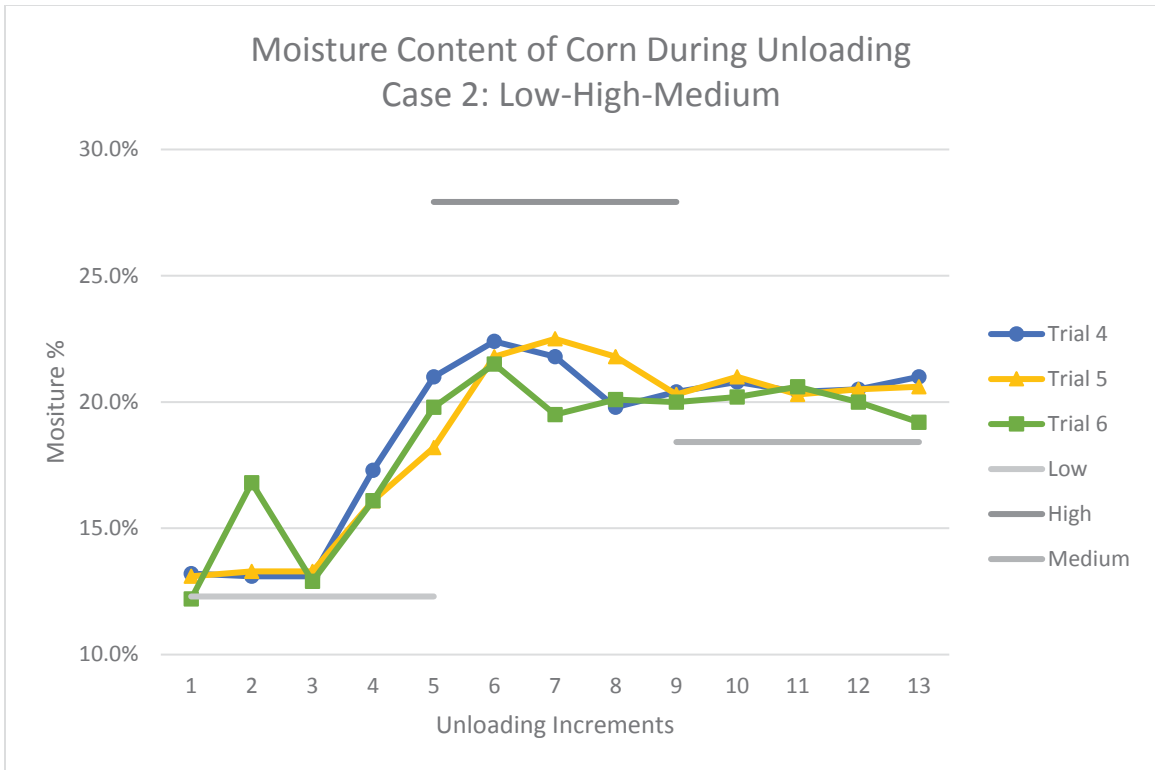


Figure 4.1-2: Moisture Content Readings for Case 1: Load 1-Low Moisture Content, Load 2-High Moisture Content, and Load 3-Medium Moisture Content

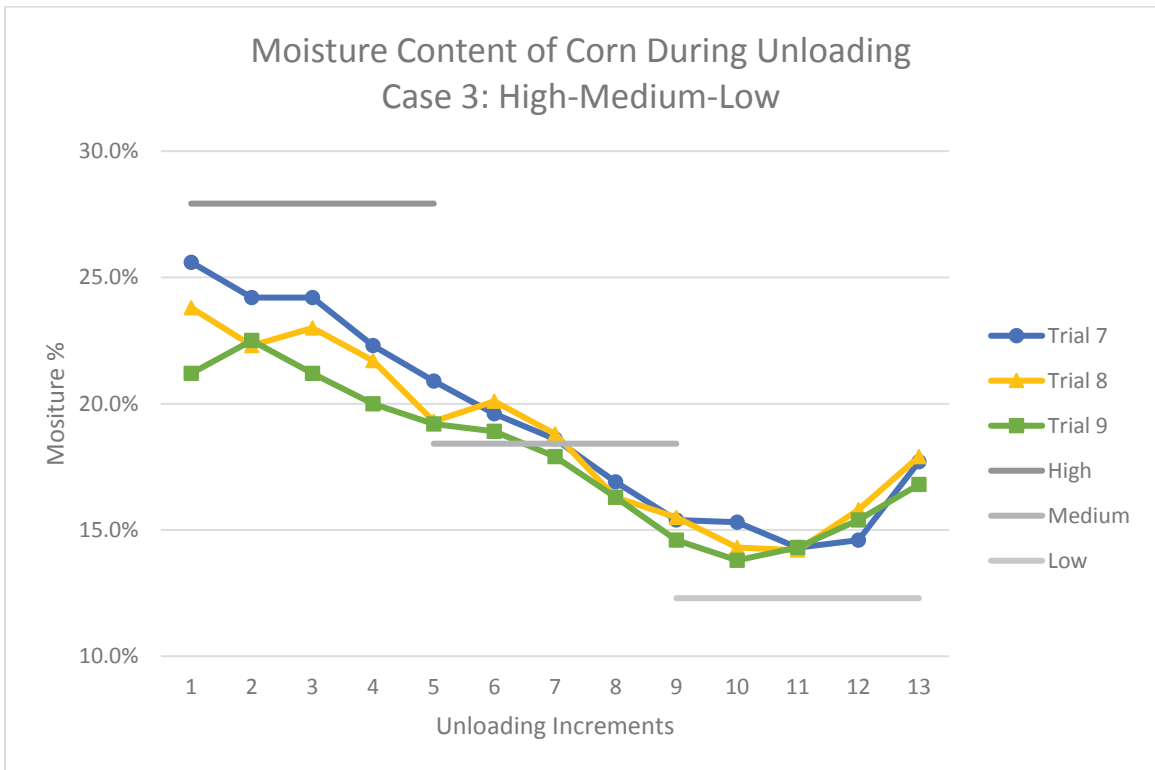


Figure 4.1-3: Moisture Content Readings for Case 1: Load 1-High Moisture Content, Load 2-Medium Moisture Content, and Load 3-Low Moisture Content

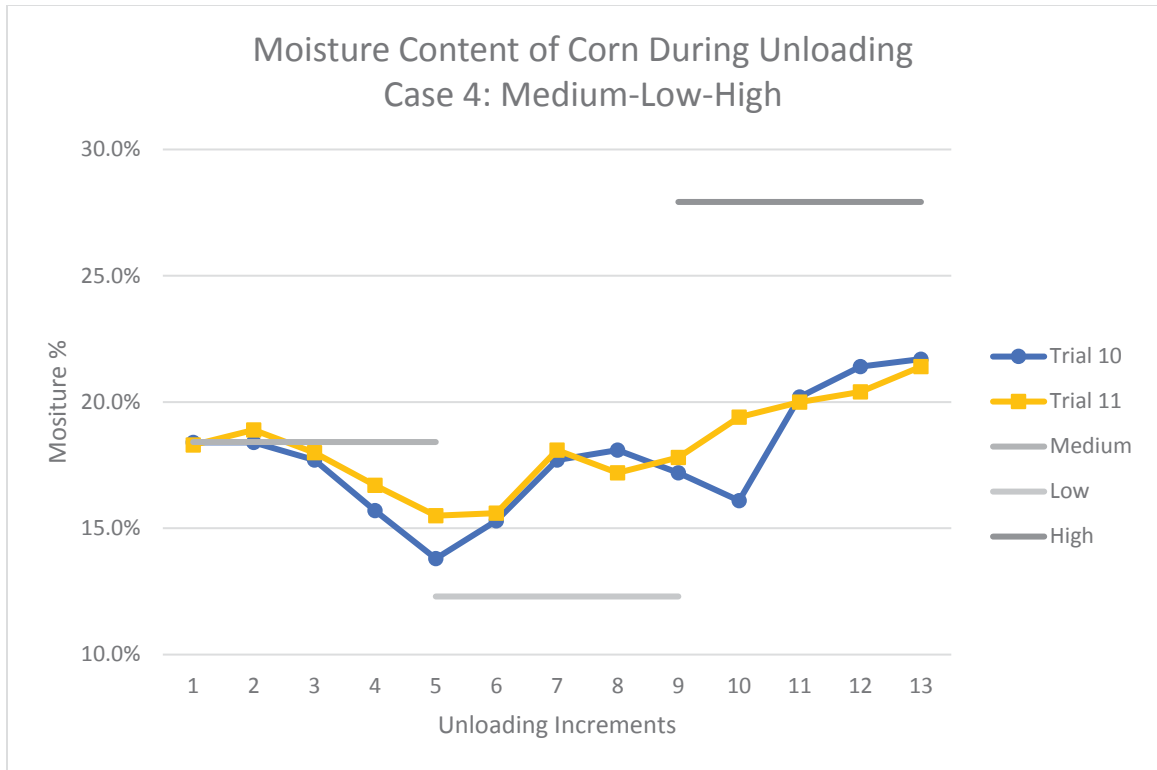


Figure 4.1-4: Moisture Content Readings for Case 1: Load 1-Medium Moisture Content, Load 2-Low Moisture Content, and Load 3-High Moisture Content

4.2 DYE TEST RESULTS

The percentage of each load, or volume fraction, was determined for each of the unload increments. The results are shown in Table 4.2-1. To determine if these results would create an accurate profile, the moisture content that was recorded for each load before it entered the wet bin was applied to the dye test results. These predicted moisture content results versus the actual moisture content results are shown in Figure 4.2-1 to Figure 4.2-4.

If load mixing had been the only phenomenon to affect the moisture content of corn as it left a hopper bottom grain bin, the predicted results and actual results would be a match. It can easily be seen in the figures that this is not 100 percent true. The results are trending in similar directions, but the values do not always match. If a feed mill were to use this profile instead of assuming a fully homogenous or fully segregated profile, the efficiency of their grain drier may not be significantly impacted. There would still be some under dried and some over dried grain entering the long term storage grain bins. To improve this profile, there needed to be an investigation into an additional phenomenon.

Table 4.2-1: Load Percentage Results of Dye Test

Unload Increment	Load 1: Yellow	Load 2: Blue	Load 3: Red
1	100.0%	0.0%	0.0%
2	99.9%	0.1%	0.0%
3	91.1%	8.9%	0.0%
4	49.0%	51.0%	0.0%
5	25.1%	74.9%	0.0%
6	15.5%	66.6%	17.8%
7	1.4%	53.3%	45.3%
8	2.3%	37.0%	60.7%
9	0.1%	34.5%	65.4%
10	0.0%	28.7%	71.3%
11	0.4%	17.8%	81.9%
12	0.6%	28.0%	71.4%
13	0.3%	42.6%	57.1%

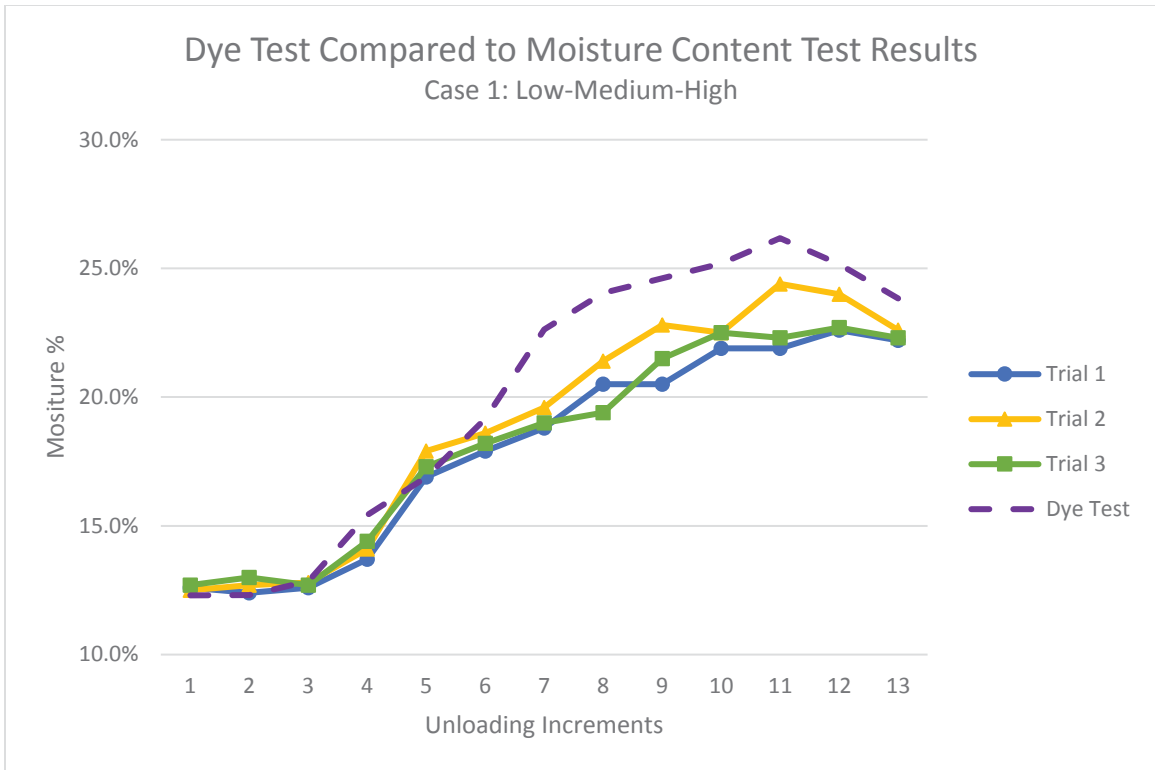


Figure 4.2-1: Dye Test Results Compared to Moisture Content Test Results: Case 1

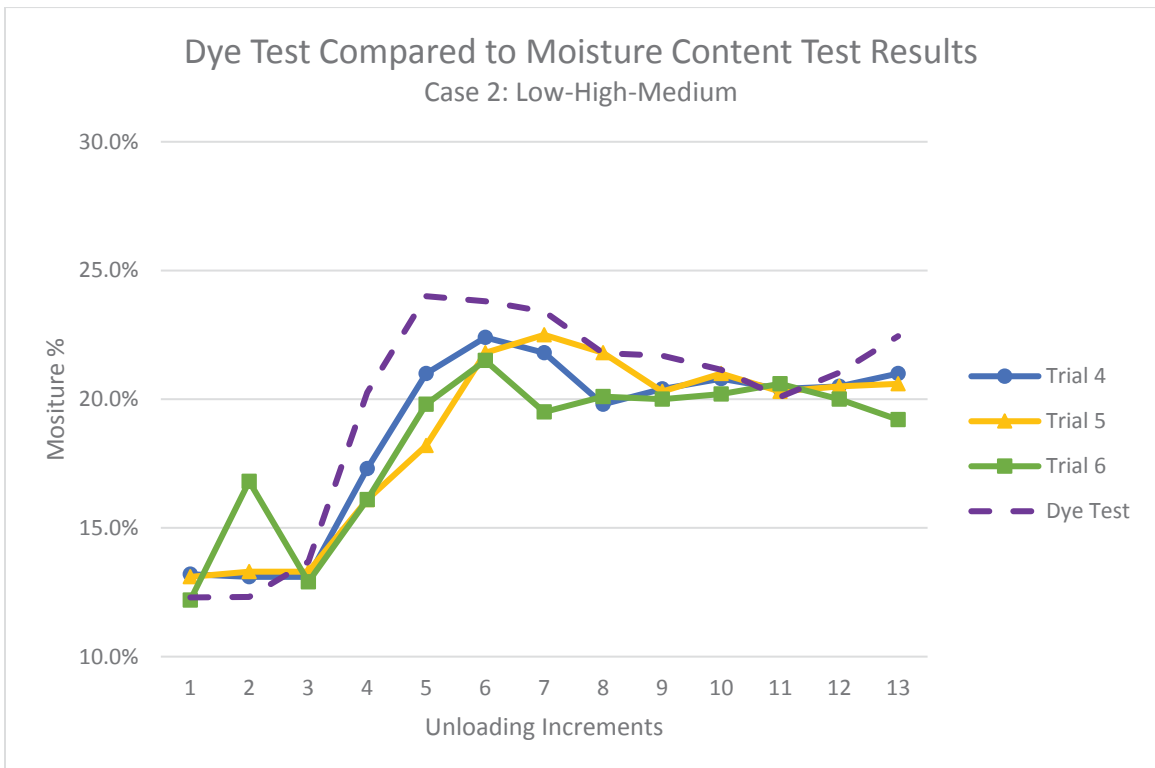


Figure 4.2-2: Dye Test Results Compared to Moisture Content Test Results: Case 2

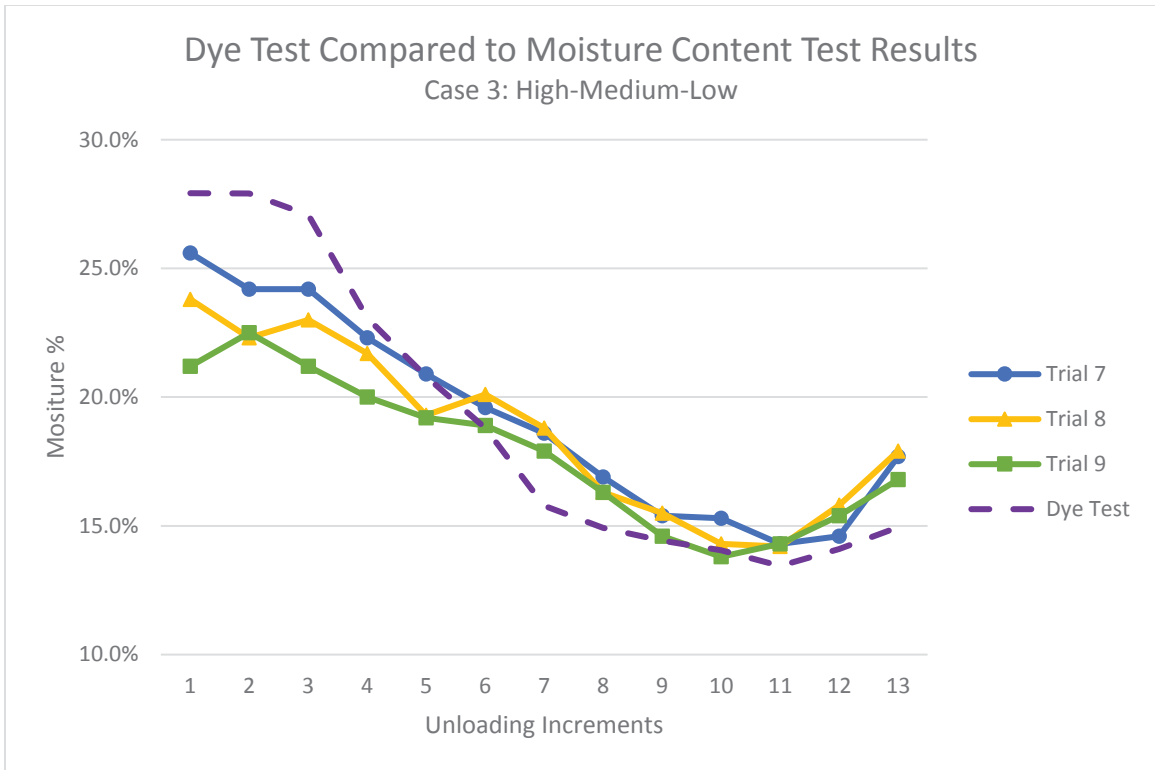


Figure 4.2-3: Dye Test Results Compared to Moisture Content Test Results: Case 3

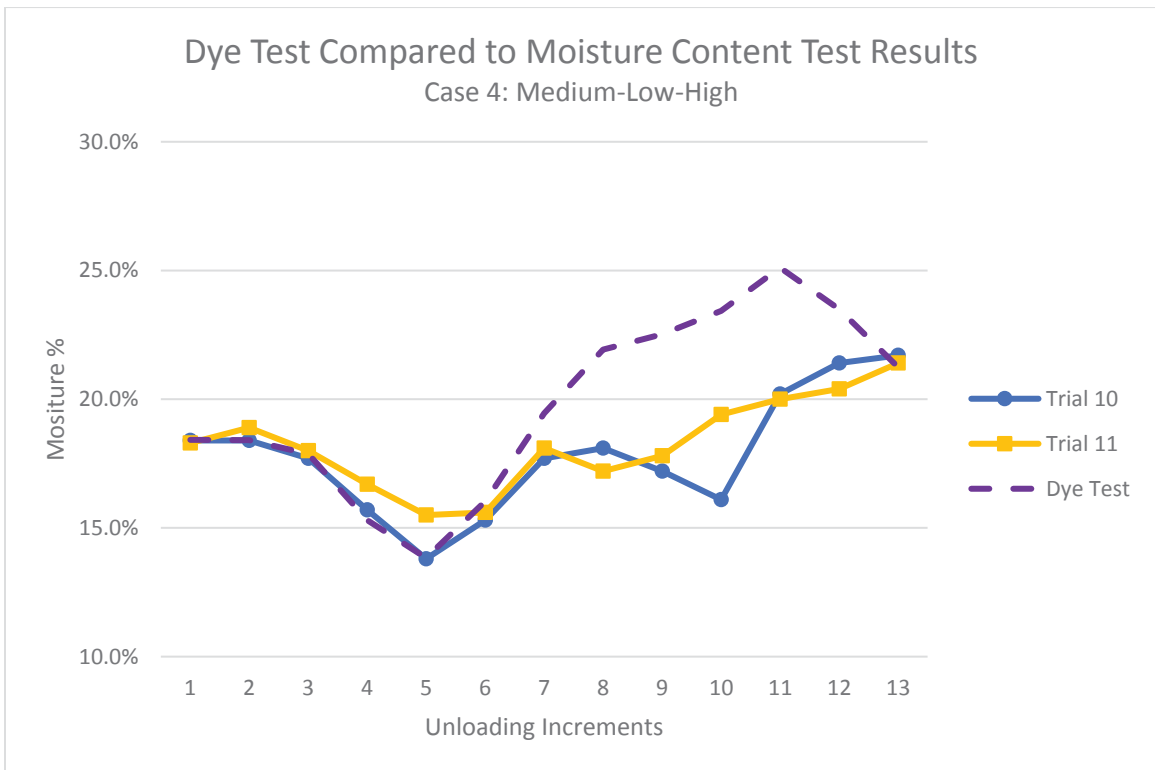


Figure 4.2-4: Dye Test Results Compared to Moisture Content Test Results: Case 4

4.3 NUMERICAL ANALYSIS RESULTS

The CFD simulation was transient. To collect the desired data, monitors needed to be setup. The phase ID for the mixture as well as the volume fraction for all of the phases were monitored at the outlet of the wet bin. The results from Fluent were loaded into ANSYS's CFD-Post to be analyzed. The simulation collected the data for each time step, but the experiments were done based on the volume of the unload increments. Therefore, the simulation data was grouped so it could be compared to the experimental results.

Figure 4.3-1 shows the visual phase ID results. The red phase (phase ID 3) is load 1, the green phase (phase ID 2) is load 2, and the cyan phase (phase ID 1) is load 3. These were the profiles that were reviewed to ensure that the correct viscosity was chosen.

The volume fraction of each phase was also monitored at the outlet of the wet bin. The results were again grouped so it could be compared to the experimental results. The percentages of each phase can be seen in Table 4.3-1. The profile created by these results had each load case applied and the predicted moisture content that it created was compared to the moisture content test results in a similar manner as the dye test results had been compared. Figure 4.3-2 to Figure 4.3-5 shows the comparison to the moisture content results. These figures show that the CFD simulation results give similar results to the dye test, but they did not create a profile that can accurately predict the moisture content of the grain as it leaves the wet bin.

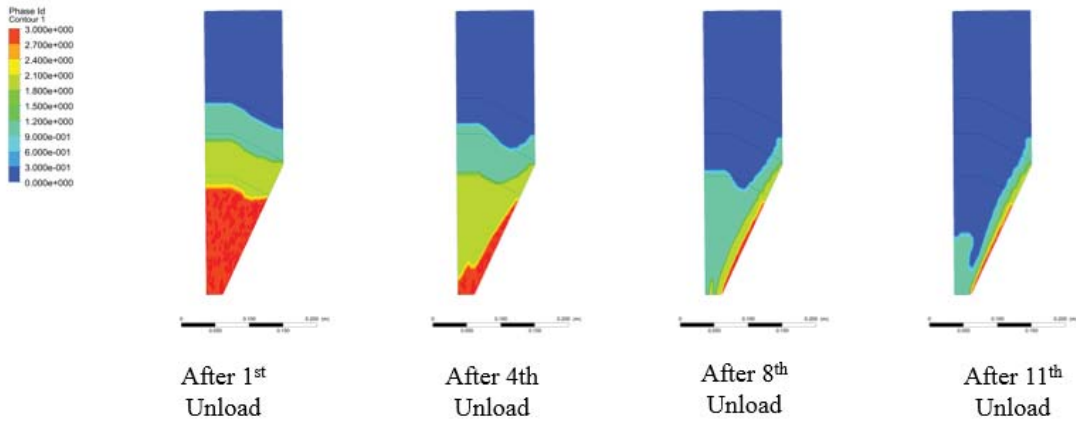


Figure 4.3-1: CFD Simulation Phase ID Results at Various Stages of Unloading

Table 4.3-1: Load Percentage Results of CFD Simulation

Unload Increment	Load 1	Load 2	Load 3
1	100.0%	0.0%	0.0%
2	100.0%	0.0%	0.0%
3	100.0%	0.0%	0.0%
4	100.0%	0.0%	0.0%
5	44.6%	55.4%	0.0%
6	14.0%	86.0%	0.0%
7	7.3%	92.7%	0.0%
8	5.7%	93.0%	1.3%
9	4.6%	37.1%	58.4%
10	3.8%	21.1%	75.1%
11	3.0%	13.2%	83.8%
12	2.0%	26.0%	69.0%
13	3.8%	46.3%	50.9%

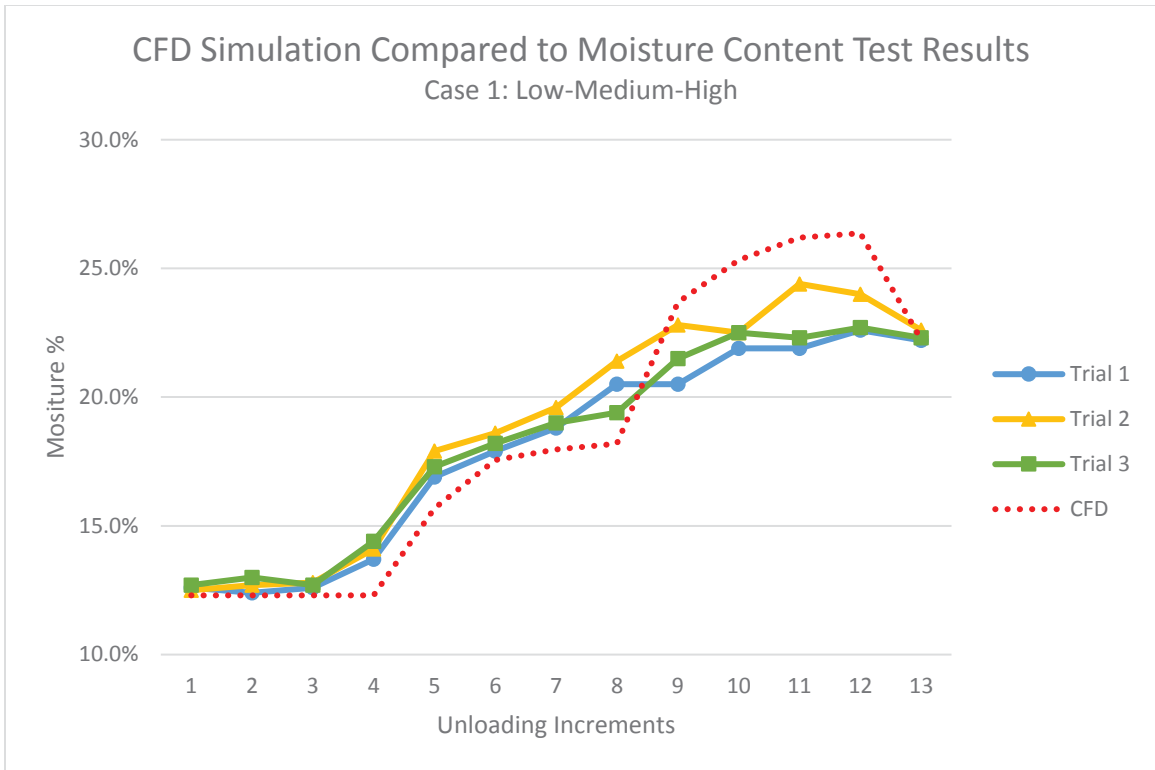


Figure 4.3-2: CFD Simulation Results Compared to Moisture Content Test Results: Case 1

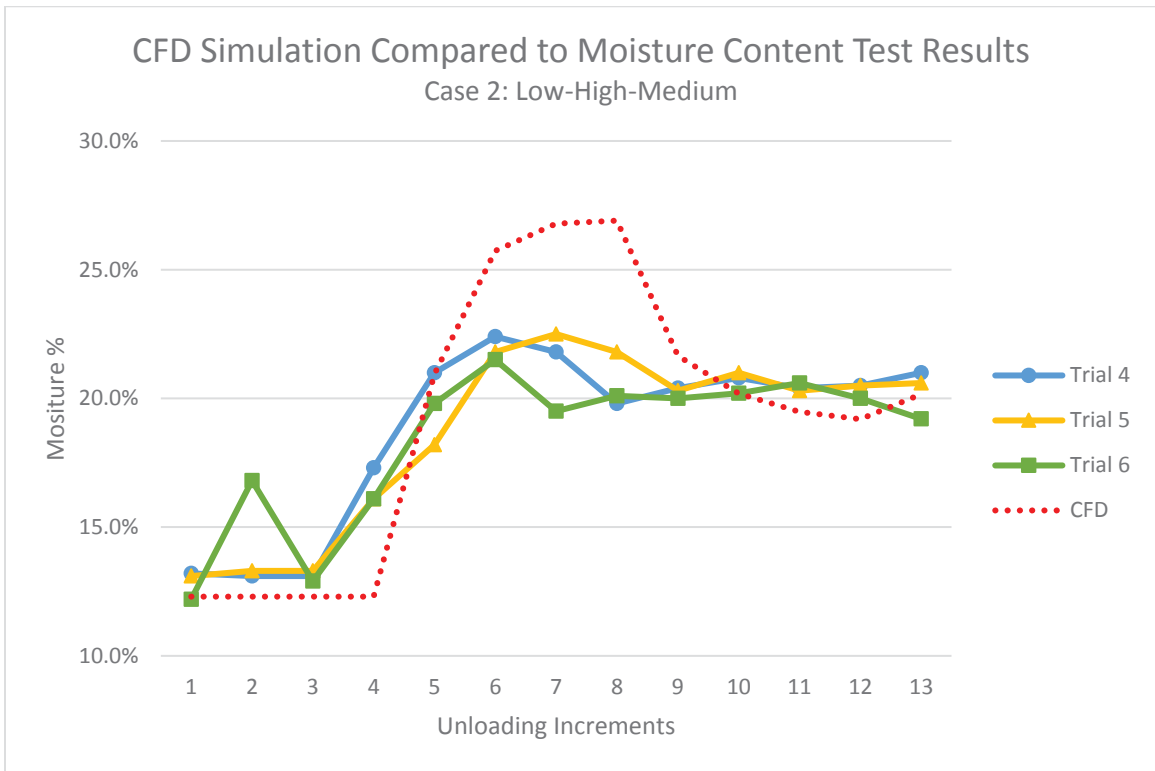


Figure 4.3-3: CFD Simulation Results Compared to Moisture Content Test Results: Case 2

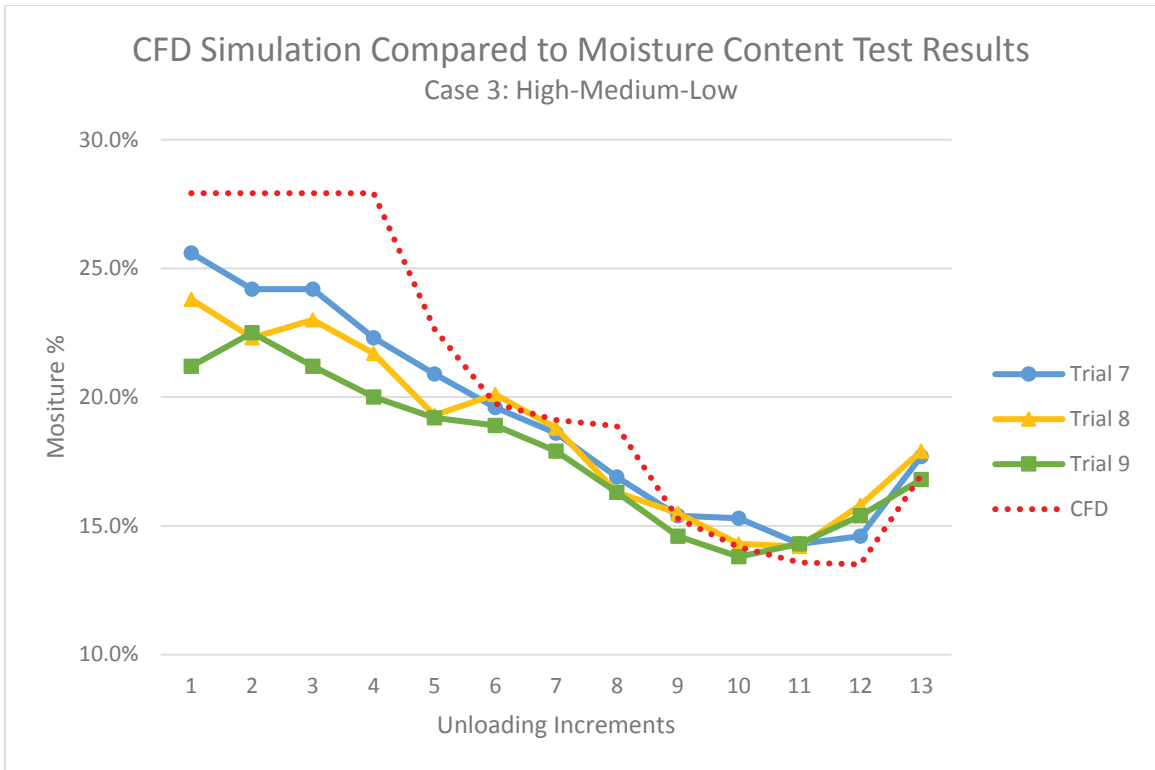


Figure 4.3-4: CFD Simulation Results Compared to Moisture Content Test Results: Case 3

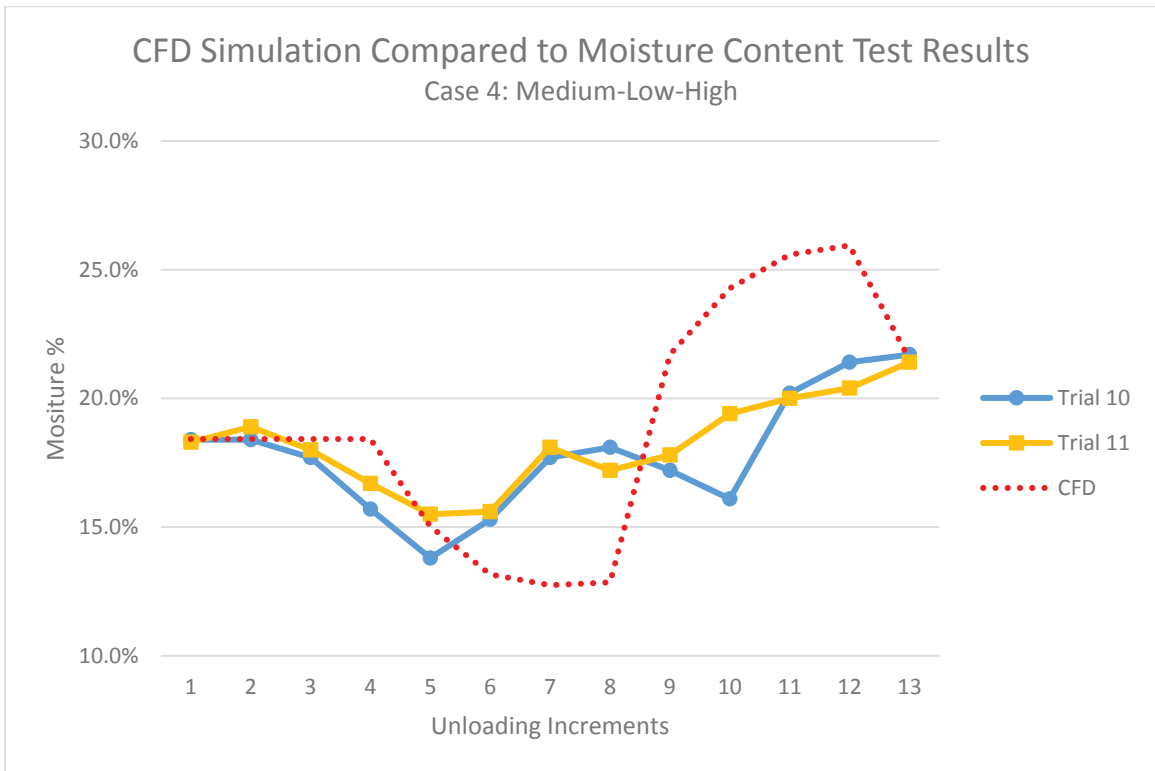


Figure 4.3-5: CFD Simulation Results Compared to Moisture Content Test Results: Case 4

4.4 SINGLE LOAD DIFFUSION TEST RESULTS

The phenomena that affect the moisture content of corn as it exits a hopper bottom wet bin were not fully defined by the moisture content test, dye test, or CFD simulation. So additional investigation was done into the affect that diffusion to air had on each load. The results of the single load diffusion test are shown in Table 4.4-1 below. From the results, it can easily be seen that the higher the starting moisture content, the more moisture that is lost during the thirty minute wait period that was observed in the moisture content tests.

Instead of applying the original moisture content of each load to the dye test results, the modifications seen in this single load diffusion tests were applied first. These new final moisture contents were applied to the profile created by the dye test. Figure 4.4-1 to Figure 4.4-4 shows the new predicted moisture content values in red and compares them to the original dye test values and moisture content test results. For all four cases, the new profile closely predicts the moisture content results.

Table 4.4-1: Results of Single Load Diffusion Test

Load	Moisture Content Change
Low	No change
Medium	0.4% loss
High	4.8% loss

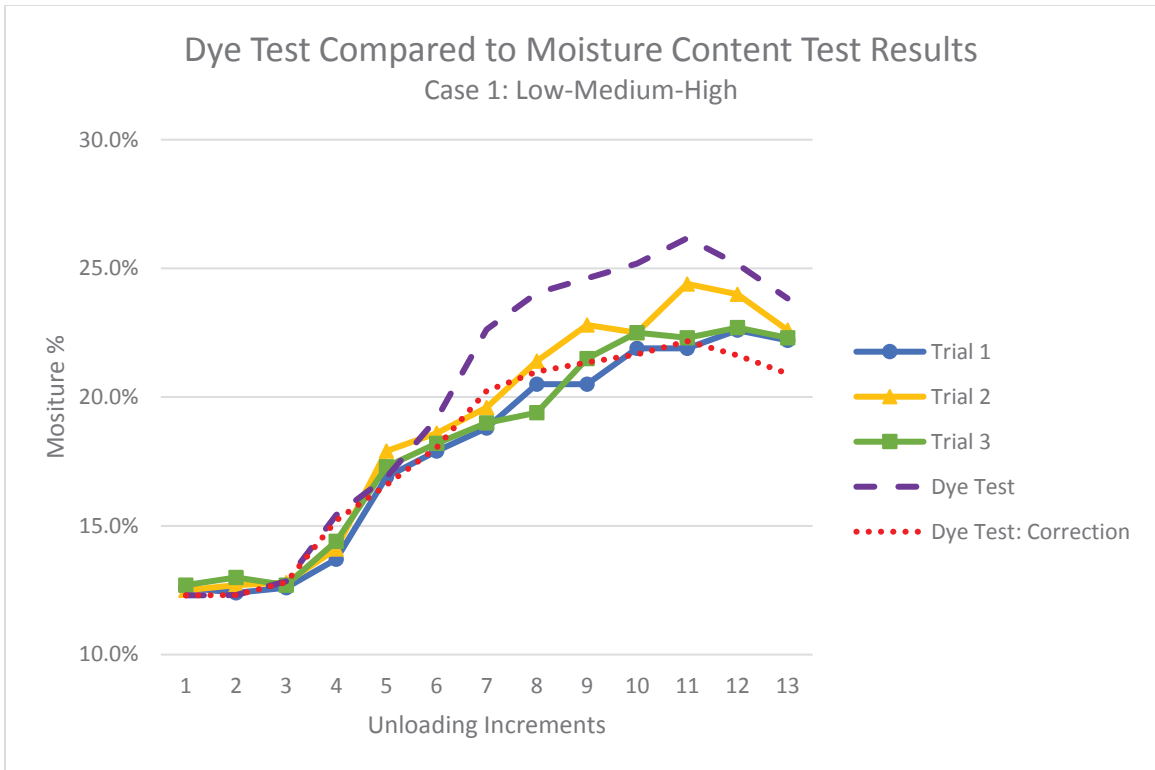


Figure 4.4-1: Dye Test Results with Both the Original Moisture Content and the Corrected Moisture Content Compared to the Moisture Content Test Results: Case 1

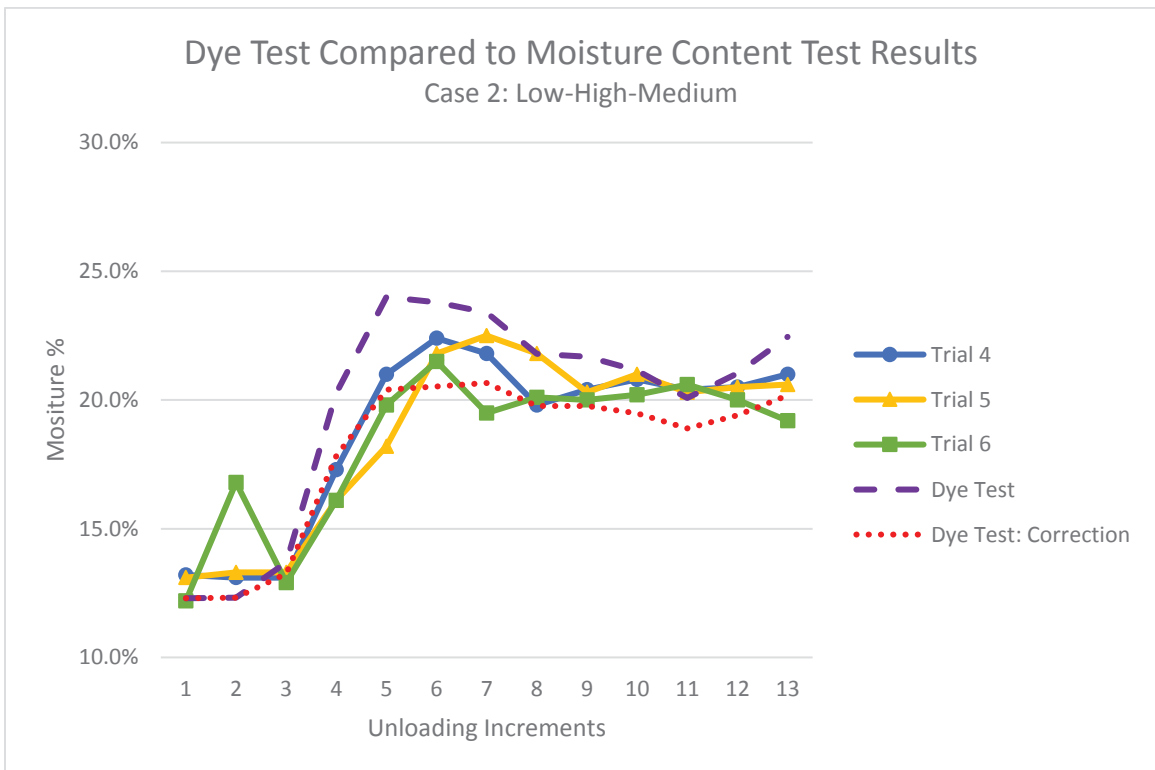


Figure 4.4-2: Dye Test Results with Both the Original Moisture Content and the Corrected Moisture Content Compared to the Moisture Content Test Results: Case 2

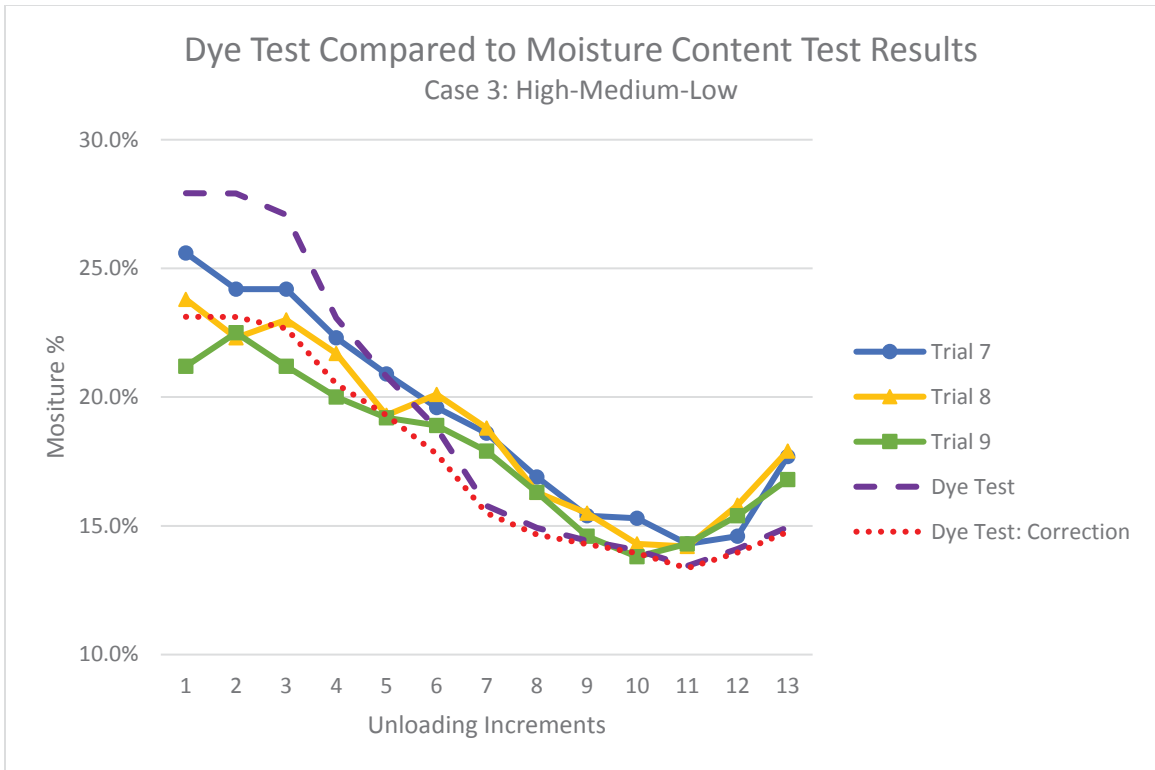


Figure 4.4-3: Dye Test Results with Both the Original Moisture Content and the Corrected Moisture Content Compared to the Moisture Content Test Results: Case 3

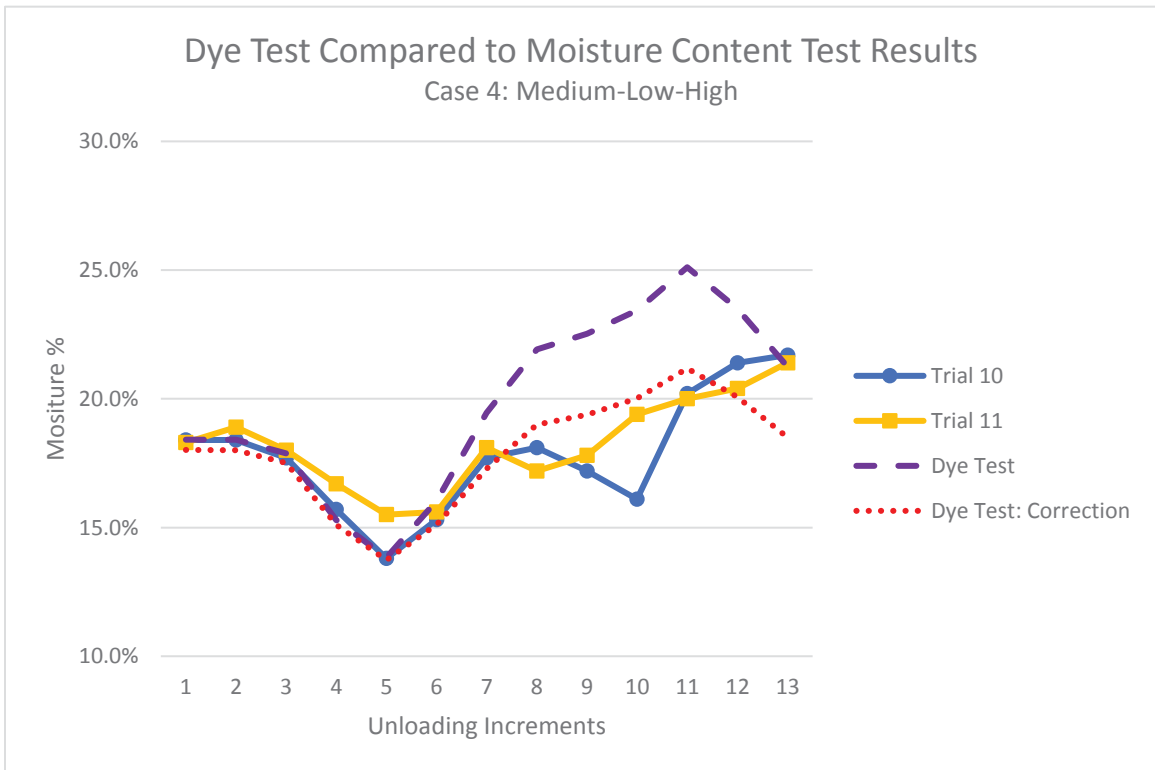


Figure 4.4-4: Dye Test Results with Both the Original Moisture Content and the Corrected Moisture Content Compared to the Moisture Content Test Results: Case 4

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 CONCLUSIONS

The results of this research show that a profile can be created that could predict the moisture content of grain as it leaves a hopper bottom wet bin and enters a grain dryer. To determine this profile, two major phenomena need to be investigated; the mixing of the loads during filling and unloading and the diffusion of each load to air. By limiting this research to just a small scale drying setup with only three loads being held in a hopper bottom wet bin, such a profile was created for the 1/16th scale experimental test setup. A graph of the mixing portion of this profile can be seen in Figure 5.1-1. This profile appears to be segregated into three distinct sections.

- Section 1: Unload increments 1-3 are primarily load 1 only.
- Section 2: Unload increments 4-6 are primarily mixing of only load 1 & 2
- Section 3: Unload increments 7-13 are primarily mixing of only load 2 & 3

These 3 sections can also be seen in the results from the CFD simulation shown in Figure 5.1-2. The major difference between the two profiles is the number of unload increments in each section.

- Section 1: Unload increments 1-4
- Section 2: Unload increments 5-8
- Section 3: Unload increments 9-13

With these results, this research shows that there is a potential for CFD simulation to be used to predict the moisture content profile.

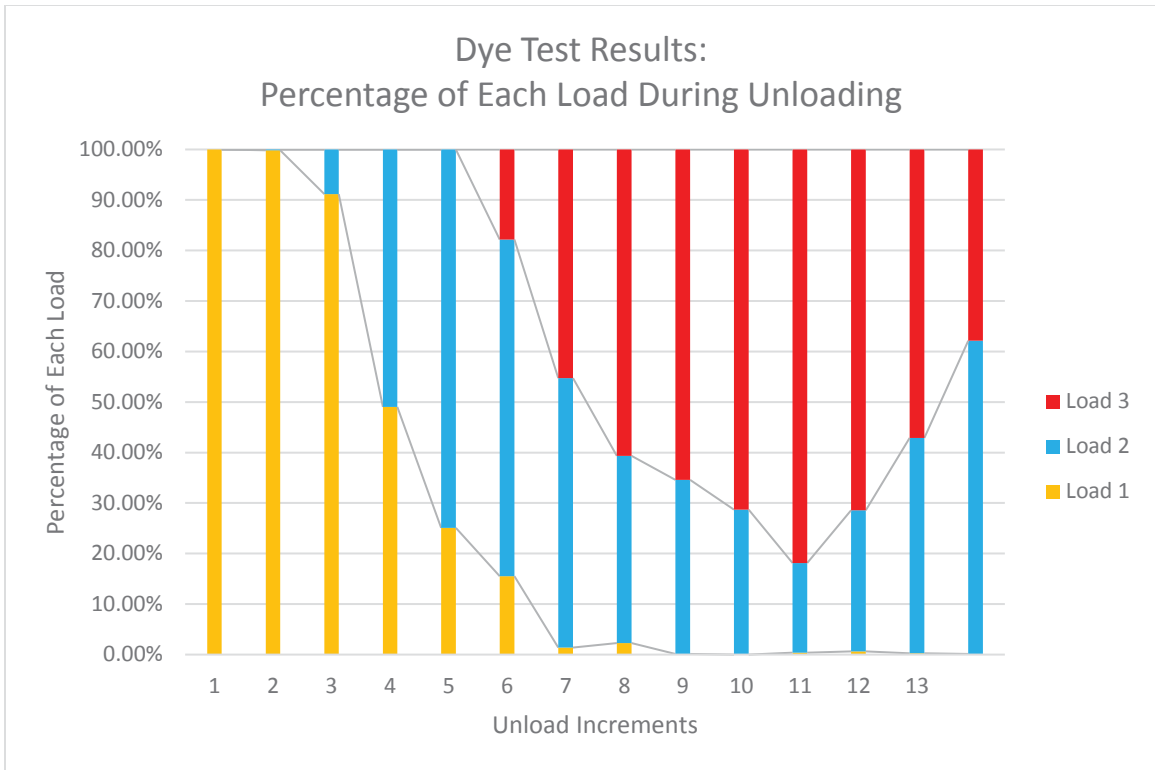


Figure 5.1-1: Percentage of Each Load During Unloading of the Dye Test

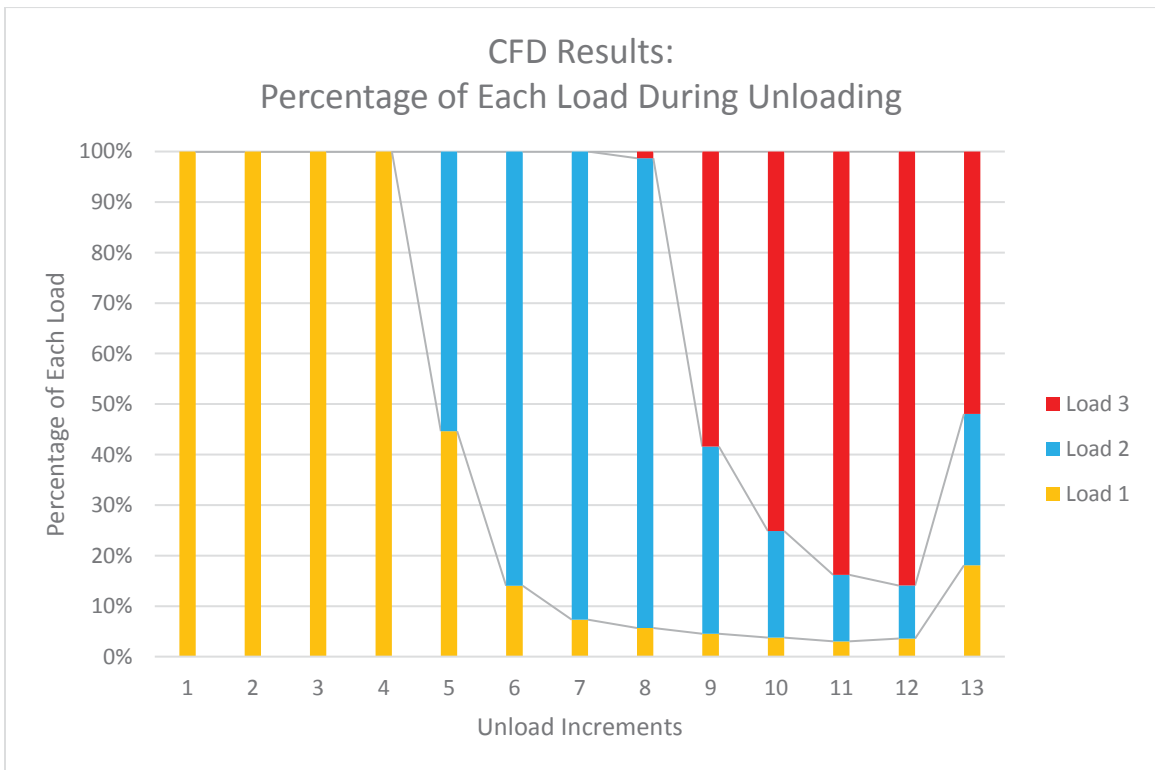


Figure 5.1-2: Percentage of Each Load During the Unloading of the CFD Simulation

5.2 FUTURE WORK

This research gives great preliminary indications that a profile could be created that would accurately predict the moisture content of grain as it leaves the wet bin and enters a grain dryer. This profile could then be used to optimize the parameters of a grain drier and potentially reduce costs. To continue this work, all of the possible load cases should be tested to verify the accuracy of the profile that was created by the dye test and single load diffusion test. After those results were confirmed, all of the testing should be repeated with variations in the test setup. Suggested variations are listed in Table 5.2-1.

After profiles were generated for scaled test setups, they would need to be scaled to full size wet bins. These full scale profiles would then be used to optimize the grain dryer parameters. Finally the cost to dry using the current best practices versus the new profile would need to be compared to see if there would be a cost saving.

Additionally, this research has shown that CFD simulation has a potential to generate a profile that would predict moisture content of grain as it leaves a wet bin and enters a grain dryer. With additional work, a CFD model profile could also be applied to a full scale drying setup and the cost savings could be determined. There is even a potential that software could be created that would directly interface the CFD model or its data and the grain dryer settings to ensure consistent optimization.

Table 5.2-1: Potential Parameter Variations for Future Research

Parameter	Research Scope	Variations
Grain	- Corn	- Other grains, such as soybeans
Load Size	- Gravity Wagons, 250 bushel	- Grain Trucks, 2 times gravity wagon capacity - Grain Trailers or Rail Cars, 4 times gravity wagon capacity
Bin Configurations	- 12' dia. 45° hopper bottom bin	- Varying dia. 45° hopper bottom bins - Varying dia. 60° hopper bottom bins - Flat bottom bins with auger

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