A STUDY OF A DRY KILN WALL IMPLOSION

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SUMMARY

On February 6, 1957, an outside wall of a new dry kiln installation was severely damaged by an implosion. The cause of the implosion was not known. Investigations conducted at that time were inconclusive. This led to the setting up of a series of tests in order to determine what factors contributed to the implosion.

Rapid condensation of the vapor in the kiln appeared to be responsible for the implosion. The problem was to determine what caused the vapor to condense. There was nothing that appeared to be unusual about the weather or the lumber charge. The weather was freezing and foggy, while the lumber charge was frozen and snow covered.

Three theories were advanced as a basis for the cause of the implosion. These theories were based on cold air, fog, and frozen lumber. Cold air and fog were eliminated because calculations indicated that the volume of the condensed vapor was less than the volume of air, or fog, required to condense the vapor. Frozen lumber appeared to be a possible cause.

Recording instruments installed in the test kiln indicated that the low pressures developed during the earlier part of the drying cycle, and when the fans reversed. Controlled tests indicated that it is unlikely that the implosion resulted from a fan reversal while the steam spray was on.

The kiln controller chart that was in use when the implosion occurred shows that the warm-up rate was slower than normal. This slow warm-up rate was duplicated by heating a kiln of frozen lumber with the steam spray on and the fans off. Atmospheric tests made in the kiln indicated that a dangerous condition did exist.

It appears probable that the implosion resulted from the fans not being on at the start of the drying cycle. The steam spray increased the vapor content in the kilns and then when the fans started the vapor was forced through the frozen lumber. The vapor condensed with a resultant pressure drop which caused the wall to fail.

At some unknown hour on the morning of February 6, 1957, an implosion severely damaged an exterior wall of a new dry kiln at the Emmett mill of the Boise Cascade Corporation. Investigations conducted at the time of the implosion brought forth so many conflicting statements that it was not considered advisable to draw any conclusions from them. This led to the setting up of tests in a kiln at the plant where the implosion occurred. The purpose of the tests was to determine what unusual conditions existed in the kiln, what conditions could cause an implosion, and how to prevent another one. The tests were conducted with the assistance of Mr. Ed Knight of the Western Pine Laboratories.

There is evidence that implosions have occurred elsewhere. However, they have not been as severe and most of the observations showed damage limited to the doors.

The dry kilns are of the cross-ventilation type (Fig. 1) with the fans mounted overhead and on the output shafts of gearhead motors. Heat is provided by overhead steam coils and there is an overhead 3 inch spray line. There are two rows of automatic vents and two rows of hand controlled vents. The building is constructed with an insulated structural concrete roof and
block walls. Each kiln is a single track unit, 104 feet long, by 17 feet—4 inches wide, and 24 feet high.

Operation of the kilns requires a minimum amount of attention. Fan reversals are made automatically. The kiln controller regulates the heating coils, the spray line, and the automatic vents. Hand controls are provided in case of the failure of the controller, or for changes in operational requirements not allowed for by the controller.

Standard operating procedure at the time of the implosion was to close the hand vents and leave the humidity control on full automatic. The controller then closed the automatic vents and opened the spray valve. Fan reversal was on a full automatic schedule with no zero reset at the beginning of the drying cycle.

The lumber charge, of 4/4 select, went into the kiln at 2 a.m. It was frozen and snow covered. The ambient temperature at that time was recorded by the powerhouse at 27°F. At 8 a.m. the ambient temperature was recorded at 10°F. and at 9 a.m. it was 12°F.

The implosion was discovered between 8 a.m. and 9 a.m. (Fig. 2 & 3). At the time of discovery the weather had become foggy.

This is about all of the positive information that was available to investigators. A shift change at 7 a.m. caused a second crew of operators to become involved. The men were nervous and their statements failed to shed any light on the problem.

There was only one logical explanation for the implosion. It had to be the rapid condensation of water vapor within the kiln. Therefore, the first thing to do was to stop using the spray during the early stages of the drying cycle. This change in operating procedure was made immediately.

The second precaution taken was the installation of spring-loaded safety doors. These doors (Fig. 4) were installed in the main kiln doors and were designed to open under a very low pressure differential.

The main question was “what caused the water vapor to condense.” There were three possibilities available, and each of them was the basis of a theory. These were—fog, cold air, and frozen lumber.

According to a staff member of the Boise weather station, fog is always made up of tiny water droplets, regardless of temperature. We didn’t know much about the nature of fog, so it was decided to check into this one a little further.

Cold air could be responsible. Some of the vents would have to be open, but there is no record showing that they were open or closed. However, several doors were drawn in prior to the failure of the kiln wall. We know that at times the atmosphere in the kilns did approach critical conditions while they were being operated in a normal manner.

Frozen lumber had been dried before. In fact there were times when the kilns had been charged with lumber that had been stored under worse conditions. However, there was no evidence to single out this particular charge as being different or unusual.
Fog was investigated theoretically by means of a heat balance based on values taken from the steam tables.

The worst possible condition that could be set up in the kilns would be to have a temperature of 212°F, and the air saturated. Under these conditions, the following information can be taken directly from the steam tables.

1. Volume of one pound of saturated vapor = 26.8 ft.³
2. Volume of one pound of saturated liquid = 0.01672 ft.³
3. Heat of evaporation of one pound of saturated liquid = 970.3 B.T.U.
4. Heat in one pound of saturated liquid = 180.07 B.T.U.

However, fog below an ambient temperature of 32°F is a super-cooled liquid. The heat required to raise a pound of fog from 0°F is approximately 212 B.T.U.

The maximum amount of heat that could be transferred to a pound of fog would be 212 B.T.U. using 0°F as a base line. Any additional heat would start to evaporate the fog which in turn would reduce the volumetric changes. If one pound of fog could absorb 212 B.T.U., it would require approximately 4 1/2 pounds of fog to absorb the 970.3 B.T.U. required to condense one pound of vapor. If this could be done there would be a volumetric reduction of approximately 26 cubic feet, and a pressure drop to correspond to this change.

The amount of air required to suspend 4 1/2 pounds of fog should also be considered. To do this we will consider another extreme condition. The maximum amount of water that a cubic foot of air could possibly hold as fog would result from cooling saturated air at 212°F until all of the vapor had condensed with no fall out.

1. If one pound of saturated vapor at 212°F occupies 26.8 cubic feet, then one cubic foot of vapor would weigh approximately 0.037 pounds.
2. If one cubic foot of air could hold 0.037 pounds of water in the form of fog, it would require approximately 122 cubic feet of air to hold 4 1/2 pounds of fog.

The Encyclopedia Britannica states that a cubic meter of fog will hold approximately three grams of water. This is equivalent to approximately 0.00019 pounds of water per cubic foot of fog.

Under ideal conditions it would require 122 cubic feet of fog-laden air to enter the kiln in order to condense 26.8 cubic feet of vapor. This is an impossibility since the volume taken in would more than fill the void left by the condensing vapor. It, therefore, eliminates fog as a possible cause of the implosion.

Cold air was eliminated because of its low heat capacity. For example, the heat capacity of air is 0.24 B.T.U./lb. · °F. At 68°F, one pound of air will occupy 13.3 cubic feet of space. At 212°F, it will occupy more space, so the 13.3 cubic foot value is conservative for this case. One pound of air raised from 0°F to 212°F will require approximately 51 B.T.U. To get the necessary 970.3 B.T.U. required to condense a pound of vapor would require approximately 19 pounds of air occupying a volume of approximately 253 cubic feet. This is another impossibility because the volume of air required is greater than the void left by the condensing vapor.

A charge of 4/4 lumber may have 130,000 square feet of surface. If the surface temperature of the lumber is cold enough, it would make a beautiful condenser. Frozen lumber certainly could be a contributing factor.

To be absolutely sure of the cause of the implosion it would be necessary to set up a test kiln where a vacuum could be produced at will under controlled conditions.

There was no question that we were playing with a powerful force. It would certainly be embarrassing, to say the least, to have one of the tests pull in another wall. We decided to install recording instruments in the test kiln and just record the normal kiln operation until enough information was obtained to justify any test procedure.

Even though fog and cold air were not considered responsible for the implosion, we wanted to know everything we could about the workings of the dry kiln. To achieve this we set up instruments to record ambient air temperature, wet and dry bulb readings, the opening and closing of the automatic and hand controlled vents, the operation of the spray valve, flow of air in through, or out of, the vents, and the pressure differential between the inside and outside of the kiln. One pressure point was located about four feet from the floor and beside the outside wall. The other two points were taken above the first point with one on each side of a fan and located on the fan center line. In addition to this information, the kiln operators recorded the weather conditions each hour for us. They also marked on the pressure chart when they changed the kiln and the run number.

All charts were on a 24 hour basis. The pressure recorder could also be set for a 96 minute chart if desired. The reason for this was that the standard kiln chart is based on seven days. Disturbances recorded on such a chart would be difficult to distinguish because the pen recording would be too compressed to be readable.

After the first series of observations were completed, the recorded data was analyzed. The important factors influencing the pressure changes in the kilns were noted. These were found to be:

1. Fan reversals coincided with the development of the vacuums.
2. The vacuums were noted to occur in the early phases of the cycle. For this reason it was concluded that the condition of the lumber in the charge had a bearing upon the development of the vacuums.

Intermediate tests were conducted without the use of the spray. Limited vacuums of one inch of water pressure were obtained. Since the winter of 1957-58 was very mild it was decided that the tests should be continued for another winter.

In the fall of 1958 the recording instruments were started again. Cool weather in the middle of November provided a chance to do some testing without the danger of extreme conditions.

At 7:30 a.m. on the 16th of November a charge of 4/4 red fir common was loaded into the test kiln. This
lumber had been stored in temperatures ranging from 24°F to 40°F. About one-half of this time was below the freezing point. The lumber was subject to rain and snow. The safety door was held closed by an arrangement of springs. This was done to increase the opening resistance.

The test procedure was to operate the fans for a few minutes to allow the atmosphere in the kiln to reach equilibrium. The spray was turned on ten seconds before stopping the fans, and allowed to continue for varying lengths of time. When the fans started up, the pressure recording pens would oscillate several times before returning to zero pressure. The spring-loaded safety door was opening and relieving the vacuum. The springs would then close the door and the vacuum would build up again.

Pressure differentials of one inch of water were recorded. Restraining the safety door while the fans were started produced a vacuum of three inches of water. One inch of water is equal to a pressure of 5.2 pounds per square foot. A pressure of three inches of water is equivalent to 15.6 pounds per square foot, or a total force on the kiln wall of over 19 tons. It was also observed that the duration of the reduced pressure was a matter of only a few seconds.

The results of this test were very encouraging because we had produced a partial vacuum under controlled conditions. However, additional information was necessary to correlate the conditions within the kiln to the intensity of the vacuum produced.

A lumber charge consisting of 4/4 half & half pine common was placed in the test kiln. The temperature of the lumber was 46°F. The test procedure consisted of spraying the kiln for 15 seconds before stopping the fans. The spray was continued for varying lengths of time during the reversal cycle. Wet bulb and dry bulb readings were taken when the fans started. Lumber temperature readings were taken immediately afterwards. The safety door was blocked for this test.

The final run was made approximately two hours after the kiln was charged. The spray was on for the full time the fans were reversing (2 minutes, 15 seconds). Wet bulb temperature was 135°F. and dry bulb temperature was 153°F. Lumber temperature was 120°F. and the vacuum developed was 3.0 inches of water.

Test data indicated that the vacuum produced during the fan reversal was a function of a length of time the spray was on. When the spray was on for one and one-half minutes the vacuum produced ranged from about one-third to one-half of the vacuum produced when the spray was on for two minutes and fifteen seconds.

Tests made by the Western Pine Laboratory have recorded a temperature drop of 22°F across a 9 foot load of Ponderosa Pine sapwood lumber during the early portion of the kiln drying period. We recorded a temperature drop of 19°F through frozen spruce in our Emmett kilns. Multiple passes through the lumber doesn't appear to increase the intensity of the vacuum produced, or to lower the air temperature. Each cycle of the air includes a pass through two banks of finned pipe with a temperature of approximately 335°F. The net result is a gain in air temperature. Of course, the temperature of the air entering the lumber would have a bearing on the temperature drop.

Our testing entered a new phase at this point. We began the investigation of atmospheric changes that take place in a kiln when the spray is on and the fans are off.

After charging the kiln with frozen lumber, the fans were turned on for a few minutes to establish equilibrium conditions. The spray was turned on and then the fans were stopped. The spray was allowed to continue for about 3½ minutes. At the end of the spraying time the atmosphere under the kiln roof had a dry bulb temperature of 186°F. and a wet bulb temperature of 128°F. The atmosphere six feet from the floor had a dry bulb reading of 100°F. and a wet bulb reading of 80°F.

The dew point for the atmosphere under the roof was approximately 123°F. This means that a temperature drop of 63°F. would be required before condensing vapor could create a vacuum. An additional drop of 8°F. would be required to develop the 50 p.s.i.f. vacuum that the walls were designed to withstand. At the 6 ft. level we had a dew point of 73°F. A temperature drop of 27°F. would be required to create any vacuum. A total temperature drop in excess of 68°F. would be required to endanger the walls.

These conditions were recorded after the spray had been on for approximately 3½ minutes. When the implosion occurred the fans were only off for 1½ minutes, and they coasted for all of that. Possibly ½ to ¾ of a minute was available when the fans were turning very slowly, for vapor to accumulate in the kiln. It appears probable that temperature drops in excess of 22°F. do occur. The mixing of the atmosphere by the fans may also produce a more dangerous condition than exists at the instant the fans start.

Three variables appear to control the intensity of a vacuum—the relative humidity and temperature of the kiln atmosphere, and the surface temperature of the lumber charge. In some cases lumber species may have a bearing, but if the lumber is coated with ice and snow the species is of less importance. Higher relative humidity and temperature require less of a temperature drop through the lumber to create a vacuum. Lower lumber surface temperatures likewise can produce vacuums with lower atmospheric temperature and relative humidity.

The amount of steam injected into a kiln is constant for each fan reversal period. For normal operation of the kilns, the only uncontrolled variable is the temperature of the lumber charge. Prior to the implosion lumber charges had been subjected to temperatures of 20°F. to 25°F. below zero. For some unknown reason these more severe conditions didn’t destroy any walls.

It can not be stated definitely that the wall failure didn’t occur during normal operating conditions. However, when all of the available information is considered, it appears probable that the implosion was not the result of a fan reversal occurring while the spray valve was open.

This casts doubt upon the last of the three theories that were advanced at the time of the implosion. It still leaves the question of how the critical conditions were developed in the kiln.
The kiln controller chart (Fig. 5) that was in use at the time of the implosion is rather confusing. There is one thing though that seems to have been overlooked. That is the indication of a very slow warm-up rate for the first four hours that the charge was in the kiln. We know that if the spray is on and the fans are operating the warm-up rate is rather good, even with frozen lumber. There is a possibility that the kiln operator set the controller but that the fans failed to start.

Another test was set up to check this theory. A frozen charge of 4/4 red fir common was placed in a kiln. The fans were left off while the spray and the heaters were turned on. The surface temperature of the lumber was 24°F. when it entered the kiln. The kiln controller appeared to require calibration, so wet and dry bulb thermometers were placed in the kiln at the 6 ft. level.

After two hours of spraying the following conditions were recorded. Under the kiln roof, the dry bulb temperature was 232°F., and the wet bulb temperature was 196°F. At the 6 ft. level, the atmosphere was saturated at 62°F. The lumber surface temperature was 34°F. at a point about 10 ft. above the floor. Snow was on the lumber at the lower levels. After four hours of spraying the following conditions were recorded: Under the kiln roof the dry bulb temperature was 239°F. and the wet bulb temperature was 202°F. There was no change at the 6 ft. level. The lumber surface temperature was 35°F. at the 10 ft. level and there was still some snow between the courses at the lower levels.

The dew point for the atmosphere under the roof was approximately 201°F. A temperature drop of 38°F. would be required to start forming a vacuum. An additional drop of 4°F. could create a vacuum exceeding the design strength of the wall. Under these conditions there exists a maximum temperature difference of 198°F. between the kiln atmosphere and the lumber. At the end of the four hour spray the top half of the kiln was filled with steam. This fact coupled with the 198°F. temperature difference between the lumber and the upper atmosphere created a more dangerous condition than anything we were able to produce during normal operation. Actually conditions nearly as dangerous probably existed in a matter of minutes after the spray started, since a 3 1/2 minute spray produced a wet bulb reading of 128°F. and a dry bulb of 186°F.

After this four hour spray cycle the vents and the door were opened. The fans were started one at a time and then the kiln was closed up again. The controller chart (Fig. 6) shows the same basic warm-up pattern that appears on the chart made when the wall failed.

The atmospheric conditions that developed in the kiln during the four hour spray, and the similar chart record indicate that the implosion probably resulted from an operational error or a mechanical malfunction. This also explains the unusual conditions that existed in the kiln at the time of the implosion.

The safety doors limited a three inch vacuum to one inch. They are probably capable of doing much better than that, however, we didn't want to exceed a three inch vacuum in our tests.

Door failures were occurring with the 1 1/2 minute fan reversal period. A series of fuse failures in the fan motors caused the reversal period to be lengthened to 2 1/4 minutes. It is possible that the use of the spray could cause a wall failure in normal operation of the kilns now where it didn't appear to before.

There are a few methods that could be employed to help keep dangerous atmospheric conditions from developing in the kilns while using the spray for the warm-up period. Among these are: the installation of timers to reverse the fans one at a time, the lengthening of the fan operating periods while the lumber is cold, and the installation of solenoid valves in the spray valve air control lines. These solenoid valves would be wired to the fan motor leads so that any time the fans were off the spray valves would be closed. The last method is the one to be preferred because it would keep the steam out of the kilns when the fans are off.