1. Evaluation of Steam and Vacuum Treatment to Control *Chlorophorus annularis F.* in Naturally Infested Bamboo Poles-September 2017

Chen, White, Mack, and YU

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Abstract

More than twenty six species of invasive insects have been intercepted in bamboo stakes from China, in recent years. To prevent the migration of such pests it is necessary to pre-shipment or quarantine treat these bamboo products. As an alternative to fumigation, preliminary heat treatment tests were conducted using steam and vacuum. About 1200, 90cm long, naturally infested, poles were harvested in southern China and treated in June of 2017 in Shenzhen. About 961 *Chlorophorus annularis* and 9 *Bostrychopsis parallela* were recovered from treated and control bamboo specimens. All stages from larvae to adults were present in the poles. Using an initial pressure of 100 mmHg, tests were conducted using eight (8) different temperatures from 30 to 60°C. One hundred percent morbidity was achieved at 47.5°C and above. The estimated vacuum lethal temperature is between 47.5°C and 50°C. The insects remained living in the control specimens. The average pole diameter was 5cm and average wall thickness was 1.47cm. The average treatment time to achieve this lethal temperature and hold for 30 minutes, throughout the poles was 45.8 minutes. During treatment the average increase in pole moisture content (MC) was 3.5%. The treatment did not adversely affect pole quality.

2. Feasibility of using steam and vacuum to control coconut rhinoceros beetle infestations in bark and chip mulches Preliminary assessment – January 2018

Chen, White, and Mack

Abstract

Mulch is an organic material, such as bark, wood chips, and compost, which covers the soil. Mulch can benefit soil and plants by keeping the moisture. It breaks down over time and adds the nutrients to soil. The primary goal of this project is to control the spread of the coconut rhinoceros beetle, *Oryctes rhinoceros (L.)* (CRB). It is believed that treating the mulch can reduce the spread of the beetles. Because of this preliminary assessment in Blacksburg, Virginia, the Japanese beetles, *Popillia japonica* were selected as surrogates because these beetles have life cycles similar to the CRB and available. Three initial vacuum levels (100, 250, 400 mmHg) were used and the treatment schedule used was 56°C/30 minutes holding. The silo styles of treating barrel and flexible container were designed. The results show that the cylindrical system or silo type of container can effectively treat bark mulch and chip mulch in average 45.7 minutes in the steel barrel design. The moisture contents of hardwood mulch and bark mulch increased about 12.1% and 28.8% during the treatment and does not affect other properties such as color. The flexible container is not recommended for mulches or other fine particles because vacuum can compact the mulch, thus increase mulch density so that treating time was much longer.

3. Steam and Vacuum Treatment of Large Timber in Solid Wood Skids – September 2016

Chen, White, and Mack

Abstract:

Forest pests are commonly transported with wood packaging materials. Ports in US continue to intercept invasive pests in large cross section timbers used to transport heavy consignments. The large cross section timbers present a greater risk because the fumigation and hot air treatment as currently used for treating wood packaging materials are not effective. The objective of our study is to determine the effectiveness of steam and vacuum for heat treating large cross section timbers in wood skids and crates, according to the heat treating requirements of ISPM 15. Three wood species of large dimension (8×8 and 4×4 inches) timbers were tested. These represented a high density hardwood, a low density hardwood and a commonly used softwood. These were mixed oak (*Quercus spp*), yellow-poplar (*Liriodendron tulipifera*) and mixed southern yellow pine (*Pinus spp*.). The timbers were partially air dried and are typical of large timbers used in heavy wood skids. Larvae of pinewood sawyer beetles (*Monochamus spp*.) were used as a representative surrogate for invasive cerambycids.

During each test, three skids assembled from each wood species were treated. Separate and untreated large timbers and a 4×4 inch deck timber were set aside as control specimens during each test. Prior to each test, eight larvae were inoculated into two large timbers (four each), and single larvae seeded in a deck timber. Four larvae were inserted in the large control timber and one larva in the control deck timber. The initial vacuum pressure was 100mm Hg and the test chamber temperature was 90°C. The treatment cycle continued until the core temperature of the large timber reached the required 56°C for 30 minutes. To measure temperature profiles within the timbers, thermocouples were placed at various locations. After each test, larvae were recovered and assessed for mortality. Potential treatment effects on the quality of the timbers and the structural integrity of the skid were examined. The ends of each large timber were photographed before and after treatment to monitor end splitting.

In order to document the change in moisture content (MC), large timbers were weighed before and after treatment. Overall heating time to achieve 56°C for 30 minutes to core was less than 7 hours for all 3 wood species tested (100 mmHg and 90°C steam). This is at least 30% less time than predicted treatment cycles using hot air at atmospheric pressure. Using hot air would dry the ends of the timber and result in splitting and degradation of skids. There was complete mortality (100%) of larvae as a result of treatment. The quality of 8x8 timbers was not affected by the treatment. The average MC of the 8×8 inches timber increased 4.1% after each test.

4. Using vacuum and steam to sanitize hardwood veneer logs for export – April 2011

Chen, White, and Mack

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Abstract The goal of this project is to investigate the utilization of vacuum/steam technology to sanitize the veneer grade logs for export. The combination of steam condensation and vacuum is one of most effective heat transfer mechanism because the steam carries large amount of heat and the condensation is fast to release the energy. The vacuum/steam system consists of a vacuum source (vacuum pump), controlling device, flexible container and a steam generator. The treatment system can create vacuum in the container and at the same time it can produce steam and maintain the saturation state within the container. Monitoring devices were attached to the equipment to record and control the process.

The veneer logs of five species (Red oak *Quercus rubra*, Pignut Hickory *Carya glabra*, Black Cherry *Prunus serotina*, American Walnut *Juglans nigra*, Yellow Poplar *Liriodendron tulipifera*) from eastern US were treated and the quality of logs were evaluated before and after treatment to find out whether the vacuum and steam treatment has any effects on it and the subsequent veneer quality. After vacuum was drawn to 200 mmHg inside the container, steam was injected into the container. The steaming was continued on until 56°C was reached at the center of the logs. Total fifteen logs were treated to document the treating times and five control logs were used in the comparison of the quality affected during the treatment. Log diameters ranged from 17 to 21 inches in the small end and the logs were cut into 8 feet long. The testing time for all the logs varied from 18 to 29 hours. Energy used in the treatment is about 54 to 205 kwh to treat a log. Overall the vacuum steam treatment had no significant affect the veneer volume and quality. The walnut veneer after treatment appeared to be little darker. And end splits of logs were enhanced after vacuum steam treatment. Adversary of the vacuum steam treating seems to be minimal. The conclusion from this study can be described as that the vacuum steam heat can effectively penetrate logs and raise the internal temperatures to levels that can kill pests without causing significant damage on the log and veneer quality.

5. Using vacuum and steam to sanitize hardwood veneer logs for export- September 2013

Chen, White, and Mack

Abstract

Twenty long hardwood veneer logs (four each of hickory, red oak, walnut, cherry and yellow-polar), were acquired in the eastern US. Each log was cut in half; one served as treated sample and another one as the control sample. Log small end diameter varied from 15 to 32 inches and their lengths varied from about 8.5 to 10.7 feet. Four different treating schedules were used. The treating duration and energy consumption were measured. Chamber temperature during treatment was 90°C. Vacuum level varied from 25 mmHg to 570 mmHg. During treating, the geometric centers of logs were heated to 60°C and held for 60 minutes. Veneers from treated logs were produced in a veneer manufacturing facility. The effects of vacuum/steam treatment on the log quality and the veneer yield and quality after treatment were analyzed. The results have shown that the hardwood logs of five important wood species have been successfully treated with vacuum/steam technology to 60°C for 60 minutes at the log center. The treating time for logs varied from 15 to 40 hours depending on the species, size and treating schedule. The energy consumed during the treatment was measured and calculated to vary from 1.32 to 2.17 kwh/kg of log depending on the treating schedule. The vacuum/steam treatment did increase the size of end checks and cracks in the hickory, red oak and cherry logs by the extension of the existing cracks or checks. However, this can be reduced by using “S” irons and end coatings. The treatment did not significantly reduce flitch or veneer yield or quality when compared to the control, non-treated, logs. Denser woods, such as hickory required slightly longer treatment than yellow-poplar. The results also indicate that with the range of 15 to 30 inches diameter logs, treatment times will increase by about one hour for each

one inch increase in mid log diameter. Cycling extreme vacuum reduced treatment time by about 25% due to heat of hydration. However energy consumption increased by about 40%. The most efficient treatment schedule tested, was the saturated steam environment of 90°C temperature and a constant 570 mmHg vacuum. This indicates modest vacuum levels may be used for log treatment.

6. Phytosanitary treatment of the Mediterranean snails, (*Cernuella cisalpina and Eobania vermiculata*), hitchhiking with the imported tiles in packaging, using steam and vacuum – November 2015

Chen, White, and Mack

Abstract

Alien species are being moved around the world at the unprecedented rates as a result of the increase in the international trade. Snails may be also transported from one country to another country in and on internationally traded commodities. Snails consume vegetation, but more importantly carry and spread diseases. Snails indigenous to Italy have arrived to the US on unit loads of tiles. In this study, two species of Mediterranean snails, (*Cernuella cisalpina* with weight of 0.096 g *and Eobania vermiculata* with the weight of 2.06g) were field collected in Maryland, transported to and quarantined at Virginia Tech. Unit loads of tile were inoculated with these snails and then subsequently treated with the saturated steam at the initial levels of 100, 250 and 500 mmHg. The results revealed that vacuum and steam technology can be used to kill both snails, *Eobania vermiculata* and *Cernuella cisalpine* at the temperature of 56°C with the holding time of 30 minutes in less than 61 minutes with average treating time of 51.1 minutes at the initial vacuum levels of 100 mmHg and 250 mmHg. However, it took longer than 4 hours to treat the products at 500 mmHg. There are no measureable color and shape change to either tile. The average breaking strength for ceramic tiles for both treated and control samples are 408.35 and 430.75 lbs respectively. And average breaking strengths for marble tiles for both treated and control samples are 609 and 689.5 lbs respectively. The average bending strengths of treated tiles were 5% and 12% less than that of untreated tiles respectively. For ceramic tile, it adsorbed about 0.78% moisture of total weight during treatment. There was no change in the MC of marble tiles. The corrugated paper boxes pick up about 4% moisture during treatment. For the corrugated paperboard boxes, the average Burst strengths of control and treated samples are measured to be 203.2 and 267.1 lb/in^2. The treated paper board boxes has slightly higher in the burst strength than control paperboard boxes. ECT for control and treated corrugated boxes 37.3 and 37.9 lbs respectively. The average compression strength of control and treated box samples are 407 and 375 lbs respectively. There are no significant differences between them in both box compression and ECT strengths before and after treatment. Corrugated packaging must be protected from liquid condensate during treatment.

7. Efficacy of Vacuum Steam Treatment to Kill Thousand Canker and Oak Wilt Disease in Infected Oak and Walnut Logs* - February 2017

Chen, White, and Mack

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Abstract

Oak wilt has been found in 24 states in the eastern United States and is one of the most destructive tree diseases nationally. In the same way, thousand cankers disease (TCD) is impacting walnut trees. The overall goal in this study is to determine the efficacy of steam and vacuum to kill the thousand canker fungus (*Geosmithia morbida*) and associated vectors in live infested black walnut (*Juglans nigra*) logs and to kill the oak wilt fungus (*Ceratocystis fagacearum*) and associated vectors in live infested oak (*Quercus spp*.) logs.

The infested oak trees were felled and 30 logs were removed. The logs were then heat treated with vacuum and steam technology in Shakopee, Minnesota. More than 20 walnut logs were cut from live infested trees in eastern Pennsylvania and heat treated near Lancaster. The results confirm that vacuum and steam heat treatment to 56ºC for 30 minutes and 60ºC for 60 minutes to targeted depths to kill both the *Ceratocystis fagacearum* and the *Geosmithia morbida*. The average treating time was 378 minutes for green oak at 56ºC/30 minutes and 519 minutes to 60ºC/60 minutes for log diameters ranging from 22.9 to 49.5 cm to a targeted depth of 50 mm. The average treating time was 256 minutes for green walnut at 56ºC/30 minutes and 308 minutes to 60ºC/60 minutes for logs with diameters ranging from 22.5 to 37 cm to a targeted depth of 32 mm. Because of the growth habits of the respective fungus, the treating cycle depended on heating the sapwood of the oaks and the cambium of the walnut logs. It is concluded that the 56ºC/30 minutes to specified depths, is effective to treat the infested logs. The average energy consumption was from 0.05 kwh/kg for oak logs at an initial temperature of 19ºC and 0.078 kwh/kg for walnut logs at an average initial temperature of 15ºC. The moisture content of green oak logs did not change. The average moisture gain for the walnut logs was around 4%MC. No significant log damage was observed.

8. Efficacy of Vacuum/Steam Treatment for Control of Emerald Ash Borer in Naturally Infested Wood – December 2008

Chen, White, and Poland

Abstract:

The efficacy of using vacuum/steam technology to kill Emerald Ash Borer (EAB) in the naturally infested ash was studied. EAB infested ash logs were vacuum/steam treated using the Xorella vacuum equipment. Various vacuum/steam cycles were used during the tests. Two separate experiments were conducted, each testing 25 or more infested logs. For the first experiment, ash trees infested with overwintering pre-pupal EAB were felled and cut into bolts during the winter 2008 then held in cold storage (3°C) until used. The average large end diameter was 12 cm and 54 cm in length. The initial log temperature was 32°C. Three treatment cycles were evaluated. Treatment conditions were designed to have the log surface temperature reach 70°C for 60 minutes. Total treatment time lasted about 100 minutes. Under these conditions, 97.7% of EABs in the ash logs were killed. For the second experiment, trees infested with late-instar larval EAB were freshly cut in fall 2008. The average log diameter was 15.3 at the larger end and the length was 68 cm. The initial log temperature was 16°C, and more cycles were applied in order to raise log temperature and holding time was extended to meet both of the following conditions, 1), the core temperature of 56°C and holding time of 30 minutes and 2), surface temperature of 70°C and holding time of 60 minutes. All EABs in the ash logs were killed under these conditions.

9. Preliminary investigation of vacuum/steam treatment of Asian long-horned beetles in naturally infested wood- July 2012

Chen, White, Mack, and Wang

A study to control Asian long-horned beetles (ALB) *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae) in naturally infested logs with the vacuum/steam technology were conducted at the Inner Mongolia Agriculture University, Hohhot City, Inner Mongolia Autonomous Region, China. As an environmentally friendly alternative to chemical treatment, this research focus on using vacuum and steam to treat ALB infested logs. The logs cut from willow trees were obtained from the heavily infested area in the north China were vacuum/steam treated at vacuum level 350 mmHg and steam temperature of 90°C. The results have shown that vacuum/steam treatment can kill the all ALB larvae in the naturally infested wood in less than 500 minutes for diameter ranging from 10 to 26 cm at various initial temperatures.

10.Vacuum Steam Phytosanitation of Wood Pallets and Pallet Stringers -February 2011

Chen, White

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Abstract The goal of this project was to investigate the utilization of vacuum/steam technology to accelerate the phytosanitation treatment of wood pallets and pallet parts (stringers) for compliance with ISPM 15. The combination of steam condensation and vacuum is one of most effective heat transfer mechanism because the steam carries large amount of heat and the condensation is fast to release the energy. The vacuum/steam system consists of a vacuum source (vacuum pump), controlling device, flexible container and a steam generator. The treatment system can create and regulate vacuum in the container. At the same time it can produce steam and maintain the saturation or superheated state within the container. Monitoring devices were attached to the equipment to record and control the process. Green and dry hardwood pallets and green pallet parts (stringers) were treated in this study. Vacuum was drawn to set pressure and then steam was injected into the container. The steaming was continued on until 56°C was reached at the center of stringers in assembled pallets or in the dead packed stringer parts. A series of tests were performed to document the treating times. The test results showed that the vacuum/steam treatment of pallets and parts is faster than currently used, hot air systems. Both dry and green pallets can be treated in less than 65 minutes which included a vacuum time around 5 minutes and holding time of 30 minutes after the stringers in the assembled pallet reached 56ºC. The dry pallets were treated faster than green pallets. The average treatment times of dry pallets were 7.1% and 10.4% faster than green pallets at 300 mmHg (400 mbar) and 500 mmHg (665 mbar) respectively. Wood species affects the treatment time. Yellow-poplar pallets were treated faster than the red oak pallets. The average treatment time of dry yellow-poplar pallets was 15.9% faster than that of dry red oak pallets at 300 mmHg (400 mbar). The stringer parts can be treated with various stacking methods, dead packed 2 layer, 5 layer and 12 layer stingers. The treatment took longest for the 12 layers (212 minutes) and shortest for 2 layers (132 minutes) with an average treatment time of 201 minutes for 5 layers. The vacuum/steam treatment of the assembled pallets and pallet stringers is faster than the current heat treatment and it can be a replacement for methyl bromide fumigation currently used to comply with ISPM 15.

11. Vacuum and steam to sanitize ash firewood - February 2011

Chen, White

Abstract

The goal of this project was to investigate the efficacy of vacuum/steam technology to sanitize low quality ash logs and ash firewood. It is difficult to heat treat logs and firewood because of the relatively large cross sectional dimension. Compared to hot air, steam has a greater heat capacity and the condensation without reducing the moisture content of wood results in more efficient heat transfer. Also, the pressure gradient created by the vacuum accelerates heat transfer

through the wood cross section. The vacuum/steam system consists of a vacuum source (vacuum pump), controlling device, flexible container and a steam generator.

The white ash logs and firewood were harvested in the Montgomery, Virginia. Ash log diameters ranged from 6.5 to 11 inches on the small end. The logs were cut into 6 foot lengths. After vacuum was drawn to 300 or 500 mmHg inside the container, steam was injected into the container. The steaming continued until 56°C was reached at the center of the logs. The treating time for all the logs varied from 5.5 to 14.5 hours which includes a vacuum and holding time of 30 minutes. The six feet logs were cut into 16 inches long bolts and then split into firewood, rarely larger than 6 inches on the wider side. The treating time for firewood varied from 80 to 137 minutes which includes vacuum and a holding time at 56°C of 30 minutes.

12. Determination of vacuum desiccation rate and lethal percentage weight loss of asian longhorned beetle and emerald ash borer larvae- July 2006

Chen, White, Keena, Poland, and Clarke

Abstract:

The potential was assessed for using vacuum technology to kill larvae of the Asian longhorned beetle (ALB), *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), and emerald ash borer (EAB), *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), in solid-wood packing materials (SWPM) and other wood products. Current regulations require that wood packing material be heat treated or fumigated prior to export. Vacuum treatment requires less energy input compared to heat treatment and eliminates environmental problems associated with chemicals used in fumigation. Low pressure, achieved by applying a vacuum to a system, imposes a controlled atmosphere and desiccating environment that results in death of wood infesting insects. Larval ALB and EAB, exposed or inserted into wood of various moisture levels, were subjected to different temperatures and pressures to determine desiccation rates and lethal percentage weight loss. Some ALB and EAB larvae died at 26% weight loss and all were dead at 40%. Desiccation under low pressure vacuum also killed ALB pupae and eggs. The desiccation rates of both ALB and EAB larvae under vacuum were linear until death. ALB lost weight faster than EAB under the same desiccating conditions; at 20 mmHg and 20 ºC the desiccation rates for ALB and EAB were 3.35% weight loss per hour and 2.39%, respectively. Temperature, pressure, and relative humidity affected desiccation rate. Larvae desiccated slower when inside moist wood. Lethal vacuum time could vary from 42 to 175 hours depending on wood moisture content.

13. Preliminary investigation of high vacuum to control Chinese longhorned beetles in naturally infested wood. -October 2006

Chen, Barak, White, Chen, Xie, and Yang

Abstract

Cooperative research to control wood boring beetles in naturally infested wood with high vacuum were conducted during 2006 at the Fujian Agriculture and Forestry University, Fuzhou City, Fujian Province, China. The wood infested by yellow grey longhorned beetle, *Apriona germari* (Hope), (Coleoptera: Cerambycidae) and pinewood longhorned beetle, *Monochamus alternatus* (Hope), (Coleoptera: Cerambycidae) was vacuum treated at 25±5 mmHg and room temperature of ca. 25°C in this study. The results have demonstrated that vacuum has potential to kill the beetles in the infested wood. It also showed that vacuum treating time was related to moisture content of wood.

14. Evaluation of the Efficacy of Vacuum Treatment for the Control of Emerald Ash Borer and Pinewood Nematode in Naturally Infested Wood-October 2007

Chen, White, Eisenback, Poland, Kuhn

Abstract:

The goal of this research was to develop a vacuum treatment process to eliminate insects and pinewood nematodes in wood products that include wood packaging materials. Vacuum treatment could be an alternative to the currently-used heat and chemical fumigation treatment procedures which consume energy and are harmful to the environmental associated with the generation of heat and chemical fumigants. Low pressure, achieved by applying a vacuum results in a desiccating environment and the death of wood-infesting insects and nematodes. The project consists of a series of experiments to investigate the vacuum treatment of naturally-infested wood. Ash stems naturally infested with emerald ash borer (EAB) larvae and southern pine boards naturally infested with the pinewood nematodes (PWN) were treated at 25°C and 6-10 mm Hg pressure. Both the ash and southern pine host material was green (i.e., fresh). The results showed that both EAB larvae and pinewood nematodes in naturally-infested wood were killed under vacuum conditions. EAB died in stems with a final average moisture content (MC) as high as 28%. However, a much lower average wood MC of around 7-9%, was required for PWN mortality.