Forintek Canada Corp.

Forintek Canada Corp.
Western Division
2665 East Mall
Vancouver, British Columbia V6T 1W5

Initiating Evaluation of Thermal-Oil Treatment for Post-MPB Lodgepole Pine

by

Jieying Wang
Wood Treatment Scientist
Durability & Protection

Prepared for

Forestry Innovation Investment

Recipient Agreement No.: FII-MDP-07-0014
Contract No.: 2007 - 5420

March 2007

Jieying Wang Project Leader	Rod Stirling Reviewer	Erol Karacabeyli Department Manager

© 2007 Forintek Canada Corp. All Rights reserved.

Summary

The general objective of this research was to investigate the feasibility of using oil-thermally treated post-Mountain Pine Beetle (MPB) lodgepole pine for above-ground residential products such as siding. As a continuation of the author's previous research on oil-thermal treatment done at the University of Toronto and extension to post-MPB lodgepole pine, the current project focused on the initiation of a series of field weathering, decay and termite field tests, and completion of some lab tests. During the year siding tests in Mississippi and in Vancouver, sandwich tests in Mississippi and in Vancouver, and termite test in Kincardine, were all successfully established, and all samples await evaluation one year after the setup.

The laboratory tests indicated that the oil-thermal treatment at 220ºC for 2 hours or even for 1 hour masked the blue-stain of post-MPB lodgepole pine sapwood very effectively. However, the oil thermally-treated pine showed unsatisfactory weathering performance in the very severe and wet accelerated weathering program. For real-world exposure this will only become apparent with much longer term natural exposure and can also be prevented by applying appropriate coating systems. The treatment also reduced the nail holding resistance significantly as expected, since thermal treatment is known to reduce certain mechanical properties of wood. The small-scale fire retardation evaluation tests showed that the oil-thermal treatment did not have a large impact on fire resistance, and the fire retardation was remarkably improved by post treatment with a commercial fire retardant.

Special surface treatments, or appropriate coating systems, should be developed for oil thermally-treated wood targeted at above-ground residential products.

©2007 Forintek Canada Corp. All rights reserved

Acknowledgements

Forintek Canada Corp. acknowledges the assistance provided by the Province of British Columbia through the Forestry Innovation Investment Market Development Program.

Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, Newfoundland and Labrador, and the Yukon Territory, for their guidance and financial support for this research.

The author would like to thank Dr. Paul Cooper and Mr. Tony Ung of the Faculty of Forestry, University of Toronto for the cooperation and collaboration of the oil-thermal treatment and other lab tests.

The author would like to thank Dr. Sam Williams and Mr. Peter Sotos of the Forest Products Laboratory of USDA of Madison, Wisconsin for the use of their Mississippi test site.

The author would also like to thank the Kincardine town council for the use of the termite test site in Kincardine, Ontario.

©2007 Forintek Canada Corp. All rights reserved

Table of Contents

©2007 Forintek Canada Corp. All rights reserved

List of Tables

List of Figures

©2007 Forintek Canada Corp. All rights reserved

©2007 Forintek Canada Corp. All rights reserved

1 Objectives

- Determine color changes of post-MPB lodgepole pine sapwood during the oil-thermal treatment
- Determine the weathering, fire and nail withdrawal performance of oil-thermally treated post-MPB lodgepole pine sapwood using laboratory tests
- Initiate field tests of weathering, decay and termite resistance for oil-thermally treated post-MPB lodgepole pine sapwood

2 Introduction

Wood thermal modification has been of particular interest in terms of its ability to improve dimensional stability and biological durability. Compared with wood treatments with preservatives or other chemicals, thermal treatment has the environmental advantage of being pesticide-free. The treatment processes which have been industrialized in recent years include: Thermo Wood (or Premium wood) developed in Finland (Syrjänen and Kangas 2000; Syrjänen 2001; Jämsä 2001; Militz 2002a, 2002b; Welzbacher and Rapp 2002), the Retification process (New Option Wood) and Bois Perdure in France (Dirol and Guyonnet 1993;Vernois 2001; Militz 2002a, 2002b; Welzbacher and Rapp 2002; Jermannaud *et al.*, 2002), and the Plato process in Netherlands (Tjeerdsma *et al.*, 1998a, 1998b, 2000; Militz and Tjeerdsma 2001; Boonstra *et al.*, 1998; Militz 2002a, 2002b; Welzbacher and Rapp 2002). All of these processes use steam or nitrogen gas in the case of the Retification process as the heating medium to exclude oxygen during the high-temperature treatment, and require accurate control of high temperatures for a given length of time to improve some wood properties. The duration for the high-temperature treatment lasts a few hours or longer, depending on the processes, heating media, wood species, and treatment purposes. In addition to the above industrialized processes, a somewhat different approach using oil as the heating medium has also been extensively investigated in Germany (Sailor *et al.*, 2000a, 2000b; Rapp and Sailer 2001; Militz 2002a, 2002b; Welzbacher and Rapp 2002; Nunes *et al.*, 2006), and it is likely to be commercialized in the near future. In recent years the research on oil-thermal treatment has been joined by the University of Toronto and other organizations (Wang and Cooper 2003; 2004; 2005a; 2005b; Spear *et al.*, 2006). It was demonstrated that the moisture resistance and biological durability of treated wood not only benefit from the high-temperature treatment, but also from the shell formed by water-repellent oil during the treatment.

This project is a continuation of the author's previous research on oil-thermal treatment done at the University of Toronto (Wang and Cooper 2003; 2004; 2005a; 2005b) and extension to post-MPB lodgepole pine. The previous research compared different heating media, including various vegetable oils, industry-use thermal oils and slack wax. Soybean oil stood out as the best option because soybean oil-treated wood showed higher decay and mould resistance than other types of vegetable oils during laboratory tests and exterior weathering tests. This was likely due to polymerization of the unsaturated fatty acids of soybean oil. Generally, vegetable oil is more thermally stable, cost-efficient and user-friendly than most mineral oils. Hence soybean oil has been chosen as the heating medium in this project. The previous research also investigated the effect of treatment temperatures and times on moisture, biological and mechanical resistance, and it was found that 220ºC was an optimal treatment temperature, with 2 hours as the best compromise for properties of treated wood between moisture resistance, biological durability and mechanical performance. It was found that after thermal-oil treatment of spruce and fir at 220ºC for 2 hours, both the hygroscopicity reduction and dimensional stability improvement (two indices for wood moisture resistance) were about 40%, and the mass loss was reduced from over 60% to 32% during laboratory decay tests against *Gloeophyllum trabeum*. Meanwhile, MOR and MOE

©2007 Forintek Canada Corp. All rights reserved

were reduced by about 40% and 20% respectively, together with significant reductions in abrasion resistance and hardness. So thermally treated wood is usually only recommended for above-ground non-structural uses where the reduced strength properties are less critical. The previous research has also indicated that thermal oil-treated wood can still hold coatings reasonably well, and that coating was very effective against weathering in outdoor applications. Additional research is needed to identify appropriate coating systems for outdoor above-ground residential applications.

Tests on thermally treated wood have not shown improved termite resistance. Plato-treated wood (non-oil process) did not show improved termite resistance either in lab tests or in field tests (Doi *et al.*, 2004). Both the choice and no-choice lab tests with *Reticulitermes* in both Canada (Cooper 2006, Report for Value to Wood Program) and Europe (Nunes *et al.*, 2006) indicated that oil-thermal treatment did not improve the termite resistance of spruce, Scots pine, Norway spruce or Eucalyptus, except under the conditions of very high retentions of oil in the case of using Scots pine and rape seed oil (Nunes *et al.*, 2006). Similar phenomena were also observed in research with more aggressive Formosan subterranean termites (*Coptotermes formosanus* Shiraki) (Smith *et al.*, 2003). Data on termite resistance of soy oil-thermal treated wood from field tests is still needed.

This project focuses on oil-thermal treatment of post-Mountain Pine Beetle (MPB) lodgepole pine to investigate the feasibility of using oil-thermally treated wood for above-ground residential products such as siding. The current stage emphasizes the initiation of a series of weathering, decay and termite field tests. This report also presents the color changes of blue-stained lodgepole pine during the treatment, data from the accelerated weathering test, as well as results from preliminary nail withdrawal resistance tests and fire retardation tests. All these tests were designed mostly as complementary tests to the previous research done at the University of Toronto.

3 Staff

Jieying Wang	Wood Treatment Scientist
Paul Morris	Group Leader, Durability and Protection
Dave Minchin	Wood Protection Technologist
Janet K Ingram	Wood Preservation Technologist
Shane McFarling	Wood Preservation Specialist
Lisa McCuaig	Chemical Technologist
Jaimie Garlough	Wood Preservation Process Technologist

4 Materials and Methods

4.1 Sample Preparation and Treatments

The wood used in this project was mainly 1 in. by 6 in. post-MPB blue-stained lodgepole pine sapwood boards. The boards were cut into different lengths, including 600 mm for siding tests, 400 mm for termite tests, 300 mm for above-ground sandwich tests, and smaller lengths for accelerated weathering tests (Weather-Ometer test) and other preliminary tests. End-matched pine samples from the same boards were processed for the various treatments and various test sites wherever possible, with approximately 20 replicates for each test. Non-blue-stained pine samples were also included as reference samples for the treatment and also for some tests. The air-dry wood samples had moisture content ranging from 9% to 11% before the oil-thermal treatment. The treatment was carried out with a one-metre long oil bath in the

©2007 Forintek Canada Corp. All rights reserved

wood science lab at the University of Toronto, instead of much smaller oil baths used in the previous research. Soybean oil was used as the heating medium, and the same oil was used for all the samples in this project, with fresh oil added occasionally, instead of using a maximum oil heating time of about 40 hours in the previous research. All treatments were carried out at 220ºC, with treatment times of 1 or 2 hours. The temperature in the oil and in the wood was monitored using thermocouples, and recorded during the first few batches of the treatment. It was found that the temperature control system of the treatment facility was sufficiently precise for this purpose. Based on the temperature changes in wood during the treatment (Figure 1), it was determined that it took half an hour for the centres of 1 in. by 6 in. samples to reach the target temperature. Therefore, the actual treatment time, i.e. the time wood immersed in hot oil, was the target treatment time of 2 hours or 1 hour plus an extra 0.5 hour preheating time. Wood was conditioned in an oven at 100ºC for about 20 hours after the thermal treatment. In general, the entire treatment process was very easy, indicating such a treatment should be able to be carried out on a larger scale without too many barriers.

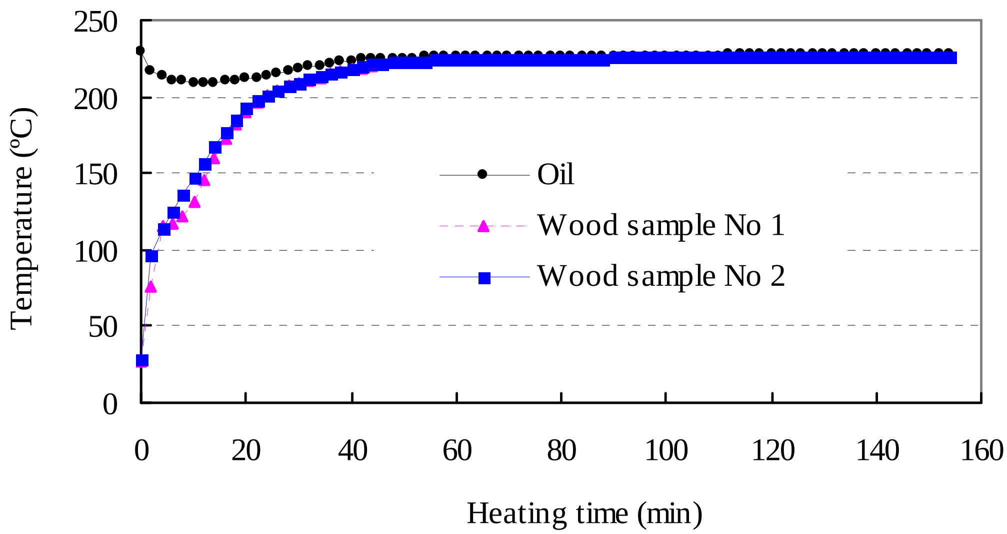


Figure 1   Temperature changes of oil and wood during the oil-thermal treatment at 220ºC

Pine samples with various dimensions for various tests were pressure treated with alkaline copper quat (ACQ-D) targeting at the retention 4.0 Kg/m^3 for above-ground application. The solution strength was 0.62% using the following treatment schedule: 30 min vacuum at 740 mm Hg, filling retort under vacuum, applying pressure for 1 hour at 1035 KPa, empty retort, then a final 15 minutes vacuum at 740 mm Hg. These samples were used as reference samples for the siding tests, sandwich tests, termite test and accelerated weathering test. The western red cedar reference samples for these tests, each with about 20 replicates, were processed from different boards.

4.2 Siding Tests in Mississippi and Vancouver

4.2.1 Setup of Siding Tests in Mississippi and Vancouver

The main purpose of the siding test is to investigate the outdoor above-ground performance of differently treated samples, under UV exposure, attack by microorganisms, and moisture and temperature fluctuations. Five treatments were included in the tests: pine samples oil-thermally treated at 220ºC for 2 hours, pine oil-thermally treated at 220ºC for 1 hour, untreated pine, ACQ-treated pine, and untreated western red cedar. The samples were set up vertically (90º) facing south on wood racks in Mississippi in

©2007 Forintek Canada Corp. All rights reserved

early November 2006 (Figure 2), and against walls in the Forintek backyard test site in Vancouver in early January 2007 (Figure 3). Stainless steel nails were used as fasteners, and all samples with the same treatments were set up in same columns on cedar racks to avoid potential contamination by leaching. The first assessment is scheduled to be carried out in one year after the setup.

4.2.2 Conditions of the Mississippi Test Site

The Mississippi test site is in Gulfport Mississippi, managed by the USDA Forest Products Laboratory. It represents a southern warm and humid climate (Table 1, Morris *et al.*, 2004; Morris and McFarling 2005). It has a Scheffer's climate index around 70, representing a high decay hazard for outdoor above-ground wood products (Scheffer 1971). Such a test site can also be used as a naturally accelerated condition experienced in Canada for tests of outdoor products, and based on the research on coating performance done by Forintek, the acceleration factor was around 2 between Mississippi and Vancouver for most coating systems. However, the same acceleration factor may not apply for wood weathering in this case.

Table 1 The weather conditions at the Mississippi test site based on a two-year on-site monitoring (Morris et al., 2004)

Weather		**Mississippi**
Normal mean annual temperatures (ºC)		19.9
Normal mean annual rainfalls (mm)		1593
On-site measurements (2.5 hour intervals)	Mean RH (%)	85
	Frequency of 100% RH (%)	49

4.2.3 Conditions of the Forintek Backyard Test Site

The Forintek backyard test site represents the west coast mild climate, very different from the climate in Mississippi. It has an average annual temperature about 10°C, with a December average of 3°C and a July average of 17°C. It receives about 1900 hours of bright sunshine and approximately 1250 mm of precipitation per year, with an average 34 mm of rain in July and 140 mm of rain in December. It falls within the moderate decay hazard zone based on Scheffer's climate index, with a Scheffer's climate index of 45 (Setliff 1986). The predominant wood rotting basidiomycetes at this site, as indicated by fruit body production, are *Gleophyllum sepiarium*, a *Merulius* species, a *Stereum* species and *Gleophyllum protractum*.

©2007 Forintek Canada Corp. All rights reserved

Figure 2 An overview of the siding test at the Mississippi test site

Figure 3 An overview of the siding test at the Vancouver test site

Forintek Canada Corp.

©2007 Forintek Canada Corp. All rights reserved

4.3 Sandwich Tests in Mississippi and Vancouver

The sandwich test was developed by Dr. Paul Morris and the main purpose of the test is to investigate wood deterioration under shaded outdoor above-ground conditions with potential accumulation of entrapped water, simulating conditions experienced by outdoor above-ground wood structure components. Samples were set up on aluminum racks with corrugated plastic boards (Coroplast) separating samples from each other. The aluminum racks were surface protected with Tuck Tape in order to avoid potential corrosion, especially by copper leaching from ACQ-treated wood. Just as in the above siding test, five treatments were included in the sandwich tests, and samples were set up in Mississippi in early November 2006 and in Vancouver in early December 2006 (The test site conditions are described in 4.2.1). At the Mississippi test site plastic coated wire was used through pre-drilled holes of each plastic board to fix all samples together and also to the racks (Figures 4 and 5), and at the Forintek backyard test site in Vancouver elastic was used instead to bind samples together on racks (Figure 6). In Mississippi each aluminium rack was fixed on an additional wood rack in order to keep samples above the tall grass. The first assessment is scheduled to be carried out in one year.

Figure 4 Setup of the sandwich test at the Mississippi test site

©2007 Forintek Canada Corp. All rights reserved

Figure 5 An overview of the sandwich test at the Mississippi test site

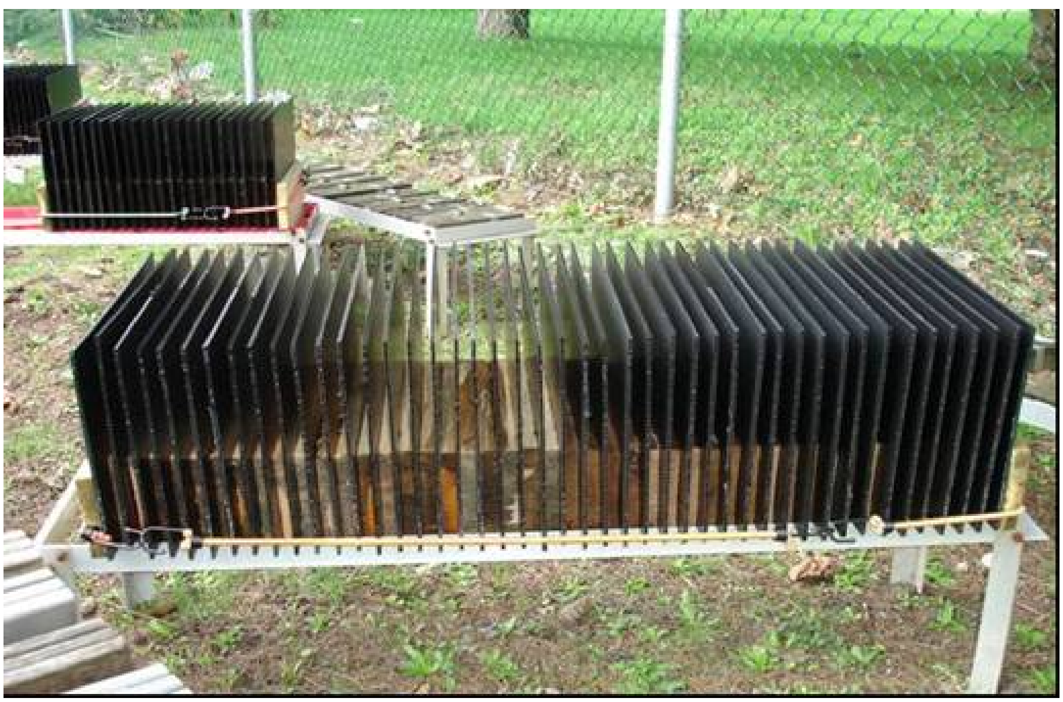


Figure 6 Setup of the sandwich test at the Vancouver test site

©2007 Forintek Canada Corp. All rights reserved

4.4 Termite Test in Kincardine

4.4.1 Setup of Termite Test

In order to evaluate the termite resistance of oil-thermally treated wood in the field against *Reticulitermes*, one of the most common termite species threatening wood products, a termite field test was set up in Kincardine at the end of August 2006. As in the above siding tests, five treatments were used, and five samples with different treatments were assembled in advance into bundles, tied with plastic strings, separated by plastic boards, in a total of 20 combinations. These bundles were placed on concrete blocks, which have holes allowing inside feeder strips connecting these bundles to the ground. Ponderosa pine heartwood was used as feeder strips (Figure 7). The sample bundles and concrete blocks were then housed in wooden frames topped with a double layer of shade cloth. The shade cloth allowed for exposure to full precipitation but only to partial sunshine (Figure 8). Hence, this test is a partially protected above-ground termite test, intending to simulate conditions which could be experienced by outdoor above-ground wood uses such as siding in areas with *Reticulitermes* termite hazard. The turf in the surrounding area was removed during the setup, and extra feeder stakes were distributed between this test and the most active area of the site in order to attract termites. The first termite assessment is planned to be carried out one year after the setup.

4.4.2 Conditions of the Kincardine Test Site

The Kincardine test site is located within the town of Kincardine near Toronto, ON. It was established in 1988, with an active subterranean termite population ever since (Morris and Ingram 2004). The site receives a mean annual precipitation of 998 mm and has mean daily maximum and minimum temperatures of -2°C and -10°C in January, and 24°C and 13°C in July. The climate places it within the moderate decay hazard zone for outdoor above-ground wood structures, with a Scheffer's climate index of 43. The soil in the test site is sandy loam.

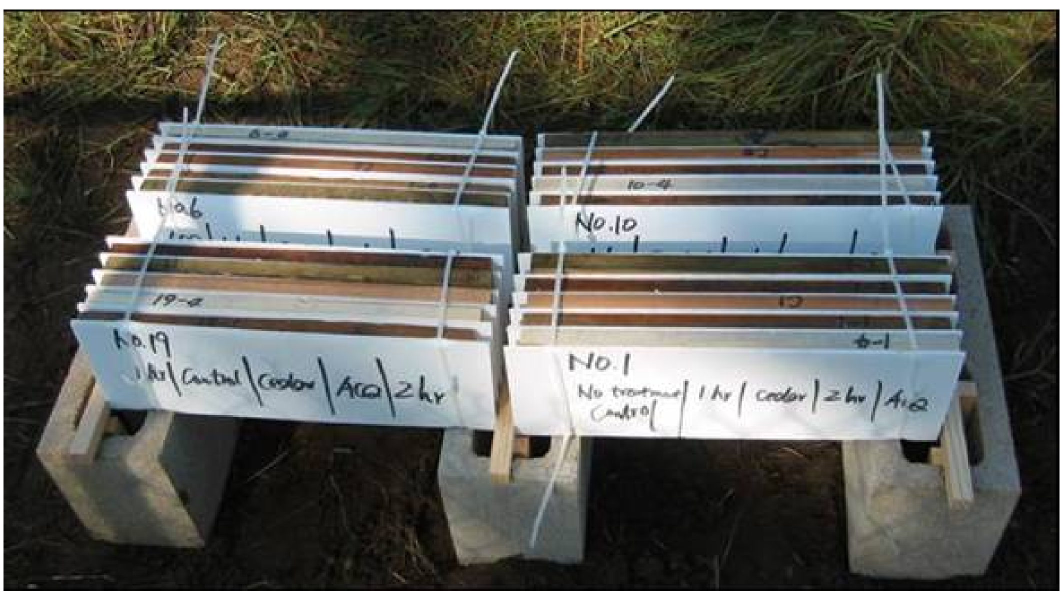


Figure 7 Assembly of samples on concrete blocks for termite test at the Kincardine test site

©2007 Forintek Canada Corp. All rights reserved

Figure 8 An overview of the termite test boxes at the Kincardine test site

4.5 Accelerated Weathering Test in the Lab

The accelerated weathering test was done using an Atlas Weather-Ometer® (model Ci65A) equipped with a 6500 watt, Xenon arc UV lamp and borosilicate inner and outer filters. This light source irradiated samples with near equal sunlight exposure with lower UV wavelength cut-off at about 290 nanometers. As the other tests in this project, five different wood treatments were tested under the same conditions. All the pine samples were end-matched lodgepole pine sapwood samples, with replicates of 20 for pine samples oil-thermally treated at 220ºC for 2 hours, and replicates of 16 for pine thermally treated at 220º for 1 hour, untreated pine, ACQ-treated pine and western red cedar. This weathering test lasted a total of 2000 hours, from late November 2006 to the middle of February 2007. The test program consisted of four phases (Figure 9): in each 2-hour cycle, there was light with water spray in the first 30 minutes, no light and no water spray in the second 30 minutes, no light with water spray in the third 30 minutes, and light and no water spray in the last 30 minutes. The purpose was to test the weathering performance of the oil-thermally treated samples under extremely severe UV and moisture conditions and also to compare the performance of the different treatments, as a complimentary test to the two-year natural weathering test done in Toronto.

©2007 Forintek Canada Corp. All rights reserved

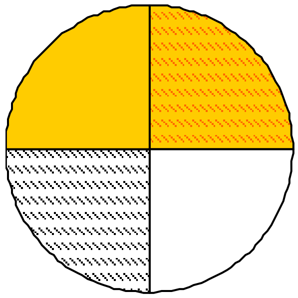


Figure 9 Weather-Ometer cycle

During the weathering test, moisture contents of all samples were monitored by weighing each sample in order to see the water resistance changes of these different treatments. They were weighed occasionally right after a dry phase (the phase with UV but no water-spray) or a wet phase (the phase without UV but with water-spray). After the test when the samples were sufficiently dry, the front face (facing UV and water spray during the test) and back face of each sample was visually assessed based on a rating system adopted from the Forest Products Laboratory (FPL) that inspects for discoloration, mold/stain, erosion and so on (Table 2, Morris *et al.,* 2004). Each evaluation was rated on a scale from 1 (complete failure) to 10 (perfect), and the overall general rating was assigned as the average rating of the evaluation group. Samples were also photographed in order to compare the surface changes before and after treatments or the weathering test.

4.6 Preliminary Nail Withdrawal Resistance Test

The preliminary nail withdrawal resistance test was done according to ASTM D 1037: Nail Withdrawal Test, in the wood science lab at the University of Toronto, with the mechanical testing machine Zwick/Z100. The samples were air-dry, about 160 mm long, with a cross section of 1 in. by 6 in. Oil-thermally treated samples were end matched with untreated references, both for blue-stained and non-blue-stained lodgepole pine. Fourteen to sixteen replicates were prepared for each condition. All the oil-thermally treated samples were treated at 220ºC for 2 hours. The nails were purchased from a local Home Hardware store. They were galvanized roofing nails, 2 inches long, with a shank diameter of 0.15 in. and nail head diameter of approximately 0.45 in. This type of nail was chosen instead of siding nails or other common nails, since it had the right size for the test fixture, with a big nail head to produce ease and accuracy for driving nails vertically into wood samples. On the other hand, it was reported that thermal modification does increase corrosion (Jermer and Andersson 2005), so galvanized or stainless fasteners, despite being much more expensive, could be a necessity for long-term exterior applications. The nails were driven into and just through wood using a small press, so no splitting occurred during the process, and immediately after that the nail withdrawal resistance was tested. At a testing speed of 1.5 mm/min, the maximum load required to withdraw the nail was recorded. Small samples were then cut and used to determine the moisture contents of test samples.

©2007 Forintek Canada Corp. All rights reserved

4.7 Preliminary Fire Retardation Test

Samples of three treatments were included in the fire retardation test: untreated post-MPB lodgepole pine sapwood (untreated pine), pine treated with soybean oil at 220ºC for 2 hours (oil thermally-treated pine), and hot oil- and fire retardant-treated samples (double-treated pine). For the double treatments, pine samples were first treated with soybean oil at 220ºC for 2 hours at the University of Toronto, then they were shipped to Chemco in Ferndale Washington, one of Forintek's associate members, for treatment with their commercial fire retardant. This fire retardant is mainly used by Chemco to treat exterior cedar shingles and shakes and it is one of the very few commercial fire retardants in North America for treating wood shingles and siding to meet the very rigorous fire requirements in California. A solution strength of 19.5% was used for pressure impregnation and the chemical loading was approximately 16% based on the oven-dry weight. Due to the limited funding of this project, small-scale fire retardation evaluation tests, including the crib test and the two-foot tunnel test, were carried out by the wood science lab of the University of Toronto. The replication for both tests was five for each condition.

The crib test was mainly used to observe the burning process. It was done according to ASTM standard E 160-80: Standard Test Method for Combustible Properties of Treated Wood by the Crib Test. The test was carried out in a fume hood with ventilation as low as possible. 24 pieces of small strips with the dimension of 0.5 x 0.5 x 3 in. were assembled in a wire frame according to the standard, and samples were ignited by a gas burner standard flame intensity for 3 min before left with continued flaming and glowing. The duration of the continued flaming time and the mass loss during the combustion (based on oven-dry weight) were determined and compared. The continued glowing time was observed but not determined since it is very subjective to determine once wood samples split into small pieces during combustion.

The two-foot tunnel test was mainly used to observe flame spread on material surfaces, and the main reference used in this project was ASTM D 3806-98: Standard Test Method of Small-Scale Evaluation of Fire-Retardant Paints. During the test, each group of samples consisted of 2 pieces (with the dimension of 1 x 3 x 11.5 in.) of samples with the same treatment. Each group was placed in the two-foot tunnel and ignited by a burner with standard flame intensity for 4 min. The total flame spread length (according to the color change of wood), as well as the absolute mass loss (based on air-dry weight), was evaluated after glowing had completely ceased. Cement board was used as a non-combustible reference to compare the flame spread.

5 Results and Discussion

5.1 Color Changes and Other Phenomena during Oil-Thermal Treatment

After the oil-thermal treatment, the color of pine changed to brown, and most of the original blue stain caused by mountain pine beetles was efficiently masked by this dark color, especially at the longer treatment time of 2 hours. On average, the 60 cm long blue-stained samples picked up about 8% of their weight in oil at 220ºC for 2 hours and also for 1 hour (assuming that 5% of the wood mass was lost due to thermal decomposition (Wang and Cooper 2005b)). Full-size lumber will pick up less oil during the treatment due to its lower ratio between the end grain areas and the total surface areas. Oil absorption varied greatly, and it was found that a small number of samples picked up significantly more oil, which darkened the wood color greatly. The blue-stain may increase the oil absorption, but for most of the samples the differences were not significant. One of the concerns that surfaced was that the oil-thermal

©2007 Forintek Canada Corp. All rights reserved

treatment loosened most of the knots, probably by thermally breaking down and even dissolving the surrounding structures.

Figures 10, 11 and 12 show that the wood color changed to brown, most of the blue-stain was efficiently masked by the dark color, and generally the wood color became more uniform after the oil-thermal treatment.

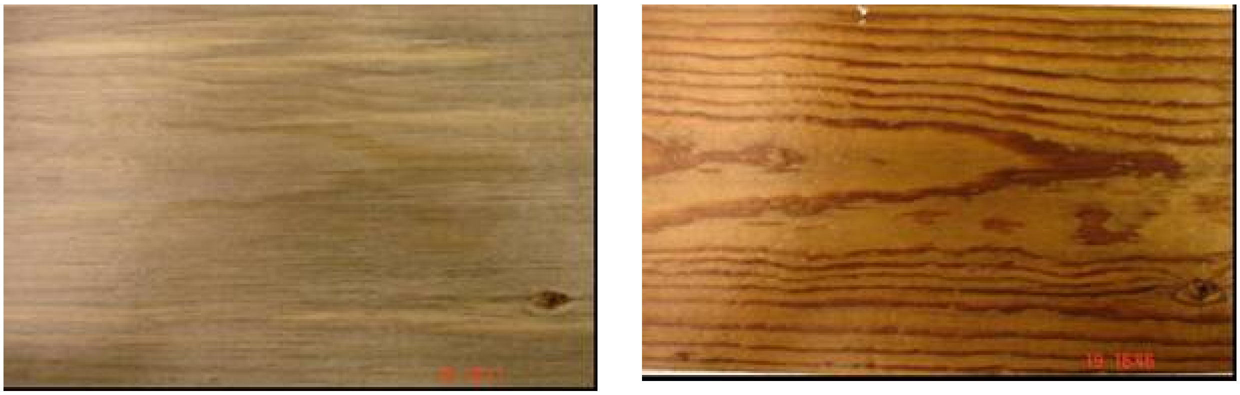


Figure 10 Sample 50-2, 2 hour's treatment, blue-stain was masked

Figure 11 Sample 8-2, 2 hours' treatment, blue-stain was masked

Figure 12 Sample 16-2, 2 hours' treatment, blue and brown-stain were masked

©2007 Forintek Canada Corp. All rights reserved

Figures 13 and 14 show that the oil-thermal treatment loosened knots, except for the originally tight ones.

Figure 13 Loose knots were missing after 2 hours' oil-thermal treatment

Figure 14 Sample 10-2, 2 hours' treatment, tight knots survived during the treatment

After the oil-thermal treatment, oil residue was found on some wood samples (Figure 15), and some samples had extremely high oil retention and dark color (Figures 16, 17 and 18).

Figure 15 Sample 3-2, 2 hours' treatment, oil residue on the surface of the treated board

©2007 Forintek Canada Corp. All rights reserved

Figure 16 Sample 17-2, 2 hours' treatment, high oil absorption

Figure 17 Sample 18-2, 2 hours' treatment, very high oil absorption

Figure 18 Sample 18-1, 1 hour's treatment, very high oil absorption

©2007 Forintek Canada Corp. All rights reserved

Figure 19 shows that some of the blue-stain was still visible after the oil-thermal treatment, especially for samples treated only for 1 hour.

Figure 19 Sample 9-1, 1 hours' treatment, blue-stain was still visible

It was also noticed that high initial moisture content could cause wood drying defects such as blistering and honeycombing, if wood is directly immersed into high-temperature oil. Multi-step oil temperature elevation could be a solution in that case, at the cost of longer treatment times.

5.2 Performance of Oil Thermally-Treated Wood during Accelerated Weathering Test

5.2.1 Moisture Content Changes of Different Treatments

Figure 20 shows moisture content changes in the five treatment groups during the accelerated weathering process at the end of dry phases or at the end of wet phases. Figures 21 and 22 show the moisture content changes with the logarithm of time for the dry phases and the wet phases, respectively. Among the five treatments, the two oil-thermal treatments did not differ much, and both of them showed an increase trend of water absorption with weathering time. In the beginning, these samples had much lower water absorption than any of the other samples, but their moisture contents were as high as 80% after 2000 hr of weathering, either at the end of the dry or wet phases. Their moisture content was even higher than those of the untreated pine or ACQ-treated pine at the end of the cycle. The oil-thermally treated wood had much lower and more stable moisture contents than the untreated samples during the natural outdoor weathering test done in Toronto (Wang and Cooper 2005b). The significant increase in water absorption with weathering time in this test can probably be explained by the rapid leaching and redistribution of oil as a result of severe deterioration under such an aggressive weathering program. This is supported by the phenomena of wood surface changes. It was observed that the front face of oil-thermally treated samples looked oily and water-repellent only in the beginning of the test. On the other hand, it is not of great surprise to see high water absorption for thermally treated wood, especially in the absence of oil, since high-temperature treatment may open up some wood microstructures (Vernois 2001; Hietala *et al.,* 2002; Wang and Cooper 2005b). It should also be pointed out that water absorption observed and monitored here is different from concepts such as hygroscopicity, moisture adsorption or dimensional stability. The improved dimensional stability and the reduced hygroscopicity of oil-thermally treated wood were not significantly lost during water soaking, and were still largely retained after rigorous chloroform extraction. This is because oil-thermal treatment causes fundamental structure changes on a molecular level, not just changes in extractives.

©2007 Forintek Canada Corp. All rights reserved

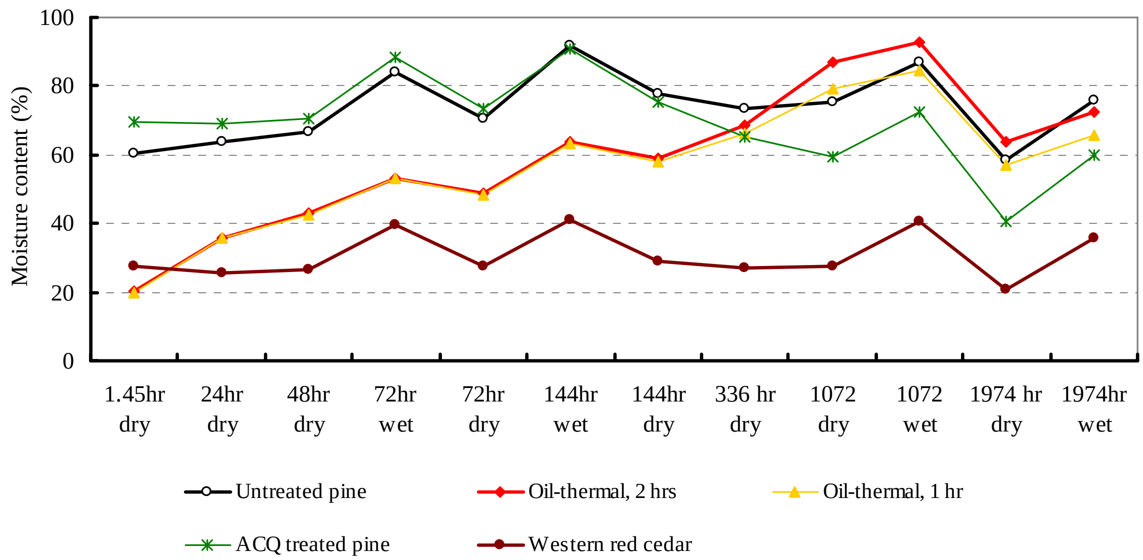


Figure 20 Moisture content changes at the end of both the dry phases and the wet phases during the accelerated weathering test

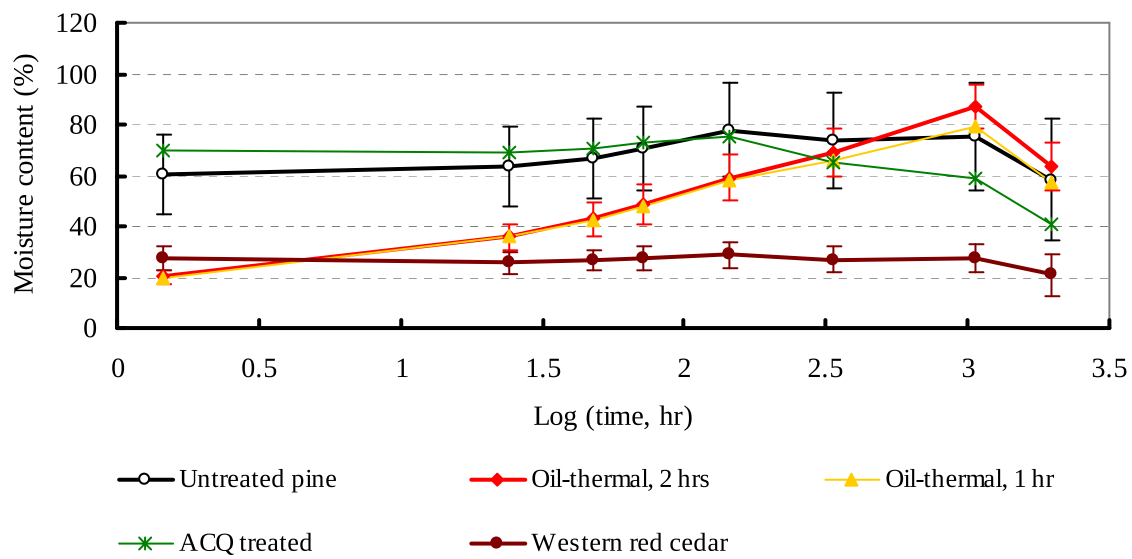


Figure 21 Moisture content changes with time (log(time)) at the end of the dry phases during the accelerated weathering test

©2007 Forintek Canada Corp. All rights reserved

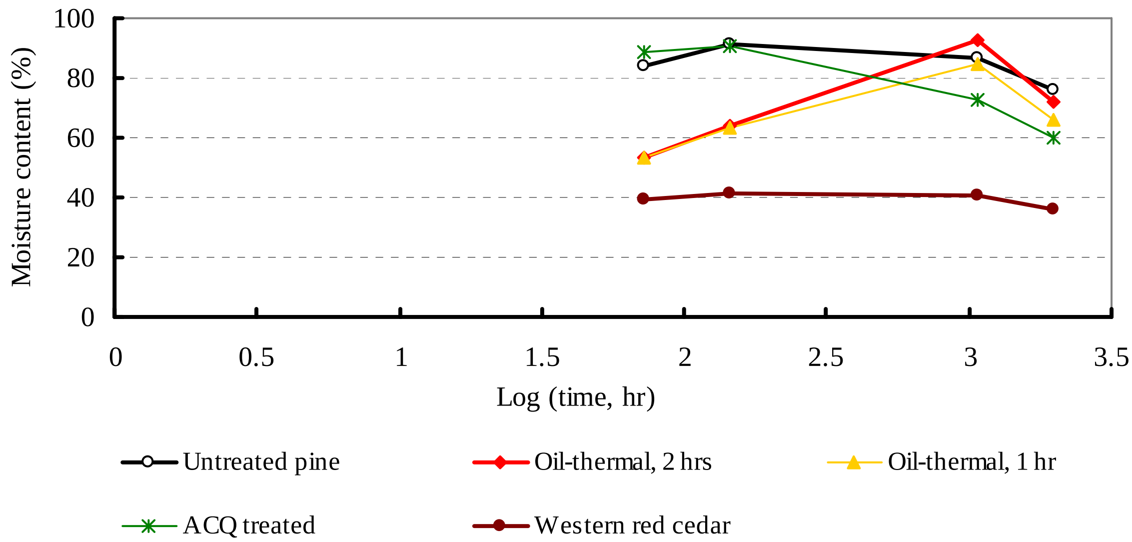


Figure 22 Moisture content changes with time (log(time)) at the end of the wet phases during the accelerated weathering test

5.2.2 Performance during the Accelerated Weathering Test

All samples experienced very dramatic color changes on the front face in the accelerated lab weathering test (Figure 23 and Table 2). ACQ-treated wood showed the least color change, and the oil thermally treated pine the most color change. The oil thermally-treated pine also had the most severe stain development on the front face at locations in contact with metal clamps in the Weather-Ometer®, with the back face appearing oilier than before the test. This was attributed to oil redistribution and leaching. These samples also showed greater surface erosion than any other groups, which could be related to lower mechanical strength after the high-temperature treatment. These results again are quite different than the observations during the two-year natural weathering test in Toronto. In that test, the oil thermally-treated wood had better performance against stain than the untreated spruce or fir. The differences were likely not caused by the difference in wood, but by the difference in weathering intensity. Comparing the oil-thermal treatment for 2 hours and 1 hour in this project, the back faces of samples treated for 1 hour showed more stain after the test, indicating 2 hours treatment is better than 1 hour treatment in terms of improving biological durability of treated wood, which is consistent with the observation at the University of Toronto. This accelerated test indicates that oil thermally-treated wood could have unsatisfactory weathering performance during long-term outdoor use, without any other surface protection. For real-world exposure this will only become apparent with much longer term natural exposure and can also be prevented by applying appropriate coating systems.

©2007 Forintek Canada Corp. All rights reserved

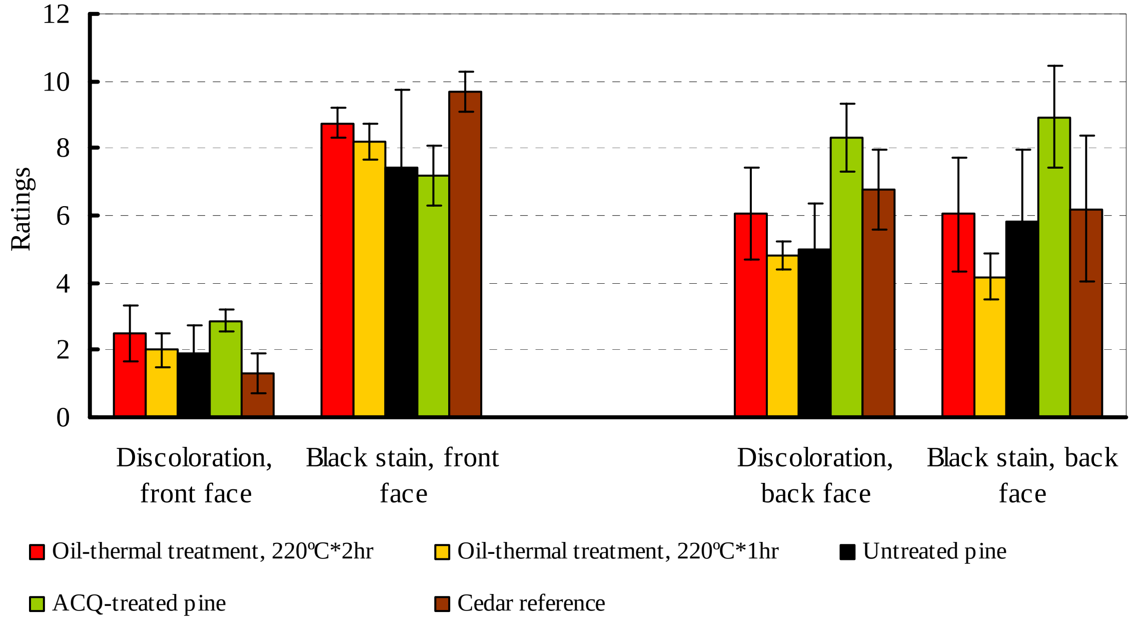
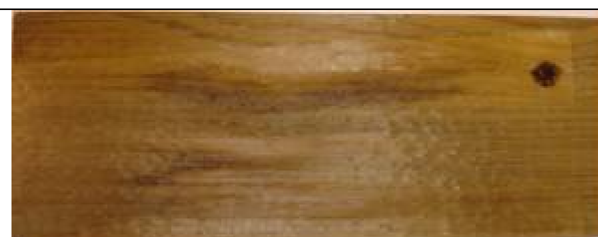


Figure 23 Discoloration and black stain ratings of the front and back faces of samples during the accelerated weathering test

©2007 Forintek Canada Corp. All rights reserved

Table 2 Discoloration and black stain on the front and back faces of samples after the accelerated weathering test

Front face	***Back face***
	
	
	
	
	

*The treatments are, from the top down, oil-thermal treatment at 220ºC for 2 hours, 220ºC for 1 hour, untreated pine, ACQ-treated pine, and western red cedar.

5.3 Results of the Preliminary Nail Withdrawal Resistance Test

The oil-thermal treatment at 220ºC for 2 hours caused about a 40% reduction in nail holding resistance, both for the blue-stained and non-blue-stained samples (Figure 24). Previous research at the University of Toronto showed such a treatment condition reduces MOR by about 40% and MOE by about 20%. It also reduces wood hardness and surface abrasion (unpublished data). During the nail withdrawal testing, the

©2007 Forintek Canada Corp. All rights reserved

untreated samples had about 10% moisture content, while the moisture content of the hot oil treated samples was only about 4%, due to the much lower hygroscopicity after the oil-thermal treatment. Therefore it is not reasonable to condition the samples to the same moisture content. The reduction in nail holding can be attributed to the lower binding strength between wood fibres as a result of the thermal decomposition of wood components, especially the lignin and hemicellulose, and the oil in wood potentially acting as a lubricant. For siding and shingles use, since the wood will be nailed to the base supporting materials such as strapping sticks, the nail holding is not so critical, but the effect of thermal treatment on splitting should also be investigated in the future.

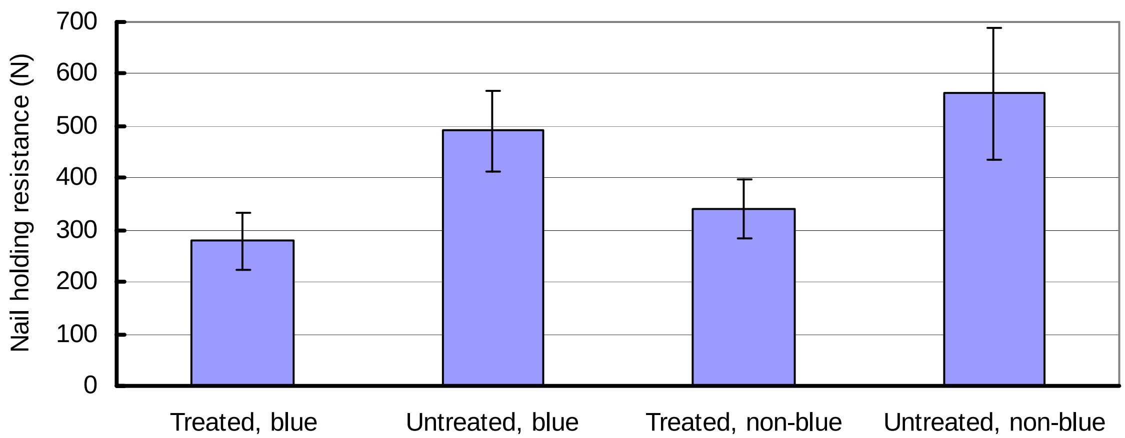


Figure 24 Nail withdrawal resistance of blue-stained and non-blue-stained lodgepole pine with and without the oil-thermal treatment at 220ºC for 2 hours

5.4 Results of the Preliminary Fire Retardation Test

The oil thermally-treated pine showed similar mass loss, but shorter continued flaming time than the untreated wood during the crib test, and lower mass loss but longer flame spread during the two-foot tunnel test (Table 3, Figure 25). Such results are reasonably consistent with the previous tests at the University of Toronto (Wang and Cooper 2007). The results indicated that the oil-thermal treatment reduced the flame resistance by approximate 10%, possibly as a result of the extra fuel from the oil residue in wood surfaces. However, the oil-thermal treatment did not have a significant impact on the general fire resistance. Part of this effect could be contributed by the changes of wood components during the high-temperature treatment, i.e., the lower proportion of hemicellulose and the higher proportion of lignin in wood as a result of the thermal treatment (Alen *et al.*, 2002, Wang and Cooper 2003). The double treatment proved that the fire retardation performance of oil thermally-treated pine can still be remarkably improved by post treatment with a commercial fire retardant.

©2007 Forintek Canada Corp. All rights reserved

Table 3 Results on fire retardation evaluation from the crib test and the two-foot tunnel test

Treatments	**Crib test**		**Two-foot tunnel test**	
	Mass loss (%)	**Continued flaming time (s)**	**Mass loss (g)**	**Flame spread (mm)**
Untreated pine	88.5	136	18.2	527
Oil thermally-treated pine	88.3	113	15.8	579
Double-treated pine	33.3	82	14.2	369
Cement board	Not determined			165

Figure 25 Flame spread pattern on untreated pine, oil thermally-treated pine and double-treated pine with oil-thermal treatment and fire retardant treatment (three treatments from the top to the bottom) during the two-foot tunnel test

6 Conclusions

After the oil-thermal treatment at 220ºC for 1 hour and 2 hours, the color of all wood samples changed to brown, most of the blue-stain of post-MPB lodgepole pine sapwood was masked efficiently, and its color became more uniform, especially after 2 hours' treatment.

During a very severe weathering test, the oil thermally-treated pine samples showed a dramatic increase in water absorption with weathering time, and they also showed unsatisfactory stain and discoloration development, as well as erosion, compared with ACQ-treated pine or western red cedar.

The oil-thermal treatment at 220ºC for 2 hours reduced the nail holding resistance by about 40% for both blue-stained and non-stained lodgepole pine sapwood.

Forintek Canada Corp.
©2007 Forintek Canada Corp. All rights reserved

The oil-thermal treatment reduced the flame resistance by about 10%, but the treatment did not have a significant impact on the general fire resistance, and its fire retardation performance can be remarkably improved by post treatment with a commercial fire retardant.

7 Recommendations

Special surface treatments, or appropriate coating systems, should be developed for oil thermally-treated wood to further improve the weathering performance for the treated wood to be targeted at above-ground residential products.

8 References

Alen, R., R. Kotilainen, A. Zaman. 2002. Thermochemical behaviour of Norway spruce (*Picea abies*) at 180-225°C. Wood Science and Technology 36: 163-171.

Boonstra, M. J., B. F. Tjeerdsma and H. A. C. Groeneveld. 1998. Thermal modification of non-durable wood species. 1. The Plato technology: Thermal modification of wood. IRG/WP 98-40123, IRG Secretariat, Stockholm, Sweden.

Dirol, D. and R. Guyonnet. 1993. The improvement of wood durability by retification process. The international research group on wood preservation, IRG/WP 93-40015, IRG Secretariat, Stockholm, Sweden.

Doi S., K. Hanata, E. Kamonji and Y. Miyazaki. 2004. Decay and termite durabilities of heat treated wood. The international research group on wood preservation, IRG/WP 04-40272, IRG Secretariat, Stockholm, Sweden.

Hietala, S., S. L. Maunu, F. Sundholm, S. Jämsä and P. Viitaniemi. 2002. Structure of thermally modified wood studied by liquid state NMR measurements. Holzforschung 56:522-528.

Jermannaud, A., L. Duchez and R. Guyonnet. 2002. Wood retification in France: An industrial process of heat treatment producing lumber with improved resistance to decay. Pages 121-122 in Enhancing the Durability of Lumber and Engineered Wood Products, Forest Products Society, US.

Jermer, J. and B. L. Andersson. 2005. Corrosion of fasteners in heat-treated wood – progress report after two years' exposure outdoors. The international research group on wood preservation, IRG/WP 05-40296, IRG Secretariat, 44 Stockholm, Sweden.

Militz, H. and B. Tjeerdsma. 2001. Heat treatment of wood by the PLATO-process. Pages 23-34 in Review on heat treatments of wood, Proceedings of the special seminar held in Antibes, France, on 9 February 2001, Forestry and Forestry Products, France. COST Action E22, EUR 19885, Edited by A. O. Rapp.

Militz, H. 2002a. Thermal treatment of wood: Europe process and their background. The international research group on wood preservation, IRG/WP 02-40241, IRG Secretariat, SE-100, 44 Stockholm, Sweden.

Militz, H. 2002b. Heat treatment of technologies in Europe: Scientific background and technological state-of-art. Pages 239-250 in Enhancing the Durability of Lumber and Engineered Wood Products, Forest Products Society, US.

©2007 Forintek Canada Corp. All rights reserved

Morris, P. I., S. McFarling and K. Groves. 2004. Field performance of commercial natural finishes. Report No. 35 to the Canadian Forest Service. Forintek Canada Corp., Vancouver, BC.

Morris, P. I. and J. Ingram. 2004. Fifteen year-performance of treated lumber in test sites with and without termites. Report No. 14 to the Canadian Forest Service. Forintek Canada Corp., Vancouver, BC.

Morris, P. I. and S. McFarling. 2005. 24 Month evaluation of novel UV protection systems. Report No. 35 to the Canadian Forest Service. Forintek Canada Corp., Vancouver, BC.

Nunes. L., T. Nobre, C. Welzbacher and A. O. Rapp. 2006. Termite response to oil-heat-treated Norway spruces, Scots pine and Eucalyptus wood. The international research group on wood preservation, IRG/WP 06-20325, IRG Secretariat, Stockholm, Sweden.

Rapp, A. O. and M. Sailer. 2001. Oil heat treatment of wood in Germany-State of the art. Pages 43-60 in Review on heat treatments of wood, Proceedings of the special seminar held in Antibes, France, on 9 February 2001, Forestry and Forestry Products, France. COST Action E22, EUR 19885, Edited by A. O. Rapp.

Brischke, C. and Rapp, A. O. 2004. Investigation of the suitability of silver fir (*Abies alba* Mill.) for thermal modification. The international research group on wood preservation, IRG/WP 04-40275, IRG Secretariat, Stockholm, Sweden.

Sailer, M., A. O. Rapp and H. Leithoff. 2000a. Improved resistance of Scots pine and spruce by application of an oil-heat treatment. The international research group on wood preservation, IRG/WP 00-40162, IRG Secretariat, Stockholm, Sweden.

Sailer, M., A. O. Rapp and H. Leithoff and R.-D. Peek. 2000b. Upgrading of wood by application of an oil-heat treatment. Holz als Roh- und Werkstoff 58:15-22.

Scheffer, T.C. 1971. A climate index for estimating potential for decay in wood structures above ground. Forest Products Journal 21(10): 25-31.

Setliff, E. C. 1986. Wood decay hazard in Canada based on Scheffer's climate index formula. The Forestry Chronicle (October): 456-459.

Smith, W. R., A. O. Rapp, C. Welzbacher and J. E. Winandy. 2003. Formosan subterranean termite resistance to heat treatment of Scots pine and Norway spruce. The international research group on wood preservation, IRG/WP 03-40264, IRG Secretariat, Stockholm, Sweden.

Spear, M. J., C. A. S. Hill, S. F. Curling, D. Jones and M. D. Hale. 2006. Assessment of the envelope effect of three hot oil treatments: Resistance to decay by *Coniophora puteana* and *Postia placenta*. The international research group on wood preservation, IRG/WP 06-40344, IRG Secretariat, Stockholm, Sweden .

Syrjänen, T. 2001. Production and classification of heat treated wood in Finland. Pages 7-16 in Review on Heat Treatments of Wood, Proceedings of the special seminar held in Antibes, France, on 9 February 2001, Forestry and Forestry Products, France. COST Action E22, EUR 19885, Edited by A. O. Rapp.

Syrjänen, T and E. Kangas. 2000. Heat treated timber in Finland. The international research group on wood preservation, IRG/WP 00-40158, IRG Secretariat, 44 Stockholm, Sweden.

Tjeerdsma, B. F., M. Boonstra, and H. Militz. 1998. Thermal modification of non-durable wood species: 2. Improved wood properties of thermally treated wood. The international research group on wood preservation, IRG/WP 98-40124, IRG Secretariat, Stockholm, Sweden.

Tjeerdsma, B. F., M. Stevens and H. Militz. 2000. Durability aspects of (hydro) thermal treated wood. The international research group on wood preservation, IRG/WP 00-40160, IRG Secretariat, Stockholm, Sweden.

©2007 Forintek Canada Corp. All rights reserved

Vernois, M. 2001. Heat treatment of wood in France--State of the art. Pages 35-42 in Review on Heat Treatments of Wood, Proceedings of the special seminar held in Antibes, France, on 9 February 2001, Forestry and Forestry Products, France. COST Action E22, EUR 19885, Edited by A. O. Rapp.

Wang J. Y. and P. A. Cooper. 2003. Heat treatments of wood (review). Proc. Cdn. Wood Preservation Assoc. 24. CWPA, Dartmouth NS, Canada.

Wang J. Y. and P. A. Cooper. 2004. Moisture properties and biological resistance of hot oil treated wood. Proc Cdn Wood Preservation Assoc. 25. CWPA, Dartmouth NS. Canada.

Wang J. Y. and P. A. Cooper. 2005a. Effect of oil type, temperature and time on moisture properties of hot oil-treated wood. Holz als Roh- und Werkstoff, 63: 417-422.

Wang J. Y. and P. A. Cooper. 2005b. Properties of hot oil treated wood and the possible chemical reactions between wood and soybean oil during heat treatment. International Research Group on Wood Preservation, IRG/WP 05-40304, IRG Secretariat, Stockholm, Sweden.

Wang J. Y. and P. A. Cooper. 2007. Fire, flame resistance and thermal properties of oil thermally-treated wood. International Research Group on Wood Preservation, IRG Secretariat, Stockholm, Sweden.

Welzbacher, C. R. and Rapp, A. O. 2002. Comparison of thermally modified wood originating from four industrial scale processes--durability. The international research group on wood preservation, IRG/WP 02-40229, IRG Secretariat, SE-100, 44 Stockholm, Sweden.

©2007 Forintek Canada Corp. All rights reserved

Appendix I

Ratings of Discoloration and Black Stain during the Accelerated Weathering Test

©2007 Forintek Canada Corp. All rights reserved

Ratings of discoloration and black stain of five treatments during the accelerated weathering test:

220º*2hr, hot oil treatment	**Front face**		**Back face**	
Sample No.	**Discoloration**	**Black stain**	**Discoloration**	**Black stain**
4-1	2	9	7	6
4-2	3	9	7	8
4-3	2	8	8	6
4-4	3	9	6	5
5-1	3	9	5	5
5-2	2	9	5	5
5-3	4	9	6	9
5-4	4	9	6	9
6-1	1	9	4	6
6-2	1	9	4	4
6-3	2	8	7	6
6-4	2	8	4	4
8-1	2	8	4	4
8-2	3	8	7	8
8-3	3	9	7	8
8-4	3	9	7	8
10-1	2	9	5	4
10-2	2	9	8	5
10-3	3	9	7	6
10-4	3	9	7	5
Average	**3**	**9**	**6**	**6**
SDV	1	0	1	2
220º*1hr, hot oil treatment	**Front face**		**Back face**	
Sample No.	**Discoloration**	**Black stain**	**Discoloration**	**Black stain**
4-5	2	9	5	5
4-6	2	8	5	5
4-7	2	8	4	4
4-8	2	9	5	5
6-5	2	8	4	4
6-6	2	8	5	3
6-7	1	9	5	3
6-8	2	7	5	5
8-5	1	8	5	4
8-6	3	8	4	4
8-7	2	9	5	4
8-8	2	8	5	4
10-5	2	8	5	5
10-6	3	8	5	4
10-7	2	8	5	4
10-8	2	8	5	4
Average	**2**	**8**	**5**	**4**
SDV	1	1	0	1

©2007 Forintek Canada Corp. All rights reserved

Untreated pine, reference	**Front face**		**Back face**	
Sample No.	**Discoloration**	**Black stain**	**Discoloration**	**Black stain**
4-13	2	4	4	4
4-14	2	5	4	4
4-15	2	6	4	4
4-16	3	6	6	7
6-13	2	6	3	3
6-14	1	10	6	9
6-15	2	8	4	5
6-16	1	10	7	9
8-13	3	7	5	6
8-14	1	9	4	4
8-15	2	4	3	3
8-16	1	10	7	9
10-13	1	10	5	7
10-14	2	5	5	5
10-15	4	9	6	6
10-16	1	10	7	8
Average	**2**	**7**	**5**	**6**
SDV	1	2	1	2
ACQ-treated	**Front face**		**Back face**	
Sample No.	**Discoloration**	**Black stain**	**Discoloration**	**Black stain**
4-9	3	7	8	9
4-10	3	9	6	6
4-11	3	8	9	10
4-12	3	8	9	10
6-9	3	6	9	10
6-10	3	6	9	10
6-11	3	6	9	10
6-12	2	8	8	7
8-9	3	7	9	10
8-10	3	7	9	10
8-11	3	7	9	10
8-12	2	8	9	9
10-9	3	7	8	9
10-10	3	7	6	6
10-11	3	6	8	10
10-12	3	8	8	7
Average	**3**	**7**	**8**	**9**
SDV	0	1	1	2
Cedar, reference	**Front face**		**Back face**	
Sample No.	**Discoloration**	**Black stain**	**Discoloration**	**Black stain**
1-1	1	10	7	6
1-2	1	10	7	7
2-1	3	9	5	7
2-2	2	9	5	3
3-1	1	10	6	3

©2007 Forintek Canada Corp. All rights reserved

3-2	1	10	6	3
4-1	2	9	7	5
4-2	1	10	8	4
5-1	1	10	8	6
5-2	2	8	5	5
6-1	1	10	8	8
6-2	1	10	8	7
7-1	1	10	6	8
7-2	1	10	8	9
8-1	1	10	8	9
8-2	1	10	6	9
Average	**1**	**10**	**7**	**6**
SDV	1	1	1	2

©2007 Forintek Canada Corp. All rights reserved

Appendix II

Nail Withdrawal Resistance Data and the Corresponding Moisture Content

©2007 Forintek Canada Corp. All rights reserved

Nail withdrawal resistance data:

Untreated, blue-stained		Hot-oil treated, blue-stained	
Sample No.	**Nail holding resistance (N)**	**Sample No.**	**Nail holding resistance (N)**
2-4	462.0	2-1	374.1
2-5	474.6	2-2	234.8
2-6	439.1	2-3	225.9
3-1	584.2	3-4	246.0
3-2	436.2	3-5	331.1
3-3	496.4	3-6	319.4
5-1	570.2	5-4	294.7
5-2	432.5	5-5	293.4
5-3	594.6	5-6	228.7
8-4	481.0	8-1	363.6
8-5	416.3	8-2	273.7
8-6	389.1	8-3	248.8
9-4	506.8	9-1	179.3
9-5	654.3	9-2	290.9
9-6	427.9		
Average (N)	**491.0**	Average (N)	**278.9**
Standard deviation	77.0	Standard deviation	55.8
Untreated, non-blue-stained		**Hot-oil treated, non-blue-stained**	
Sample No.	**Nail holding resistance (N)**	**Sample No.**	**Nail holding resistance (N)**
2-5	677.0	2-1	312.8
2-6	588.5	2-2	366.9
2-7	794.1	2-3	390.9
2-8	653.4	2-4	320.2
5-5	456.5	5-1	298.2
5-6	714.6	5-3	297.1
5-7	393.3	5-4	273.4
5-8	552.5	6-1	275.4
6-5	689.2	6-2	326.8
6-6	546.2	6-3	324.4
6-7	638.0	6-4	443.4
6-8	571.1	6-9	295.7
7-6	494.0	7-1	437.7
7-7	440.4	7-2	385.4
7-8	447.8	7-3	297.3
7-9	351.6	7-4	402.3
Average (N)	**563.0**	Average (N)	**340.5**
Standard deviation	126.0	Standard deviation	56.0

©2007 Forintek Canada Corp. All rights reserved

Moisture content measurement of samples for the nail withdrawal resistance test:

Untreated, blue-stained			
Sample No.	**Air-dry weight (g)**	**Oven-dry weight (g)**	**Moisture content (%)**
1	1.924	1.740	10.57
2	1.661	1.503	10.51
3	1.814	1.642	10.48
4	2.035	1.843	10.42
5	1.806	1.634	10.53
6	1.969	1.780	10.62
7	1.930	1.747	10.48
8	1.668	1.517	9.95
9	1.866	1.686	10.68
10	2.282	2.064	10.56
Average (%)			**10.48**
Standard deviation			0.20
Treated, blue-stained			
Sample No.	**Air-dry weight (g)**	**Oven-dry weight (g)**	**Moisture content (%)**
1	1.798	1.731	3.87
2	1.966	1.898	3.58
3	2.181	2.101	3.81
4	1.985	1.913	3.76
5	2.642	2.543	3.89
6	2.023	1.952	3.64
7	2.022	1.948	3.80
8	2.316	2.232	3.76
9	1.639	1.580	3.73
10	2.052	1.978	3.74
Average (%)			**3.76**
Standard deviation			0.10

©2007 Forintek Canada Corp. All rights reserved

Appendix III

Fire Retardation Evaluation Results

Forintek Canada Corp.
©2007 Forintek Canada Corp. All rights reserved

Results from the crib test:

Treatments	Sample No.	$M_{0\,min}$ (g)	Oven-dry weight of $M_{0\,min}$ (g)	$M_{3\,min}$ (g)	Mass loss (%)	Continued flaming time (s)
Double treatments (with oil-thermal treatment and fire retardant treatment)	1	183.74	170.13	117.65	30.8	60
	2	179.73	166.42	111.17	33.2	95
	3	178.53	165.31	103.88	37.2	101
	4	179.12	165.85	112.16	32.4	78
	5	185.72	171.96	114.99	33.1	76
	Average				**33.3**	**82**
	Standard deviation				2.3	16
Untreated pine	1	146.46	135.61	11.59	91.5	180
	2	140.77	130.34	15.16	88.4	97
	3	138.50	128.24	19.02	85.2	127
	4	148.68	137.66	17.98	86.9	133
	5	140.64	130.22	12.56	90.4	145
	Average				**88.5**	**136**
	Standard deviation				2.5	30
Oil thermally-treated pine	1	161.38	149.43	13.08	91.2	100
	2	153.42	142.05	19.11	86.5	119
	3	167.25	154.86	17.08	89.0	117
	4	153.68	142.29	19.26	86.5	103
	5	156.27	144.70	16.70	88.5	127
	Average				**88.3**	**113**
	Standard deviation				2.0	11

©2007 Forintek Canada Corp. All rights reserved

Flame spread determination based on the two-foot tunnel test:

Treatments	Sample No.	$M_{0\ min}$ (g)	$M_{4\ min}$ (g)	Mass loss (g)	Flame spread (mm)
Double treatments (with oil-thermal treatment and fire retardant treatment)	1	590.52	575.45	15.1	347.1
	2	575.65	562.06	13.6	355.6
	3	568.85	554.53	14.3	381.0
	4	607.40	591.98	15.4	389.5
	5	550.71	537.97	12.7	372.5
	Average			**14.2**	**369.1**
	Standard deviation			1.1	17.6
Untreated pine	1	437.69	414.02	23.7	575.7
	2	502.23	483.79	18.4	516.5
	3	476.92	460.42	16.5	508.0
	4	470.69	453.3	17.4	524.9
	5	475.71	460.85	14.9	508.0
	Average			**18.2**	**526.6**
	Standard deviation			3.3	28.3
Oil thermally-treated pine	1	469.22	451.98	17.2	575.7
	2	484.95	464.58	20.4	575.7
	3	487.28	473.45	13.8	592.7
	4	465.11	448.83	16.3	575.7
	5	478.95	467.48	11.5	575.7
	Average			**15.8**	**579.1**
	Standard deviation			3.4	7.6
Cement board	1				**165.1**

Forintek Canada Corp.
©2007 Forintek Canada Corp. All rights reserved