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ISSUES AND ADVANCES IN SAPSTAIN AND MOLD CONTROL

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Abstract

Fresh cut lumber in Canada, as well as other parts of the world, is highly susceptible to fungal attack and infestation. Although this fungal infestation rarely leads to lumber decay, it can severely degrade the lumber in both appearance and value. Many of the discoloration causing fungi produce either pigmented spores that discolor the surface or pigmented hyphae that discolor the interior of the wood, thus degrading the appearance of wood so that its market value may be one-quarter of the original value for unstained lumber. Sapstain and mold control of lumber using antisapstains in Canada has been exercised since the 1930's. Initially, the lumber was protected with chlorophenate and mercurial based products which provided a wider spectrum of activity but were very toxic. As a result of the impact that these products had on the environment and the workers, they were phased out by the late 1980s. Today the protection of lumber is achieved with more environmentally friendly products. Regardless of how effective the antisapstain products are, to be highly successful, the protection of lumber against sapstain and mold controlling organisms has to be approached in a holistic manner in which the causal organism, the types of antisapstain products available, application technology and treatment monitoring methods have to be considered.

Introduction

Since lumber is a naturally biodegradable product, it is invariably vulnerable to attack by biological organisms. The growth of fungi on wood is a function of moisture content (MC), oxygen levels, temperature and the type of wood (Zabel and Morrell, 1992). Freshly harvested wood is susceptible to fungal attack from time it is cut until it dries below 20 percent MC (Melencion and Morrell, 2007). Two present ways of managing this huge fungal stain and mold problem is either kiln drying the lumber below the 20 percent MC and/or treating with sapstain controlling chemicals immediately after log processing. The cost of kiln drying lumber is extremely high compared with chemical treatment and there is always the chance of KD lumber becoming susceptible to fungal attack if it becomes wet during transport, storage and use. Smith (1991) estimated that cost of kiln drying the lumber was between $50-100/Mfbm and the treating lumber with antisapstain formulations was $4-8/Mfbm.

Chapotelle (1979) mentioned 30 years ago that the control of stains and moulds is probably the lightest form of preservation in comparison to pressure impregnation but from the point of economics it is a vitally important step for retaining excellent lumber appearance and thus value. Even with the lumber market slowdown since 2004, total Canadian lumber shipments will still accounts for approximately 20 billion bf in 2009. The Canadian softwood lumber accounts for over 50% of this. Increases in lumber exports, together with the increased popularity of clear finishes, has dictated that, regardless of structural grade, both hardwood and softwood lumber producers must offer their customers discoloration-free materials to maximize their value. Since Canada heavily depends on the export market, it is critical that the wood reaches the customers free of decay and discoloration. Aesthetic quality (appearance grade) often is of greater value than that based on conventional lumber grades. Some discolorations (e.g. mineral streak) occur in living trees and cannot be prevented by logging, milling or drying practices. However, discolorations caused by the growth of microbes (e.g. mold and sapstain fungi); enzyme-mediated reactions within the sapwood of freshly-sawn lumber; or some non-microbial, non-enzymatic reactions (e.g., iron stain) can be prevented. Failure of exporters to respond to customers' expectations can result in financial claims or rejection of a shipment.

Even though the problem of sapstain can start in the log phase, the focus of sapstain control has always been in sawn lumber in which the problem becomes manifest (Byrne, 1997). Unless the harvesting schedules are adequately synchronized with the log/lumber storage and processing at mill sites, it is very difficult to absolutely control the problem of sapstain and mold development in lumber. The knowledge of where and why the problem of fungal infestation comes about is part and parcel of the holistic approach to sapstain and mold control. For achieving success in protection of lumber, it is fundamental to understand the microorganisms responsible for lumber discoloration and to understand their biology, ecology, physiology and biochemistry. Understanding of causal organism should be followed by using appropriate control methods available at ones disposal through proper application systems and then monitoring to make sure the required levels of the antisapstain product have been used and finally, monitoring the effectiveness of these treatments over time. This paper will discuss these specific issues and the advancements that have been taken over time to address all these issues.

Understanding the Causal Organisms

In the past, the lumber treatment chemicals were extremely potent and exhibited wider spectrum of activity. The desire or the need to understand the causal organism was not necessary and thus the industry was unaware of the problem fungi. From 1930's to 1980's the lumber industry was heavily dependent on chlorophenates for the protection of its lumber. Their efficacy in controlling sapstain and mould on lumber was superior to most products that are in use today. However, the discovery of dioxins in these formulations resulted in their ultimate abandonment. Concern for the environment remains a constant issue for our industry, and because of the location of many sawmills adjacent to rivers and the oceans, this translates into concern for aquatic plant life and animal life. In fact, when developing new formulations for lumber, fish toxicity is now a consideration of high priority. The bottom examples show that in the late 90's greater emphasis was placed on understanding causal organisms to tackle the problem of lumber protection.

With new sapstain control products the spectrum of activity is much narrower than the chlorophenates and thus the improvement in control strategies requires a greater need to understand the stain/mould causal organism. Adnan Uzunovic (1999) conducted detailed survey at seven selected sawmills across Canada. The objective of the survey was to identify fungi involved in the discoloration of the most important Canadian softwood species and to see whether these staining fungi differed by geographic region. Additionally, it was important to verify which of these fungi were the most prevalent species and whether staining of sawn lumber and logs was caused by the same organisms. It was discovered that Ophiostoma (97%) was the most commonly encountered genus and more diverse range of fungi were found in logs than in lumber.

Dubois et. al. (2000) evaluated the tolerance of 30 isolated fungal strains (10 strains of each species) to a range of concentrations of active ingredients in different sapstain control products. This study was as a result of fluctuations encountered in the effectiveness of some of the chemicals used to control stain over the years when applied on lumber at their recommended levels. This provokes the question of whether fungi have developed resistance to such fungicides. The final conclusion from the study was that there was no evidence of variation in tolerance to the fungicides screened.

Another study carried out by Uzunovic (2008) dealt with determining the effect of three actives (IPBC, Propiconazole and Chloromethyl and methyl Isothiazolinone) on spore germination and against established mycelium of selected test fungi. The results showed a high tolerance to some of the actives by fungal mycelia inhabiting the wood substrate prior to treatment. The Fusarium isolate tested was the most tolerant of all isolates used in the study. Of the three actives tested, IPBC was the most effective at the concentrations used in the study.

J. Clark (1997) looked at the amount of infection from softwood log storage. To address this issue, the project examined the fungi present in freshly felled western hemlock logs and re-examined the same logs after 20 weeks storage to determine which fungi were present in the log and whether these same fungi were present in the tree when felled. There were few fungi in the logs at felling but after 20 weeks of storage, large numbers of fungi known for their ability to degrade wood were isolated. The main fungi were in the Ophiostomatoid group, which cause bluestain in sapwood.

These studies are only a few sampled from many that have been conducted in an effort to understand the sapstain/mould causal microorganisms. It is very evident that this understanding will eventually lead to better and more consistent treatment products. In short, better knowledge of stain causing organisms will lead to better product screening/testing methods. Historically, the traditional reference tests for assessing antisapstain activity consisted of Disk Diffusion Test (DDT) and the ASTM D4445 Mold Test. For the DDT a paper disk containing the test antisapstain product is placed on an agar plate which has previously been inoculated with a specific fungal strain of interest. The agar plates are evaluated for fungal growth over a two week period to assess the efficacy of the antisapstain product against the specific fungal strains. ASTM D4445 method consists of placing antisapstain treated wood specimens over a glass rod in an agar plate. These wood specimens are sprayed with the spore suspension (consisting of all test fungi) and then evaluated over six weeks to assess the efficacy of test formulations.

A better understanding of the fungal organisms and their behavior in different environments lead to the development of better screening test called the Short Board Test (AWPA E24). This method utilizes the Ponderosa Pine wood as the test substrate. The inoculant (spore suspension) consists of five typical fungi that infect the softwood species in the west coast. The substrate and the inoculant can be changed depending on the specific requirements of the test. Of course, there is nothing like conducting a field trial in a specific mill site where the treated lumber is left exposed to the natural elements over a defined period of time. To accelerate the field test, the lumber is normally wrapped and evaluated on a monthly or bimonthly basis.

Types of Antisapstains

Historically, the sapstain was effectively controlled by application of Polychlorophenols (PCPs), organo-mercurial products such as Noxtane, Diatox, Permatox 100, etc. These control products were cheap and easy to use by dissolving them in water. Because of their broad spectrum of toxicity, they worked well. In Canada the mercurials were banned in the 1960's but use of chlorophenols continued on until the mid-1980s. As a result of environmental concerns and worker safety, all these broad spectrum activity products were phased out and thus the post-PCP era gave rise to newer and safer products (Table 1).

Table 1. Biocides post-PCP Era

Busan 30	2-Thio-Cyanato Methyl Thio Benzothiazole
MTB	Methylene Bis(Thiocyanate)
PQ-8, Nytek GD	Copper-8-Quinolinolate
NaOPP	Sodium Orthophenylphenate
MBC	Carbendazim
CTL	Chlorothalonil

These newer products were not entirely effective especially for lumber which was exported or when close piling or block stacking was introduced (Byrne, 1997). This lead to the development or evolution of newer formulations which were still safer than the chlorophenates and most included dual-active products to achieve an increase in efficacy (Table 2). The mixture of two biocides provides benefits in terms of providing synergy to control a wider spectrum of fungal activity and also this allows each of the actives to be used at lower levels and thus minimizing the total environmental impact.

Table 2. Biocides in 1990's

NP-1	3-Iodo-2-Propynyl Butyl Carbamate (IPBC/Didecyl Dimethyl Ammonium Chloride (DDAC)
F-2	DDAC and Borax
Ecobrite	Sodium Carbonate and Borax
Rodewood 200EC	Azaconazole
Chapco SA-1	DDAC/IPBC
AP-143	Azaconazole and IPBC
Timbercoat	DDAC and Latex

In the beginning of the 21st Century the need for the most benign actives continued with the added pressure of achieving the efficacy levels of the older products which provided a wider spectrum of activity. After the predominance of the dual-active products in the early1990's, newer actives and often tri-active containing products started to appear in the market place. Mixtures containing dual-active and especially tri-active ingredients require relatively sophisticated formulation technology (Table 3). It started to become clear that the aduvants or inert ingredients that were used in combination with the actives served a special function in enhancing the efficacy of specific actives.

Table 3. Biocides in late 1990's and 2000's

Mycostat PQ	Propiconazole and DDAC
NP-2	IPBC and DDAC
Antiblu XP64	Propiconazole, IPBC and Alkyl Dimethyl Benzyl Ammonium Chloride (ADBAC)

While these antisapstain products provided adequate lumber protection against sapstain and mold causing organisms it is often necessary to use higher and lower levels of the actives depending on the specific lumber protection requirements. Climatic and geographical conditions often determine the optimum formulations where certain actives are used at higher levels and the others used at lower levels. Therefore, this gave rise to what are termed "custom-blend formulations" (Table 4). Presently, this technology is often exercised in many lumber mills and again, it serves to minimize the environmental impact and at the same time providing greater spectrum of activity due to the synergistic action of each active. The final custom blend may consist of from two to four actives in combination with adjuvants and ancilliary products.

Table 4. Custom-Blend Formulations

Active Ingredients	+	Adjuvants and Ancilliary Products
Propiconazole		Corossion inhibitors
IPBC		Antifoams
Quats (DDAC, ADBAC, ATMAC)		Water repellents
`Borates		Colorants
Chlorothalonil		Emulsifiers/Surfactants

Application Technology

The application technology has greatly improved over the past 20 years. Prior to the 1980s the antisapstains were almost exclusively applied by dipping the lumber in large vats or by in-line dip tanks. Unfortunately, this often resulted in contamination of mill yards and ground water from spillage and dripping lumber. Whereas the in-line dip technology is completely discontinued, bulk dipping is still carried out today by many antisapstain applicators. Table 5 outlines the advantages and disadvantages for the different dipping technologies. The dip tanks that are operated nowadays have to comply with very tight regulatory guidelines to prevent escape of chemical into the environment. Such requirements are for impervious containment areas or double-walled tanks and also for a roofed primary drip areas so that there is no danger of any chemical run off during rainy weather (Byrne, 1997).

To overcome the problem with dip tanks, majority of the applicators rely on hydraulic spray systems which treat individual boards that are traveling at very high speeds. There are two types of spray systems available today (Table 5), the lineal spray system and the transverse spray system (Groves, 1996). In the lineal spray system, the lumber travels longitudinally (with the long axis pointing down line), usually after it comes out of the planer. In the transverse spray systems the lumber is traveling in the transverse direction. Spray systems provide the potential for much more even chemical coverage because coverage is less dependent on the lumber surface texture. The spray parameters could be adjusted so that optimum amount of antisapstain is applied on lumber ensuring that adequate levels are present on lumber to provide maximum efficacy but not leaving the lumber dripping with excess chemical. This minimizes worker exposure and causes less chemical to drip into the mill, yard, or surrounding environment. With the installation of spray systems it is necessary to entrap all the mist that is created during the spraying process. This is carried out by installation of mist-eliminating systems with integral scrubbers.

Table 5. Advantages and Disadvantages of Dip Technology

Type of Application Technology	Advantages	Disadvantages
In-line Dip Tanks	-Each piece of lumber dipped individually -Most effective mans of treating lumber -Handles high volume	-Subsequent trimming exposes untreated ends. -Lumber relatively wet when handled by workers on green chain. -Sludge build-up and environmentally unsafe.
Unit Dip Tanks and Automated Unit Dip Tanks	-Units can be assembled, banded, trimmed. -Various degrees of automation available. -Potentially eliminate personnel exposure to treated lumber -Allow high throughput.	–Contamination of mill yard, and ground ground water from spillage and drippings. -Sludge build-up in the tanks if not cleaned regularly. => selective adsorption of active -Leave a large environmental foot print.
Spray Systems	- Lower capital expense - Requires limited space. - Can be completely automated. - Minimal worker exposure. -Reduction in stripping of active ingredients.	- May give least uniform Coverage (difficult to optimize) - Potential nozzle plugging problems

Treatment Monitoring

In the past, monitoring of the applied antisapstain on lumber was carried out with traditional rudimentary and qualitative methods such as the spraying treated lumber with indicator solutions to assess the presence and uniformity of the treatments. The area of the treated board that was treated changed in color upon the application of the indicator solution, thus allowing a visual for the treated area. Another method that was used was to monitor the dip-tank solution with a titration kit to ensure that it was at the right concentration. Until the late 1970's this was the only measure of quality assurance and provided no quantitative evaluation of the actives retained on the lumber.

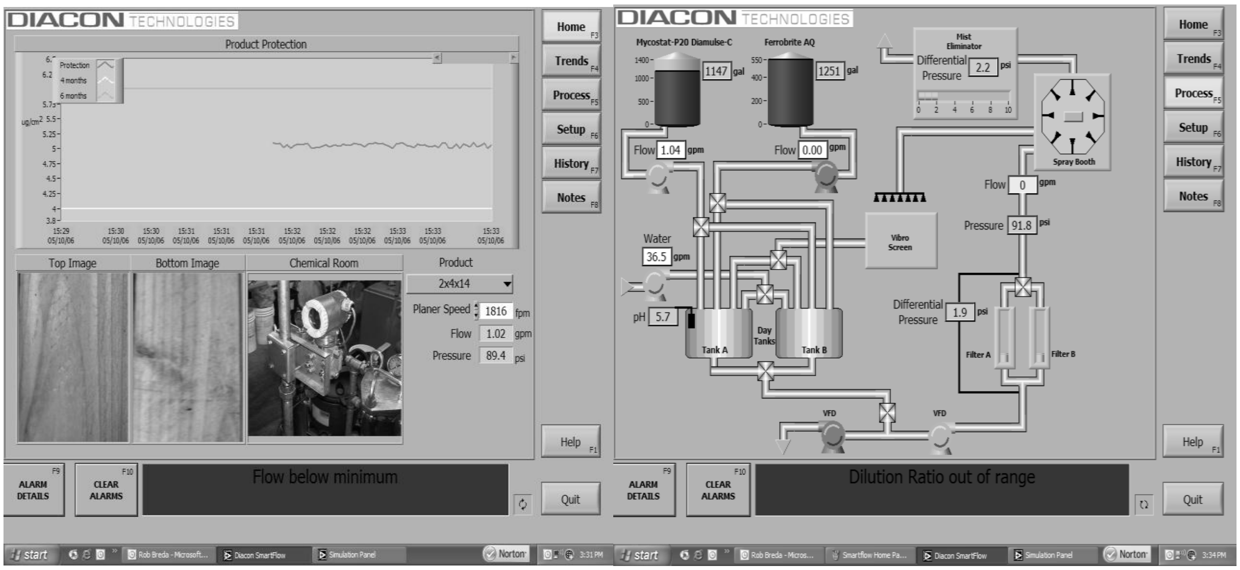
Figure 1. Retention Analysis

It was not until the late 1970's that Forintek Canada Corp. developed the program of routine measurement of lumber surface retentions (Figure 1) where an actual quantitative level of the actives was measured. Each sawmill that used the antisapstain systems took retention samples from the treated lumber and sent them to Forintek where the retention results were generated (using HPLC) within a couple of days and relayed back to the sawmill. This acted as a check of the mill's lumber protection processes and application efficiency. This worked very well but the time that it took to sample the treated product and get the retention results back to the sawmills did not allow fast enough response in case there are any discrepancies in treatment levels.

The large sawmills that produce millions of board feet of lumber each day require faster response time about whether their lumber is being under- or over-treated. For this to occur there is a requirement for in-line monitoring systems. This would allow real-time adjustments to be made in the treatment process to provide optimum efficacy and avoid any costs due to over-treatment of lumber. Presently, some of the sawmills use in-line monitoring systems (i.e. Diacon's Smart Flow System) to measure not only the amount of chemicals that are being used but to measure other parameters such as spray pressure, line speed, tank levels, temperature, etc. (Figure 2).

In addition, the real- time cameras are setup so that the system can point out any possible prestained lumber issues. For example, as soon as the cameras show lumber that has prestain, the levels of actives could be increased to higher levels to provide additional protection for the heavily stained lumber. Of course, other changing variables such as different wood sizes and particular market requirements could also dictate application adjustments.

Figure 2 In-Line Monitoring System (Smart Flow System).



Summary

For the lumber antisaptain treatment programs to be truly effective, it is necessary that a holistic approach is exercised in understanding the stain/mold causal organisms, the types of antisapstain products available (against the specific fungi), application technology and treatment monitoring methods. There have been many advancements that have taken place over the years to address this holistic approach. Better understanding of the causal organisms have given rise to more effective antisapstain formulations to deal with a wide array of fungi. More advanced antisapstain application systems have been designed to more effectively and safely apply the formulations on lumber. The newer in-line monitoring systems have been installed to provide real-time active application levels on lumber. This allows much quicker response times to optimize the application levels required to more effectively control the mold and stain fungi.

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