Questioning Conventional Wisdom Regarding the Most Suitable Sequence of Enzyme Usage in Pulp Bleaching

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Increased public scrutiny and governmental legislation towards the pulp and paper industries have motivated industrialists and researchers to seek improved bleaching sequences having the potential to minimize pollutants in bleach effluent generated during manufacturing of paper. Discovery of toxic chlorinated organics and their components in bleach effluents has focused people's attention towards finding alternative ways of bleaching pulp. Use of enzymes at industrial scale has become well known, but still it is not clear whether the sequence of enzymatic treatment most often employed in industrial applications represents the best overall practice. The point of enzyme addition is critically important to maximize benefits. Many publications describe the use of an enzyme treatment stage before the use of chemicals in a bleaching process. Insufficient attention has been paid to the alternatives of adding an enzyme in between chemical bleaching agents (intermediate) or at the end of the bleaching process.

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Are we ready to accept nature's challenge?

According to conventional wisdom, the environmental impact of pulp bleaching often can be reduced by pretreating the fibers with enzyme. The goal is to maximize benefits in terms of pulp brightness with reduced pollution load in bleach effluent in a system that can be implemented at an industrial level. We all are living in, surrounded by, or in direct contact with air, water, and everything that is required for survival on this planet; thus anything implemented on an industrial scale is likely to affect our health, either immediately or after some delay. The pulp and paper industry can be regarded as a major generator of industrial pollution, though substantial progress has been achieved in either reducing the generation of toxic substances or in treating effluent that contains them. The most serious contribution to pollution consists of the bleaching chemicals. Elemental chlorine and its derivatives, as well as hydrogen peroxide and caustic soda (NaOH) are the major chemicals used in pulp bleaching that are very hazardous towards nature. Elemental chlorine is being used in huge amounts in the traditional bleaching process in various parts of the world. Replacement of elemental chlorine by chlorine dioxide in the first stage of bleaching has been helpful to some extent in reducing the formation of pollutants; this bleaching sequence is known as the "elemental chlorine free" (ECF) bleaching sequence. But chlorine dioxide can be regarded as a form of chlorine, so in many paper mills it is also being replaced by ozone and enzymes. Such approaches make it possible for these paper mills to meet and exceed environmental regulations.

Though the industry has converted much of its production to either elemental chlorine-free (ECF) or total chlorine-free (TCF) bleaching sequences, and enzymatic treatments also have come into common use, it is still not clear what is the best bleaching sequence with respect to the use of enzymes to get maximum benefits for improving the optical properties of the paper while reducing the pollutant loads in the bleach effluent. Enzymes, which are produced by microbes, may be in blended or in single form for its use at an industrial level. Mostly xylanases are being used to improve bleaching outcomes and in order to reduce the consumption of bleaching chemicals. Laccase with mediators are also beneficial for this purpose. They can be more efficient contributors towards bleaching, but due to cost-effectiveness, xylanase has been regarded as the most favorable option for industrial use.

Do we really know the best bleaching sequence with enzymes?

An enzyme can degrade or modify the lignin component. If one uses an enzyme before the bleaching chemicals, it can help in reducing the lignin amount either by degrading (laccase) or by modifying (xylanase) it. Xylanase is capable of hydrolyzing xylan, which is found bound with hexenuronic acid (Hex-A). Lignin is entrapped in between the Hex-A components; therefore there is a higher consumption of bleaching chemicals during bleaching process and a corresponding greater generation of pollution loads. When xylanase is used in bleaching, it breaks the bond between xylan and Hex-A and helps in extracting the lignin. Consequently, less bleach chemicals are required, reducing the generation of hazardous chemicals in bleach effluent.

Though the mechanism just described might appear to justify initial treatment with enzymes, it is far more important to find out what system works best in practice. Do industrialists really know that adding the enzymes first, before the chemical bleaching agents, will give the best results? Do they know which sequence of enzymes usage will be able to reduce the pollutants or to save our environment or to produce paper at very low cost? The answer would appear to be "NO". We simply do not know, and research is needed to find out the best stage for the addition of the enzymes for bleaching of pulp and paper. Much literature is available for enzyme use before the bleaching process, while very few publications have considered its use in between or after the chemical additives of the bleaching system.

It has already been discovered that the chlorine dioxide stages in ECF bleaching can generate new unsaturated structures, and xylan is a major source of these colored chromophores, which affect brightness development and stability of bleached pulps. Implementation of xylanase treatment as an intermediate or after bleaching process may be expected to reduce these chromophores as associated with xylan and result in improving the optical properties of the pulps. To target the same brightness level as in conventional bleaching processes, there would be chances of reducing bleaching chemicals in previous bleaching stages, which will further reduce the generation of pollution load in the process. Therefore, it might be economically beneficial to add enzyme after the bleaching process or in between the bleaching stages.

The use of enzymes in between and after the bleaching process has not been implemented yet at an industrial level. In the future, individual paper companies will have to effectively evaluate their options and to develop appropriate bleaching sequences using enzymes to reduced impacts on our environment and for the progress of pulp and paper industries globally.