Microbial Life In Paper Machine : Prevention & Control

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ABSTRACT

Several problems can be caused by the bacteria growing in paper machines. Biofilms detaching from paper machine surfaces may lead to holes and spots in the end product or even break the paper web leading to expensive delays in production. Heat stable endospores can still remain viable even after passing through the drying section of paper machine. These spores can increase the microbial contamination of finished paper and board. The environmental concerns have forced paper and board mills to close their water circuits. The circulation and reuse of process waters generally lead to higher processing temperatures and increase in colloidal and dissolved materials. This review paper deals with the roles of microorganisms in the formation of slimes/deposits as well as biofilms and new strategies including enzymes, bio dispersants & electrochemically generated biocides to combat them.

Introduction

A well-known cause of quality and runnability problems in the papermaking process is formation of deposit and slime [1, 2]. Conditions favoring the microbiological growth are found throughout the paper making process from storage tanks and towers, to mixing chests and headboxes. Controlling micro-organisms on a paper machine may seem to be a costly affair especially on alkaline fine paper machines. However, if these micro-organisms are not controlled, the cost can be much higher. These microorganisms, if not controlled, will generally lead to the slime production. Slime-related problems are the cause of great economic loss. Microbiological growth in a paper mill can lead to various problems including production losses due to paper breaks, unscheduled boil-outs, poor product quality due to spots, holes and odor, microbiological corrosion & damage to paper machineries. This can also cause production of harmful gases like hydrogen sulphide, methane as well as reduced efficiency of different papermaking additives.

Many deposit control programs, including treatments of slime, are designed based on measurements done in the water loops. A mill can troubleshoot for biological problems before they cause problems and effect profits. One can usually reduce costs by considering a couple of basic ideas. First approach should be to reduce contamination. The most important part of controlling slime is to minimize the amount of trouble-causing organisms entering the system. This is called good housekeeping. Washups are an integral part of controlling contamination. Probably the most important part of a microbiological program is a proper boil-out. Second is the selection of microbiological control chemicals. Make certain that the problem is indeed a microbiological slime problem; select the correct biocide; decide how and where to apply the biocide in the system (feed system, monitoring, and control of biocide); and assess the service capabilities of the chemical supplier.

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Paper machine as a habitat for bacteria

The process water in paper machines provides growth conditions suitable for bacteria. Water temperature is 40-60^{0}C and pH 5-10. Process waters are rich in organic carbon (cellulose, starch), but other nutrients, such as nitrogen, may be growth limiting [3]. Changes in paper making processes like loop closure, reduced water consumption, high speed machines, increased use of coatings and fillers and transition to neutral / alkaline processes have been reported to increase the problems caused by bacteria [1].

Biofilm formers in paper machines

Several bacterial sp. have been reported to attach and grow under paper machine environment. These strains are considered to be primary-biofilm producers [1, 4]. Most strains grew in biofilms in mixed cultures with the primary-biofilm former, *Deinococcus geothermalis*. *D. geothermalis was reported to be* a pioneer colonizer in paper machines which helps other bacteria to grow on surfaces. There are also three recent PhD theses discussing about micro-biological growth, biofilm formers of paper machines & their control strategies [5-7]. Paper machine circuits resemble hot springs from bacterial point of view as warm water is continuously running on solid surfaces.

Spots or holes in paper product

Biofilms can occur at different interfaces such as solidliquid, solidair, liquid-liquid and liquidair [8]. The organisms are embedded in a matrix of microbial origin consisting of extracellular polymeric substances (EPS) comprising mainly polysaccharides and proteins [9]. These biofilms formed in the machine circuits lead to paper defects (spots and holes) or cause web breaks [4].

Microbial influenced corrosion (MIC)

Aggressive metabolites such as organic (acetic, succinic, isobutyric, etc.) or inorganic acids (sulphuric) are released by bacterial metabolism in biofilms. The patchy nature of biofilms may generate regions having different oxygen content. These properties may promote corrosion, called as microbial influenced corrosion (MIC).

Odor problems

Smell problem as a result of H_2S production caused by bacteria is a known phenomenon in paper machine circuits wherever reductive bleach is used. And especially if a paper mill closes its water loops, the amount of volatile organic acids increases in the process that increases the amount of compounds having pungent smells [10]. The problem becomes more acute on machines using recycled fibres and/or with a closed water cycle. The gas produced by sulphate reducing bacteria or archaea, can be more fatal especially in poorly ventilated areas [3].

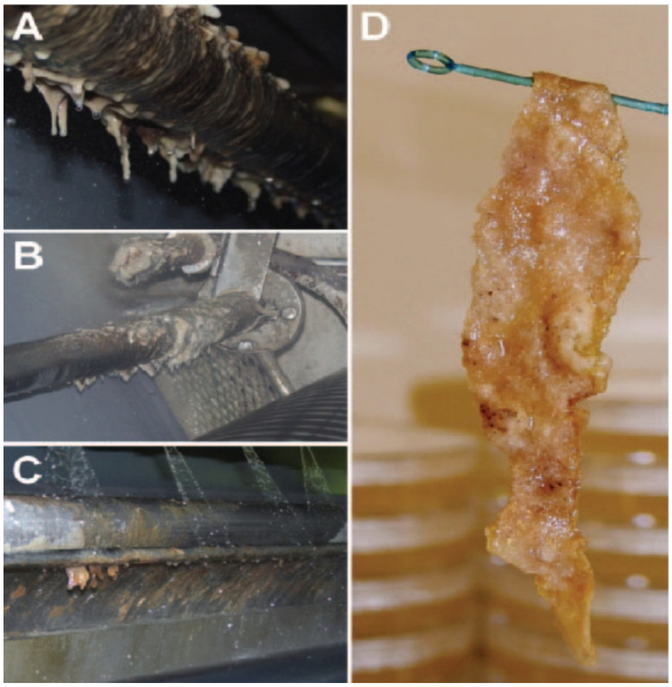


Figure 1. Photographs of biofilms (microbe slimes) grown on surfaces in the splash areas of the wet-end part of a paper machine (A-C). Areas that are constantly wet due to mist (B) or water sprays (C) are prone to be biofouled. Microbes can form coherent sheets of slime (D) that are likely to cause serious process disturbances if they detach from the machine surfaces [4]

Hygienic quality of paper products

Bacteria entering the papermaking process from different sources can also survive in the finished paper or board. Paperboard used in food packaging materials should be free of any microbes as a matter of food safety [11]. Some aerobic bacteria (Bacillus, Brevibacillus, and Paenibacillus) are capable of forming heat-resistant spores. The amount of spores in high-hygiene products such as liquid-packaging board or other food- packaging grades should be very low.

Prevention of microbial growth

Conventional biocides can be divided into three groups based on their activity towards microbes [12]:

- Biocides that inactivate the cell enzymes (quaternary ammonium compounds, methylene bisthiocyanate).
- Electrophilic agents acting on nucleophilic material of cells (dithiocarbamates).
- Biocides acting through oxidative decomposition of microorganisms also called oxidizing biocides (Oxygen, chlorine, bromine, ozone etc.).

Oxidizing biocides

Different commercial products containing oxidizing biocides are available in the market. But, more intensive work is needed to improve the stability and performance of the known oxidizing biocides. Oxidizing agents are considered to be fast acting but they do not have good preservation qualities [13]. Ozone, hydrogen peroxide, chlorine, chlorine dioxide, hypochlorite and bromine are the oxidizing agents most commonly used as biocides.

Green biocides

A chemical, especially a bactericide or fungicide that either kills or retards the growth of microorganisms and is environmental friendly, is called a green biocide or eco-friendly biocide. The different modes of action of microbicides, biodispersants and enzymes are summarized in Table 1. In the present world, microbiocides must also meet new demands, such as a broad spectrum application, no interference with other mill additives, very low toxicity, environmental acceptability, safety and ease of use in handling and control.

Table 1. Modes of action of microbicides, biodispersants & enzyme [14]

Product	Mode of Action
Microbiocides	Reduce/control microbial growth
Biodispersants/	Loosen wet-end deposits & support microbiocides
Biofilm inhibitors	Prevents the formation of EPS layer around cells
Enzymes	Cleave specific bonds in the EPS

Electrochemically generated biocides

Electrochemically generated biocides are created by electrolysis of diluted salt solutions, especially a brine (NaCl) solution. Bromine has been known to be an effective biological control agent for years. But, it is not a persistent biocide due to its rapid degradation to harmless bromide. Bromine is produced from a aqueous solution of sodium bromide and chloride [15]. Chlorine is also reported to be the primary oxidant in the electrolyzed brine solution [16]. Broke towers have been identified as the usual places where anaerobic conditions are developed. Anaerobic bacteria are more sensitive to oxidizing compounds and hence electrochemically generated biocides are powerful against anaerobes. Oxidizing biocides like hypochlorite are reported to be more effective against spores [17].

Electrochemically generated biocides can be added to water or pulp without any negative effect on the process as well as the end-product. Onsite electrochemically generated biocides can be low cost solutions based on actual biocide need. These electrochemically generated biocides have been reported to be environmentally friendly, nontoxic, hypoallergenic, easily disposable, fast acting, and powerful biocide agents.

Biodispersants

These new approaches focus on chemical treatment programs that function by preventing the microorganisms from attaching to surfaces, or by dispersing them from surfaces [18]. The dispersed microorganisms can then be killed with any oxidizing biocide. These chemical treatment programs are generally referred as biodispersants. This technology is based on nonionic polymers, which are non-toxic, non-foaming, colourless and free of organic solvents. Biodispersants having no pH limitations are suitable for use in both acidic and alkaline papermaking. These non-ionic products fall into four general types i.e. alcohol ethoxylates, alkylphenol ethoxylates, polyoxyethylene esters and derivatives of polyoxyethylene-polyoxypropylene.

Certain biocide program, specifically designed for use in preventing and slowing the development of deposits in paper machine systems have been reported [19]. These programs consist of dispersants, enzymes and potentiators added to the wet end of the paper machine. They are designed to enhance the effectiveness of traditional biocides, reducing or eliminating the use of biocides in wet end. These enzymes include blend of amylase, lipase and protease enzymes, which catalyze the attack on starches and proteins [14].

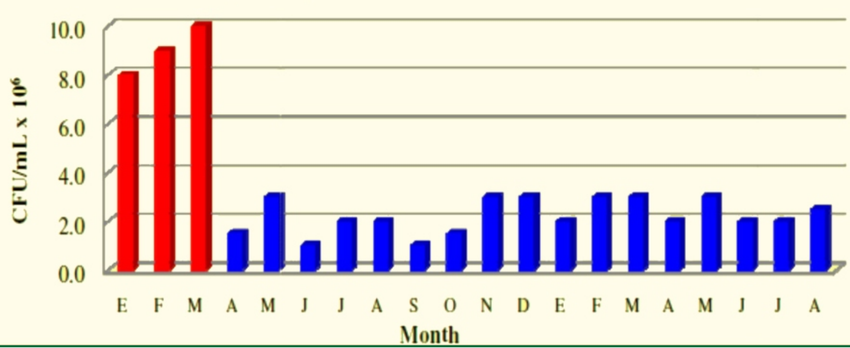
Enzyme additions

Another approach receiving considerable attention is the use of enzymes to control formation of biofilms. These approaches include the enhanced removal of biofilm, preventing the formation of biofilm and improvement in the efficacy of biocides. The aim of these approaches is to reduce or completely replace organic microbiocides that are currently being used. These substances had to be analyzed in order to identify the principal components of a biofilm matrix as the selection of enzymes or enzyme systems is decisively dependent on the nature of the extracellular polymeric substances (EPS) in a biofilm [14]. It seems doubtful whether enzymes will be the sole answer to the complex problem of biofilming in PM whitewater circuits. However, a combined use of microbiocides, biodispersants and enzymes appears to be more promising.

The boilout programs based on enzymes are successful as they target the specific compounds holding the deposits together including starch, slime, pitch, adhesives, latex and other synthetic binders [14]. Various forms of bacteria generate Levan in liquid systems, most of which are attached to surfaces. There are two types of enzymes involved in degradations of fructans- hydrolases and transferases. The hydrolytic enzymes either endo- or exo-enzymes, produce a homologenes series of oligofrucans or only fructose respectively. The transferases, on the other hand, split off fructose dimers and by simultaneous transfructosylation give rise to difructose anhydride [14].

Following case studies showing the results of application of enzymatic biocide at pulp & paper mills have been reported in the literature [20].

Graph 1: Monthly average values of Total Bacterial Count at the wire pit in a tissue mill using the enzymatic biocide. Red bars indicate Base Line values.



Graph 2: Monthly average values of Total Bacterial Count at the machine chest in an OCC recycling mill. The red bar indicates the Base Line value.

CASE 1.Control of bacteria using enzymatic biocide at a tissue paper mill [20]

CASE 4. Bacterial count at the machine chest of an OCC recycling mill after the usage of enzymatic biocide [20]

The composite enzyme systems consisting of cellulase, -amylase and protease have been shown to be more effective in treating microbially produced extracellular polysaccharides in cooling water and in papermaking broke water. Through the further development of stabilized enzyme products, the future is likely to bring new and varied use of enzyme technology to further benefit the paper industry.

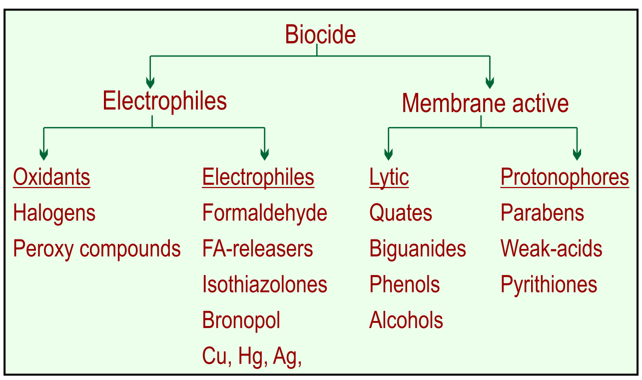
Ozone

Ozone, a water-soluble gas is naturally produced by the ultraviolet rays from the sun. The biocide action of ozone is a result of its reaction with the double bonds of fatty acids of the bacterial cell wall and membrane. Ozone application causes changes in permeability of bacterial cell and leakage of cell contents into the solution. Ozone is accepted as a better biocide compared to chlorine because it is 1.5 times stronger than chlorine and acts 3,000 times faster than chlorine without producing harmful decomposition products.

Mechanisms of biocides

Mechanisms of action of biocides can be divided into four broad categories (Fig. 2) [21]. The oxidants include chlorine and peroxides that work directly through radical-mediated reactions to oxidize organic material. Electrophilic agents include inorganic ions such as silver, copper, and organic biocides such as formaldehyde and isothiazolones. These biocides react covalently with cellular nucleophiles to inactivate enzymes. Cationic membrane active biocides such as chlorhexidine and quaternary ammonium compounds lead to rapid cell lysis. Ascorbic and benzoic weak acids are known to interfere with the ability of the cell membrane to maintain a proper pH balance [21]. This results in the accumulation of anions and cations inside the cell. As a result of different actions including membrane disruptions, inhibition of metabolic reactions and the accumulation of toxic anions, cell growth is reported to be inhibited by different preservatives. The general mechanism of biocide action over various microbes is described in Fig. 2

Figure 2. Mechanism of action of conventional biocides [21]



Analytical Methods for biofilm development

Off-line methods

According to Hilbert *et al.*2001 [22] slime measuring board is the only method for quantitatively determining biofilm growth. The performance of the slime measuring board is more or less dependent on the design of the measuring cell, the selected surface of the measuring board and the method of evaluation [23]. Other different biological activity test methods are summarized in Table 2.

On-line methods

If the formation of such deposits is detected at an early stage, efficient and economic counteractive measures can be triggered. In order to prevent financial losses associated with runnability and quality problems, a method supplying continuous online information of the actual tendency of the deposit formation is very important to be able to optimize and extend the amount of counter measure [23].

Table 2.Comparison of biological activity test methods [14]

Method	Time	Accuracy	Comments
Bio-Lert	1-4 hours	Very good	Rapid simple procedure
Standard plates	48-72 hour	Excellent	Time consuming
Dip-stick	24 hours	Yes	Time consuming
ATP-luminescence	< 30 min. excluding sample prep.	Good	Simple test, results not rapid enough
TTC, Indicator dyes	4-48 hours excluding sample prep.	Good	Results not rapid enough, sample preparation sometimes complicated
Ninhydrin spray	5 min.	Fair	Rapid amino-nitrogen test, (careful; do not tough spot) no quantitative

Conclusions and future prospects

Formation of slime deposits poses a major problem for paper mills. Extracellular polysaccharides secreted by slime producing microbes gum up the process machinery. Conventional slime control methods, generally employing combinations of biocides, lead to effluent toxicity, as well as high processing and treatment costs. Therefore, alternative control measures are in demand. Such measures include the use of enzymes, biodispersants & electrochemically generated green chemicals. This methodology can contribute to efforts to reduce water consumption and facilitate the use of recycled fibers. Industry can take advantage of using more eco-friendly processes having impact on consumers especially with respect to elimination of undesirable substances in the final product.

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