

## Innovations in Biofilm Detection and Monitoring

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Microbial biofouling is a costly problem, supporting a billion dollar industry of biocides, pre-treatment systems, cleaning chemicals, and anti-fouling materials. Five general reasons can be identified which contribute to low efficiency of anti-fouling strategies: (1) Biofouling is detected by its effect on process performance or product quality and quantity. Early warning systems are rare, although they could save costly countermeasures necessary for removing established fouling. (2) Usually biofouling is diagnosed when other explanations fail. The common practice is to take water samples which provide no information about the site and extent of biofouling deposits. (3) When finally the diagnosis "biofouling" is established, biocides are used which, in many cases, inactivate or kill microorganisms but do not effectively remove them. Killing, however, is not cleaning while frequently the mere presence of biomass and not its physiological activity is the problem. (4) Biofouling is a biofilm phenomenon and based on the fact that biofilms grow at the expense of nutrients. Biocides can make things even worse by breaking recalcitrant molecules down into biodegradable fragments. Nutrients have to be considered as potential biomass. (5) Efficacy control is performed again by process performance or product quality and not optimized by meaningful biofilm monitoring to verify successful removal; thus, further biofouling is inevitable. To avoid the above problems, an integrated strategy is suggested which does not rely on one type of countermeasure, but takes into account many complimentary approaches. An integrated approach includes the selection of low-adhesion, easy-to-clean surfaces, good housekeeping, early warning systems, limitation of nutrients, improvement of cleaners, strategic cleaning and monitoring of deposits. Any anti-fouling strategy will be greatly improved if the location and extent of biofilm growth can be monitored. A suitable monitoring system will provide early warning capacity and allow for specific optimization of countermeasures. As water samples do not give reliable information about biofilms, surface sampling is mandatory. Conventional biofilm monitoring techniques rely on removal of material from representative sites or on analysis of test surfaces which have been exposed. This procedure is time consuming and, depending on the parameters to be measured, requires skilled laboratory personnel. There is a strong demand for *direct, on-line, in situ, continuous, non-destructive real-time information* about biofilms in a system. Such demands can only be fulfilled by physical or physico-chemical methods, a number of which have been successfully applied for biofilm monitoring. It is important, however, to be aware of the actual parameter they refer to in order to interpret the data properly. Three levels of information can be identified: (1) systems which detect changes in the amount of material accumulating on a surface but cannot differentiate between biomass and other components of a deposit, (2) systems which provide biological information and distinguish between biotic and abiotic material and, (3) systems which provide detailed chemical information. Examples for all three levels are presented and discussed.