Intelligent biofilters: new control and monitoring techniques to optimise the efficiency of biological systems

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ABSTRACT. Modular biofilter systems offer an efficient, environmentally friendly and highly flexible method to clean polluted air currents from industrial and biological processes. An absolute novelty is presented by the modular control system for biological installations. By making use of intelligent control methods, ideal and stable operating conditions and compliance with the highest degrees of efficiency are achieved. For instance, as the moisture within the filter media of biofilters can only be measured by making use of very complex methods, a different approach was developed. For the first time, cost-efficient sensors to measure the humidity distribution and air current allocation within the filter material are deployed. The data of this three-dimensional view is also included into the control system.

1 INTRODUCTION

On the one hand, biological methods for air pollution control offer a very effective and well known method to eliminate odours and pollutants. On the other hand, the control and monitoring methods for biological installations have to be completely different to those for mere technical plants. Due to the very complex nature of the microbiological and biochemical metabolism which biological systems make use of to eliminate odour and pollutants, these processes could earlier only be characterised by fairly unspecific parameters such as the moisture of the filter material and CO_2-balances.

This is why modern control strategies obtain increasing priority in the domain of the biological exhaust air treatment. The ability to model complex behaviour as a collection of simple rules makes Fuzzy Logic an ideal solution for modelling complex, nonlinear systems – as they are represented by biological exhaust cleaning systems. Fuzzy-technologies enable the use of inexpensive sensors to ensure a high reliability of operation and process stability. The use of Neural Networks to interpret signals – for example from odour sensors – enables to assign certain odour patterns to certain operation modes. Neural Networks are ideally suited for such problems because, like their biological counterpart, a neural network can learn and therefore can be trained to find solutions, recognize patterns and classify data.

By making use of these “intelligent” methods to control the biological installation, problems which are due to arise can already be signalised in advance and be corrected by the control itself, before a loss in the degree of efficiency can occur.
Based on these methods a modular system to control exhaust cleaning systems and exhaust combinations has been developed in cooperation with several universities, companies and numerous research projects and has proven to control biofilters and bioscrubbers very effectively and securely.

1.1 Key features

- Implementation of odour sensors to continuously monitor the performance of biofilters and scrubbers.
- Simple graphical representation of the distribution of moistness and the gas flow in biofilters by the use of low cost sensors.
- New methods to accurately determine the relative humidity in moist environments.
- “Intelligent” control and operation of biological exhaust cleaning systems and the pre-connected raw gas conditioning.
- Online-documentation of the raw and cleaned gas quality and monitoring of thresholds.
- Function control of the system, optimisation of the degree of efficiency.
- Simple operability and relief of workers.
- Minimising of variation widths and tolerance limits.
- Simple transferability on other exhaust cleaning systems and exhaust combinations.

2. IMPORTANCE OF MOISTURE IN BIOLOGICAL SYSTEMS

Micro-organisms represent the principal item in every biological waste air purification plant. They diminish organic substances to a) gain energy and b) to grow by the decomposition of metabolites. In environmental protection a reduction of the complexity of organic compounds by micro-organisms (by biodegradation) or a removal of polluting materials (by biomediation) is being practiced. The biological exhaust air purification is thus based on the activity of micro-organisms, which oxidize organic and some inorganic gaseous compounds into biochemical not harmful, and/or no longer perceptible compounds.
In order to remove the pollutants from the exhaust air, these must be brought into contact with a sorptive medium. In high efficiency biofilters such as in figure 1, a biologically active organic material - for example a mixture out of fine compost and a substrate - serves as build-up matrix for the micro-organisms, which are settled in a liquid film on the filter material.
The water content of the filter material is the most important parameter for the efficiency of a biofilter and at the same time the most difficult parameter to measure and to control. Both for the absorption of the pollutants and for the vitality of the micro-organisms water is the "key element" in biological exhaust air purification. Sufficiently high moisture as well as a homogeneous and even distribution of moistness in the filter media is of highest importance. If some parts of the filter material run dry, tears and channels will form in which the only insufficiently purified exhaust air is passed through. Since the pressure loss in these places is obviously reduced, an increased flow connected with a further break-through and/or short-circuit flow will occur.

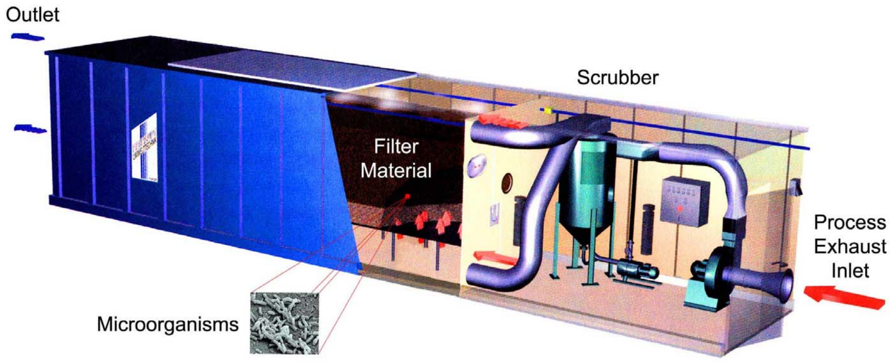

Figure 1. High-performance biofilter.

This dry filter material develops hydrophobic surfaces, which can only be remoistened with great efforts. Changing the filter material is often inevitable and causes considerable costs.

Therefore, biofilters are usually very generously dimensioned, usually with an addition of 100% on the calculated surface. If a reliable moisture monitoring and control within the filter material could be guaranteed, biofilters could be dimensioned smaller and would be accordingly more economical in many cases.

3. MOISTURE MEASURING METHODS

So far, the water content of the filter material in biological plants could not be determined adequately. Earlier methods were either too inaccurate (i.e. conductivity or capacitance measurements) or very complex and cost-intensive (i.e. time domain reflectometry measurements using the retention time shift of electromagnetic waves). Out of these reasons, a safe, variable and low-cost method was developed, which enables a continuous in situ measurement of moisture in many kinds of material.

3.1. Principle

The innovation of this invention represents a method to measure the moisture of filter materials and also many other kinds of fills. The principle is based on the collection of temperature gradients during the heating and cooling stage of a sensor that is inserted into the media. The heated element thereby emits heat to the surrounding environment. The quantity of the emitted heat energy - which is dependent on many factors such as the surrounding material structure, material moisture as well as the surface area - permits a direct inference on the humidity content of the surrounding material. Figure 2 shows the calculation of gradients of decay in a filter material in comparison to different levels of moisture.

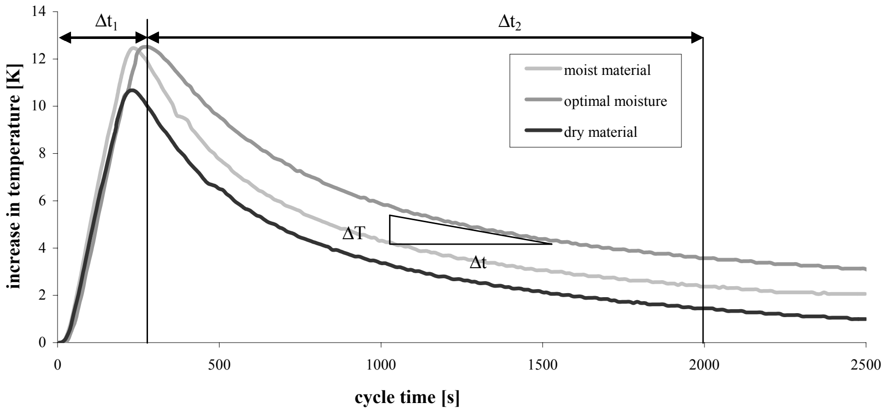

Figure 2. Graphs of different moisture levels within the filter material.

The photograph below shows such a sensor which is buried within the filter media and protected against corrosion by an epoxy – coating. It communicates with the control system using the TCP/IP protocol, which makes it possible to connect as many sensors in series as needed.

Figure 3. Moisture sensor.

3.2 Calculation of moisture distribution

By using a special arrangement of the sensors, it is also possible to calculate a three-dimensional view of the moisture distribution within the material and thereby offering a view deep inside into the biological system. In order to do so, the airflow through the fill of the biofilter is temporarily stopped – for example by switching off the ventilation unit for a short period of time - and the moisture measurement is taken. The graphically interpreted data is shown in Figure 4.

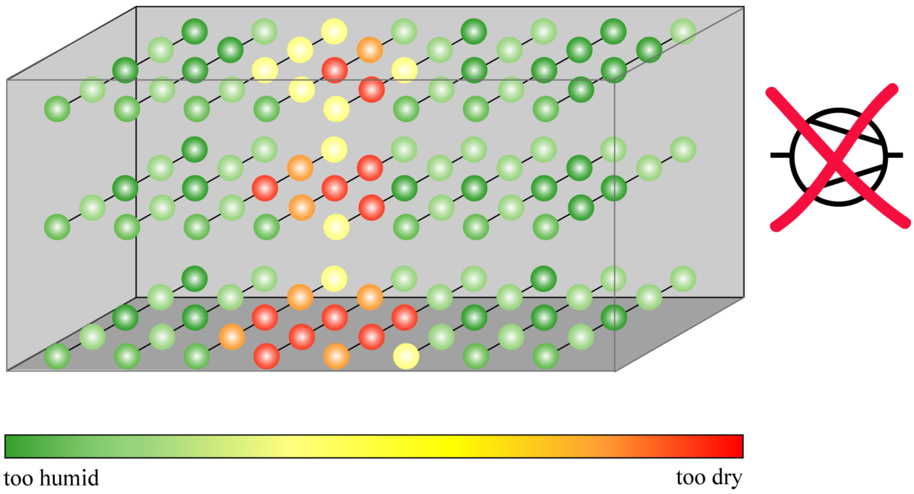

Figure 4. Stationary condition - moisture distribution within the filter material.

3.3 Calculation of air current distribution

In fills which are passed through by media such as air or water, a flow distribution can be calculated as the difference of the emitted heat amount in the stationary condition - thus without flow – in comparison to that of the flowed through or instationary condition. From the difference, which is mainly due to the increased heat energy removal of the air current, the flow rate in the vicinity of the sensor can be determined – as shown in figure 5 – and thus the flow distribution in the fill material be calculated.

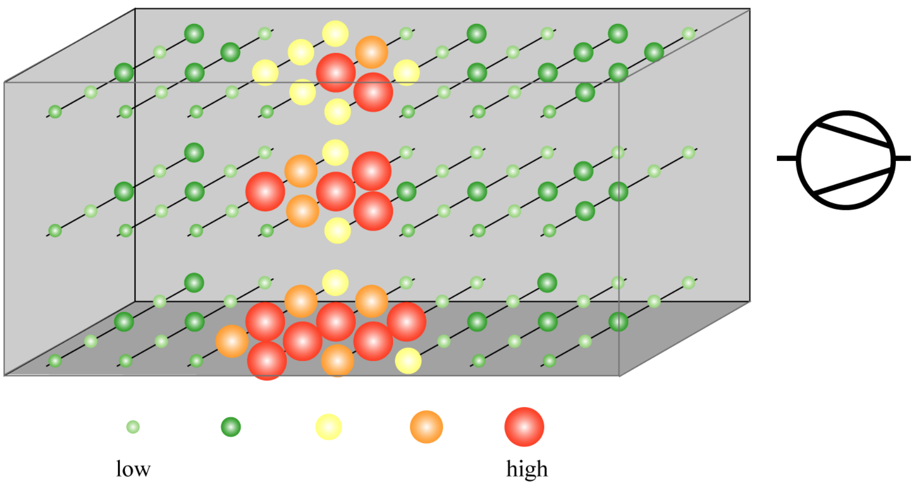

Figure 5. Instationary condition- moisture distribution within the filter material.

4. CONTROL METHODS

It is task of process engineers to ensure optimal living conditions for micro-organisms within biological exhaust air purification plants in order to obtain a high efficiency of removal and to ensure a stable operating mode. However, controlling and an influencing the biological process is not as easily realised in "living" plants as it is in purely technical plants. Rising requirements of the cleaning grade, which can be achieved by biological waste air purification plants, require operational methods with increased reliability and high process stability. To meet these demands, a measuring and a control system has to be developed which particularly integrates the parameter “filter-media moisture” into the control system.

As mainly complex, strongly interlaced and nonlinear processes with partial unknown regularities prevail in biological systems, there is a need to utilise intelligent methods such as Fuzzy Control for the process modelling and optimization. The influence of many different process variables on the optimal functioning of a biological system also complicates the modelling process. A universally applicable control method had to be developed which comprises all kinds of biologically relevant parameters. In the first phase of these control mechanisms control concepts are defined using Fuzzy Logic algorithms. For example: "If filter material very dry and flow rate normal, then smell perception unpleasant." This and many other sets of rules is extended and completed by further rule checking using an approach as shown in Figure 5.

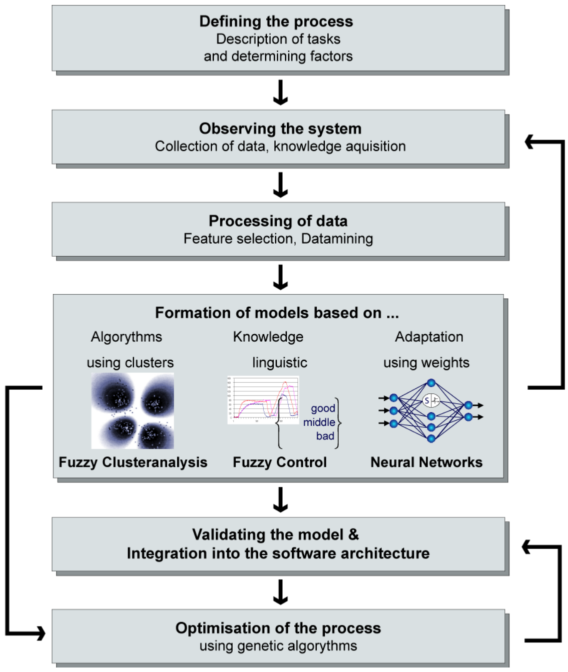

Figure 6. Method of process-modelling used in biological systems.

By keeping to this method of process-modelling, all kinds of data arising from sensors within the biological system can be analysed in real-time, visualised and the results be used to regulate biological systems. For the first time, the black-box “biofilter” becomes more transparent.

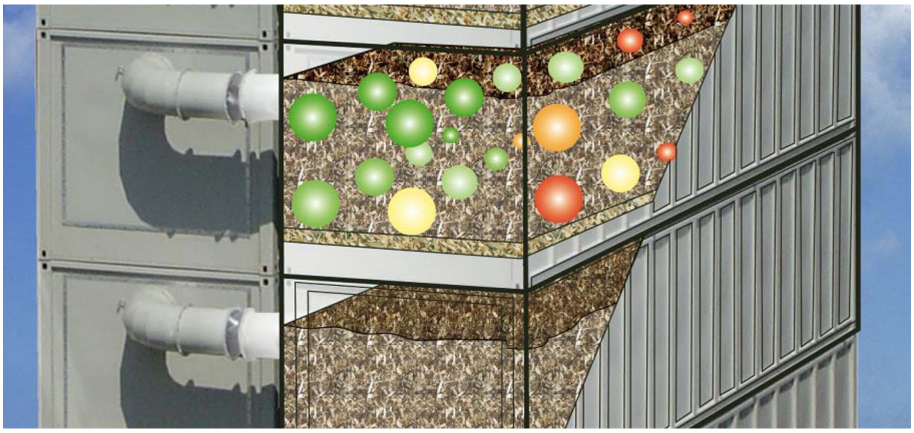

Figure 7. A look inside the “black box” biofilter.