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BIOFILTER MODELLING FOR ENVIRONMENTAL PROTECTION

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Abstract: *Industrial activities often have, beside direct positive and desired effects, negative undesired effects on the environment and society, caused by the environmental pollution. In the context of operationalising of the concept of sustainable development this issue is a very relevant one. Environmental protection by using biotechnologies did show good results, by maintaining the costs on an affordable level. Biotechnologies for environmental protection are such technologies that are using the combination of engineering processes with biological methods, based on microorganisms. The most important element of the biotechnologies for environmental protection is represented by the biofilter. For modeling the bio-filters several aspects from the field of fluid mechanics, regarding the flow rate and flow velocity have to be taken into account, by considering the assurance of the necessary conditions for microorganisms evolving in the bio-filters.*
Keywords:*sustainable development, operationalisation, biotechnologies for environmental protection, biofilters, systems modelling*

1. INTRODUCTION

Some decades before the world began to realize also the dangers and undesired effects of human activities, especially industrial ones. After the Conference for Environment in Stockholm in 1972 and the first report of the Club of Rome „The Limits to Growth“ [7] was understood that besides wanted effects of technological progress, undesired and negative effects can appear. After this time the environmental awareness especially in the Western world began changing. It was clear that the arisen regional and global environmental problems are very serious and need to be solved. Nowadays we confront us with several global problems, which can be grouped in three categories: world population growth, growth of energy and natural resources consumption and environmental pollution [5] (Figure 1). Worldwide began discussions on scientific, political and social levels in order to find solutions for the problems shown above, which could be applicable with respect to regional differences to the developed as well as to the developing countries.

The Brundtland Report of the World Council on Environment and Development represented a result of the worldwide political discussions to find solutions. The concept of sustainable development was for the first time defined in the Brundtland Report [11] and accepted as a possible solution for the global complex ecological, economical and social problems. This concept was very large discussed on the Conference for Environment and Development in Rio de Janeiro 1992 as well as stated in the closing document „Agenda 21“ (http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm). Many actions after this time emphasize that the evolution of technical, social and ecological systems has to be analysed in synergetic relation [5]. At this point several events can be mentioned like, for instance, the Western Cape Sustainable Development Conference 2005 in Cape Town, South Africa (http://www.capegateway.gov.za/eng/your_gov/406/events/101218) as well as the World Summit on the Information Society (WSIS), held in two phases, 2003 in Geneva, Switzerland, and 2005 in Tunis, Tunisia (http://www.itu.int/wsis).

Sustainable development has become a widely used term today. However, looking at texts dealing with the topic, the impression arises that there are as many definitions of sustainable development as there are users of the term. In order to make this concept more understandable rules, strategies and principles of sustainable development have been defined, see [5], [14]. The general Brundtland definition was worldwide accepted, but together with the rules, strategies and principles, it does not give a concept, which is able to be applied to the real concrete situations. The transformation of the concept of sustainable development in political measures and controlling instruments needs his operationalisation [10].

2. METHODOLOGY TO OPERATIONALISE SUSTAINABLE DEVELOPMENT

The operationalisation of the concept of sustainable development means the transformation or translation of its goals in political measures and controlling instruments. In the published literature regarding the application of the concept of sustainable development on different levels, two strategic possibilities can be found [2, 16]:

- establishing goals on global or national level, the measures to achieve these goals being prepared on global and national level and applied on national or regional level;
- establishing goals on regional level, the measures being prepared on regional or local level; but the possible effects of these measures being evaluated on national and global level too.

As an application example of the first strategy studies in form of scenarios could be mentioned, for instance with the goal to find future sustainable energy supply systems with minimal effects on the environment. Such a project has been realized at IIASA (International Institute for Applied Systems Analysis) in Laxenburg/Vienna „Global Energy Perspectives" [9] and another one was carried out in Germany, IKARUS, with the goal to deliver a concrete instrument to reduce the pollutants emissions in the air [18]. On this point international and national scenario studies could be mentioned, which try to find sustainable ways for the future national development in global context, for instance the actionplan „Sustainable Netherlands" by Friends of Earth Netherlands in 1992, the study „Zukunftsfähiges Deutschland" (Sustainable Germany) initiated from BUND (Friends of Earth - Association for Environment and Nature Protection) and Misereor and leaded by the Wuppertal Institute for Climate, Environment and Energy [2] or the study „Towards a Sustainable Europe" carried out 1995 by the Wuppertal Institute. The mentioned studies base on mathematical models to describe industrial and economic processes and their impacts. With the help of databases, which describe economic, social and political frames, simulations have been carried out and different development scenarios have been gained. The goal is to find the right ways to get the proposed aims and to help with concrete measures the decision making process on political level.

The second strategy is illustrated by many actions in form of Local Agendas 21 carried out especially in Western European countries after the Rio-Conference in 1992. Also studies concerning regional future energy supply systems in the context of economic, environmental and social impacts can be mentioned here, like the study about withdrawal from the nuclear energy program and existing options for Baden-Württemberg carried out by the Academy for Technology Assessment in Baden-Württemberg [13].

Sustainable development can be operationalised with technology assessment (figure 1). This actually means to analyse the stability of complex dynamic environmental, economic and social systems in order to try to discover possible developments which lead to instabilities [16]. In this context there are many fields where research is needed, as for instance mathematical modeling of environmental impacts of economic activities on regional level as well as defining sustainable development indicators [8].

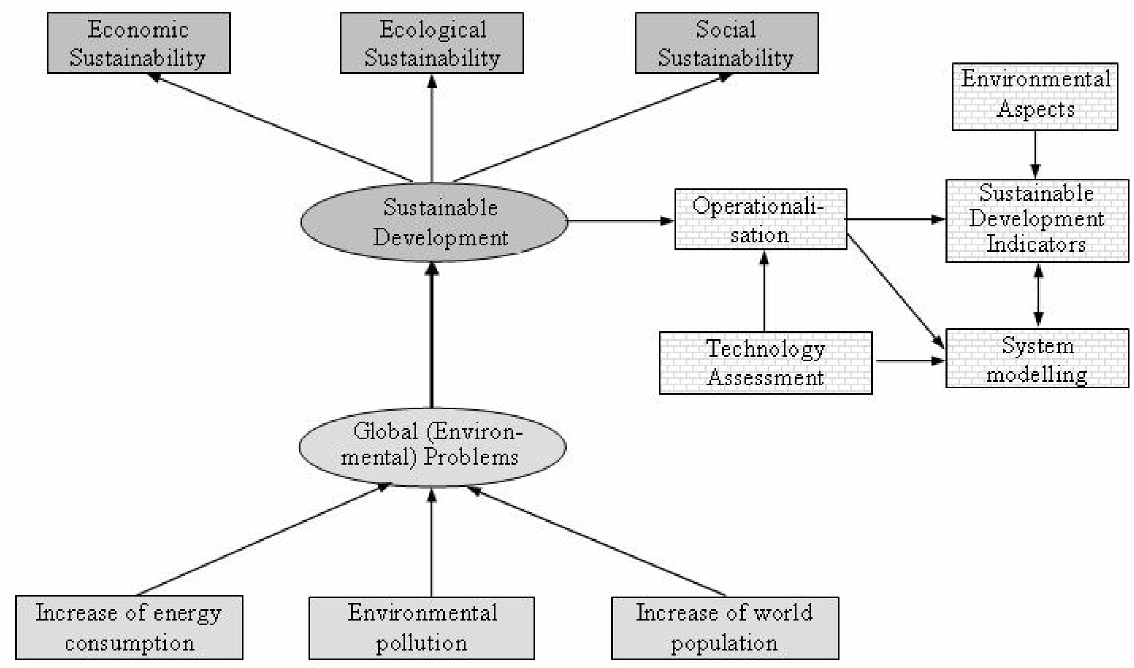


Figure 1: Global (environmental) problems and the concept of sustainable development.

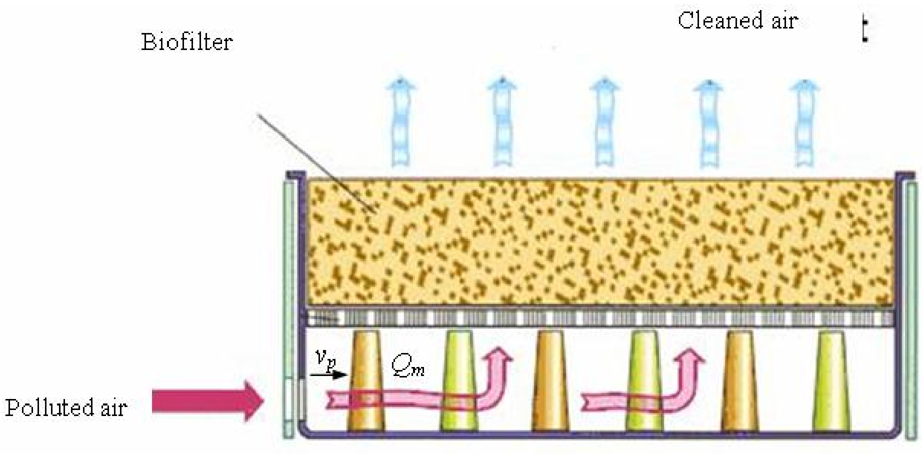
A general methodology for operationalising sustainable development can be materialized in the following steps [16]:

- defining the sustainability problem;
- establishing the space and time scales;
- systemic approach of the region by modelling the interactions;
- establishing concrete aims for the studied case;
- developing concepts and measures by establishing priorities;
- developing evaluation and control instruments, indicators;
- verifying the possible results, which could be obtained after introducing the proposed measures, comparing different scenarios;
- applying into the practice the developed concept.

The operationalisation is only possible, when for an individual problem-case concrete aims are established and from these aims concepts to achieve them are developed. Sustainability is to be newly defined for each different case [10]. The space and time scales are to be established for each case.
Very often for operationalising sustainable development, issues connected to environmental protection are very important [6, 15], especially nowadays, when the complexity of pollution processes is very high and not only technologies, but biotechnologies for environmental protection have to be used [12, 14].

3. BIOLOGICAL FILTRATION SYSTEMS OF POLLUTED AIR – BIOFILTERS

Biotechnologies are used for protecting different environment components: air, water, soil. In the followings especially biofiltration systems for polluted air will be discussed. Biological filtering systems of the polluted/ contaminated air from industrial activities represent one of the actual possible alternatives for air purification after its pollution, without affecting the natural environment [1].
The biotechnologies used for air cleaning have as a main component element the so-called biofilters. These bio-filters are based on different species of microorganisms, normally bacteria, used for cleaning the gas emissions.
It is to be mentioned from the beginning that these technologies used for air cleaning, but based on microorganisms, do not generally have a negative impact on the environment and there are as efficient as possible from a technical and economic point of view [3].
Biofilters, see fig. 2, are used for polluted air cleaning and do have a technology based on micro-organisms, in most of the cases on bacteria, that are cleaning the specific pollutants, causing the air pollution. These bacteria do live in suspension in liquids or there are deposited on a solid support, composed of wood cap pieces or woody brown coal pieces [12].
The bio-filters are in fact spongy filters, through which the polluted air is passing, as it is to be remarked from figure 2. The micro-organisms, deposited on the solid support of the bio-filters and fixed on the spongy undersurface, do represent the main component of the bio-filter, and do feed on specific pollutant elements from the polluted gas [12].



Q_m - Mass flow rate [kg/s]
v_p - Flow velocity of the polluted air through the biofilter [m/s]

Figure 2: Biofiltering system and the structure of a biofilter

The bio-filtering process is similar to other cleaning treatment processes, but in this case the bacteria do have the role of cleaning the polluted air, as it would be oxidated to get at the end CO_2 and water. The undersurface does assure the structural support and the essential nutriments for the microorganisms growing as well as reproducing, and the fact that this undersurface is spongy does represent the optimum surface conditions for the feet process for these microorganisms, taking into account that the gas pressure losses during its passing through the biofilter is also minimum. Considering the biofiltering process in this way, there are actually several issues connected to fluid mechanics, that have to be taken into account, as the optimum cleaning conditions of bacteria by feeding on specific pollutants is assured by achieving a certain flow velocity of the polluted air, v_p, and a certain mass flow rate, Q_m, through the biofilter, as it is to be recognised from fig. 2 [17].
When the polluted air does pass the bio-filter, the pollutants contained in the air do diffuse into the spongy structure, the bio-film, and remain there or are degraded. The pollutants are usually degraded by an aerobic process of biodegradation in the bio-filter. The get degradation efficiency by this procedure is usually over 90% , especially in the cases when water soluble organic substances are used, as for instance alcohol, aldehydes, or amines [12].
From this presentation it is more than clear that the cleaning capacity of a biofilter, this means the air flow rate, which can be cleaned in the respective biofilter, is dependent on the microorganisms capacity of cleaning the polluted air, in most of the cases contaminated with heavy metals.

4. MODELLING THE BIOFILTERS BY ESTABLISHING THE DIMENSIONS FOR A SPECIFIC CASE

From a technical point of view, depending on the type of microorganisms used in the biofilter, which imposes the needed flow rate, by taking into account the maximum velocity, that can be adopted for the air polluted flow, it is possible to calculate the biofilters dimensions, which will be posed in the flow evacuation pipe [5].
If there are limitations regarding the maximum dimensions of the flow pipe, because of the total space being at disposal, which can be used for posting there the biofiltering system, it is a complex process to establish the optimum dimension of the biofilter, so that the cleaning process should be an optimum one, when the polluted air emission is known, and the biofilter will work in the most efficient way [17].
It is to be mentioned that the emission of the polluted air, E, can be understood as being the mass flow rate, Q_m, of the polluted air, passing the evacuation smoke pipe. The evacuation process through the smoke pipe, where the biofilter is also posed, can be represented as being a pipe flow, as presented in fig. 3. In this way the evacuation issue of the polluted air has been transferred to a problem from the field of fluid mechanics, where the concept of flow rates is very often used. In order to know the proper dimensions of the biofilter, that should be used, by a specific type of microorganisms, used in the biofilter, the theories and equations from fluid mechanics can be applied [5, 12, 17].

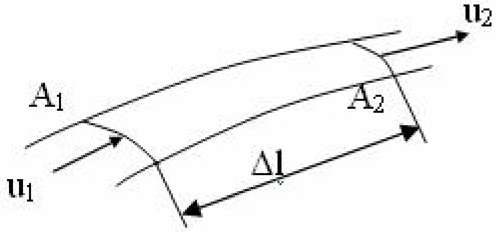


Figure 3: Continuity equation for a pipe flow

By taking into consideration a pipe flow, as presented in fig.3, the continuity equation known from fluid mechanics for a pipe flow can be applied for modeling the biofilter, by given cleaning performances of the used bacteria in the biofilter [15]. The mentioned continuity equation has the following form:

$$Q_m = \frac{\Delta m}{\Delta t} = \frac{\Delta(V \cdot \rho)}{\Delta t} = \frac{\rho \cdot \Delta V}{\Delta t} = \frac{\rho \cdot A \cdot \Delta l}{\Delta t} = \rho \cdot A \cdot u \quad \text{[kg/s]} \tag{1}$$

where: Q_m - mass flow rate, in the presented case being the pollutant air emission
Δm - gas mass passing the pipe
Δt - time interval
ΔV - gas volume passing the pipe
ρ - gas density
u - flow velocity of the polluted air

A - surface through which the polluted air passes

By using relation (1) the necessary surface of a biofilter can be calculated by using the got relation:

$$A = \frac{Q_m}{\rho \cdot u} \quad [m^2] \qquad (2)$$

In case that the gas density remains approximately constant, the volume flow rate Q_v can be used. By knowing the connection between the two flow rates types, it follows:

$$Q_m = \rho \cdot Q_v \quad [kg/s] \qquad (3)$$

Taking into account this calculation way, the bio-filter surface can be obtained as given bellow:

$$A = \frac{Q_v}{u} \quad [m^2] \qquad (4)$$

Table (1) does present possible dimensions, l, of the biofilter, having a square surface, A, resulted from specific calculations, when the polluted air emission, this means actually the mass flow rate, Q_m, is known. The mass flow rate does represent in this case the polluted air emission.

Table 1: Possible dimensions of a square surface biofilter

Nr. crt.	Polluted air emission [m^3/h]	Optimum velocity, v_p [cm/min]	Dimension of the square surface biofilter, l [cm]
1	0,1	2	28,6
2	1	2	91,6
3	10	2	289,72

From the obtained results it follows that for often met polluted air emissions of about 1 m^3/h, for a necessary velocity that should be not more than 2 cm/min, in order to get the best cleaning efficiency of the polluted air [12], the necessary bio-filter dimension in order to succeed in decontaminating the polluted air is about 91,6 cm. This calculation is made by considering A as being a square surface of the biofilter.

5. CONCLUSION

Biological filtering systems of the polluted/contaminated air from industrial activities represent one of the actual used methods in order to clean polluted air. Biofiltering procedures do have applications in several industrial fields, where other cleaning methods do not bring the same good results as the usage of biofilters.
First of all biofiltering procedures do have a direct application in each field where unpleasant smells are to be recognised, unpleasant smells because of certain organic or inorganic substances available in the pollutant emissions. Presently there are several industrial fields, where bio-filtering systems are successfully used, some of them being mentioned in the followings:
- food industry
- animal food processing industry
- waste and wastewater treatment
- plastics industry
- paper manufacture
- printing industry
- petrochemical industry
- adhesive and dissolvable substances producing industry
- tobacco producing industry
- oil recovery industry
- meat-processing industry
- dye industry

In the present paper an example regarding modelling a biofilter is presented, by calculating the necessary bio-filter surface, as well as the biofilter dimension, when the pollutants emission is known, actually the flow rate of the polluted air, as well as the maximum flow velocity through the biofilter, so that this can bring the best cleaning efficiency. For the biofilter modelling process, fluid mechanics notions and equations can be successfully used. This does demonstrate that actually solving environmental pollution issues do need an interdisciplinary approach, using basic notions and theories from different scientific fields.

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