Microbiological consideration of piping-systems concerning the contamination with micro-organisms and the use of modified polymers

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Introduction

The following considerations are focused on the contamination of piping-systems especially in the food- and pharmaceutical industry with micro-organisms. The pipes will be seen as a biological system. With this approach it is possible to describe the factors which influence the growing of a population of micro-organisms like bacteria. Moreover, the reader will get information to see all the different influences according micro-organisms. Under ideal conditions it is possible that a cell can double itself every 20 [min] by cell-division. This causes a tenfold increase of the numbers of cells in one hour. These data show the importance of understanding the mechanisms inside of the populations of micro-organisms. [1] On the other hand, the latest EU-regulation dictates a limiting value of 0 bacteria per ml for drinking-water. [2] This limit of 0 bacteria per ml shows, especially in respect of the cell-division the importance of copying with the problem of micro-organisms. From particular interest is the cost-effectiveness to reach a minimum concerning the costs for pumps e.g. and a maximum in respect of the cleanliness. As one possible way to minimise the contamination and thus the cleaning costs is a style of modified polymer which will be described at the end.

Biology aspects

Ecology

Ecology describes the part of biology which portrays the relationships of organisms among each other and the correlation to the environment. The term environment contents and describes all the organic (biotic) and inorganic (abiotic) factors which influence the being of each micro-organism. Abiotic factors can be from a material manner – like the condition of soil or the state of water- or energetic kind – like the solar radiation. The term biotic factor represents the influences of other micro-organisms regarding the considered organism or of populations of micro-organisms. [3]

Biocenosis

The characteristic of a biotope is that the organisms generate a biocenosis among each other. Thereby the organisms cause interactions to each other and constitute a self-regulating system which aspires toward an equilibrium, the so-called biocenotical equilibrium. [3]

Capacity of the environment

The term “capacity of the environment” represents the maximal possible population-density in one specific environment. [3]

Alteration of the magnitude and structure of a population

The larges possible population is named maximal population density. The most important density-limiting factor is the mass of available nutriment. The most important factors are those factors which tend to a minimum affected by the growing of the population. Next to these factors there are also factors which are independent from the population. To sum up there are factors which are strongly influenced by the increase of the number of individuals, factors which are dependent on the density and factors which are independent on the density of the population. All density limiting factors influence the number of offspring (birthdates) and the death-rate of the individuals. The population-density can be also by changed by immigration and migration of micro-organisms. The magnitude of a population is dependent on the density limiting factors which are named below:

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Factors which are dependent on the density:
- Competition among the same breed, enemies (parasites, predators), infectious-disease.

Factors which are independent of the density:
- Competition among different breeds, influence of the climate (Temperature, light, precipitation, humidity)
- The influences of the different factors can be described by a closed-loop. It is a pattern of a negative feedback which is described by that closed-loop. The prosperity of a population causes an increasing need of nutrient and this effect causes a negative impact concerning the population density for the future. Within in a balanced habitat the amount of all individuals -respectively micro-organisms – which participate in the focused ecosystem will reach a constancy regarding their numbers.

When the dynamic is seen as the reproduction character of one individual cell it is possible to describe the “growing” of one cell with the following formula.

\[ N = 2^n \]

- \( N \) = Population-density
- \( n \) = Exponent (number of cell-divisions)

Otherwise, when the dynamic is considered as the birth-rate-death-rate-ratio it is possible to describe the behaviour with the help of the following equation:

\[ \frac{\Delta H}{\Delta t} = G \text{ Birth rate} - S \text{ Death rate} \]

\( \Delta H = \) Alteration of the Population
\( \Delta t = \) Considered period

Out of these functional interrelationships the following equation has been developed.

\[ G = g N \]
\[ S = s N \]
\[ r = g - s \]

Fig. 1. Population density [3]

Population waves
- The competition among the same breed and the above-mentioned density limiting factors can cause a reduction of the population density particularly by e.g. the lack of the nutrients. But still living organisms prosper again, after that period. The new beginning increase of the population causes a population wave, because of the increase of the population density after the period with a higher death-rate. After reaching the initial point of the population-density (maximal-population-density) – caused by a higher birth-rate – it is generally possible that the process can happen again. This fluctuation around the maximal-population-density can be seen as an oscillation. It is generally possible to describe these processes in the way to use equations, but this approach can describe the different processes only approximately. But with the help of formulas it is possible to show the dynamic of the processes. [3]

Mathematical consideration of the dynamic characteristic of populations
- When the dynamic is seen as the reproduction-characteristic of one individual cell it is possible to describe the “growing” of one cell with the following formula.

\[ g = \text{Specific birth-rate} \]
\[ r = \text{Specific growth rate} \]
\[ G = \text{Birth-rate} \]
\[ S = \text{Death-rate} \]

The greatness of the population is far away from the capacity limit.
- \( N > K : N(t) \approx e^{rt} \) (Exponential growing (positive accelerated, exponential-growing))
- The greatness of the population is far away from the capacity limit.
- \( N = K : N(t) = K \) (Zero growth (stagnation))
- \( N < K : N(t) \approx e^{rt} \) (Exponential growing (negative accelerated, exponential-growing))

The ecosystem represents the interaction between the populations of – in this case – micro-organisms and the inorganic environment. The system is open and has the ability to self-regulation. The given chart below shows a small sector of the complex ecosystem. The chart describes partly a system which is based on a water-circle which is often used in e.g. the food – industry.

Open system
- The supply of material by e.g. air and loss of material by e.g. evaporation or the media-flow makes an ecosystem to an open system. An open system is characterized by a mass- and energy-transfer with the surrounding environment. Therefore, an open system has to be seen as a part of other ecosystems. Every ecosystem has a specific
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structure which is caused by specific organisms their numbers their breeds and their areal distribution. [3]

**Self-regulation of an ecosystem**

Caused by the reproduction of organisms the available nutrients drop and consequently the numbers of living organisms must diminish. It is a basic fact that the process of self-regulation depends on the density-limiting factors like stress e.g. As a result, every ecosystem is robust for a certain period of time that means that the number of organisms oscillated around an average value.

The procedure of the swing into an average value shows the self-regulation effects, because without these effects the population would grow endlessly. With the basically possible supplement of chemicals or the influence of the other different factors it is possible to reduce the average value of organisms in an artificial way.

These dynamics come from the permanent supply and the removal of utilisable products. It is not possible to circumscribe an ecosystem sparsely or temporally absolutely precisely. [3]

**Possible effects of the growth of micro-organisms**

**Possible typical effects are:**

The fouling of surfaces can cause a reduction of the efficiency of physical and chemical processes.

The reduction of the efficiency effects an increase of the pressure-drop, a decrease of the mass respectively volume flow or a reduction of the effectiveness of a plant like a reduced heat-transfer.

The fouling of pipes can lead up to a blockage and can cause a damage of equipments and can consequently cause cost-intensive down-times. These influences can lead to an increasing or the exceeding of the pump-capacity and therefore to an increase of the operating-expenses.

Moreover, it is possible that the micro-organisms can arrive into the air. Thereby it can happen that the micro-organisms can infect persons with such as e.g. the legionnaires’ disease.

The existence of micro-organisms can also support the generation of corrosion.

Besides these points the existence of micro-organisms can support the emergence of unpleasant-odours. [3]

**An overview over the potentially existing micro-organisms**

It is basically possible to divide the various micro-organisms into three categories:

- *Algae*
- *Bacteria*
- *Fungi* [17]

**Algae**

The growth of algae is only possible with the existence of solar-radiation. For this reason, algae are generally not important in the case of technical applications. [17]

**Bacteria**

Bacteria are micro-organisms with a magnitude from 1/10,000 [mm] up to 1/1,000 [mm]. [16]

**Mucilage-generation-bacteria**

Many breeds could be theoretically tolerated when they would not appear in association with mucilage-generation-bacteria or with bacteria which support the generation of corrosion. The mucilage-generation-bacteria cultivate often a film which reduces the efficiency of the process of corrosion. The nutrients for these organisms are primary soluble salts and carbon-compounds. These deposits (mucilage) enhance the absorption of dirt and consequently the degree of fouling in the system. [19]

**Sulphate reduction bacteria**

These kinds of bacteria can only reproduce each other on anaerobic (lack of oxygen) conditions. That can occur inside of sludge and e.g. below the products of metabolism of mucilage-generation-bacteria. The metabolism of these bacteria leads to corrosion of Iron (Fe). [17]

**Iron-bacteria**

These kinds of bacteria obtain their energy out of the transformation of Fe$^{3+}$ to Fe$^{2+}$, i.e. iron becomes corroded. The presence of these bacteria accelerated the oxidation of Iron (Fe). [17]

**Bacteriophage**

A bacterium as a pathogen is a bacteriophage. Bacteriophage are viruses which seized living bacteria as parasites. [3]

**Viruses**

Viruses are often etiologic-agent which causes communicable-disease in the host-organism like bacteria. In the case of being viruses they can cause e.g. polio, mumps, measles, pox, influenza and meningitis. Certain viruses are very likely to influence the support of the generation of some kinds of cancer. Viruses are not viable without the existence of host-organisms; they can only appear in association with the host. Consequently, the host-organisms act indirectly – when they carry a virus inside – as the carrier of the virus. A dispersion of the host can cause a dispersion of the bacteriophage and thus a disease. To avoid the dispersion of a disease it is necessary to minimise the progeny and the circulation of bacteria. It is interesting to point out, that when bacteria are not infected, they are harmless. For this reason, it is essential to minimise the population of micro-organisms. [3]

**Fungi**

Without the growth of bacteria and algae a growth of fungi will hardly happen. Because of the dependency of algae from the existing of the incidence of light – which is generally doesn’t exist inside of plans or pipes – also a formation of fungi can be excluded. [18]

**Main precondition for the growth of micro-organisms**

The source for the existing of micro-organisms is water, air, and e.g. dusts. In the case of water-cycles it is possible to say that the...
numbers of pathogen depend on the influx of particles in the air and the water-quality. [18]

Sources of nutrients
One source of nutrients is water. Especially the use of surface-water is dangerous, because in addition to the influx of micro-organisms there also can happen an influx of nutrients. The same interrelationship exists concerning air. One other important aspect is the residence-time, because in the case of water-cycles it can come to a densification and that causes an increase of the concentration of e.g. dirt. [18]

Temperature
The optimal interval for the growth of micro-organisms is between a temperature from 5 °C up to 65 °C. [4]

Pressure
High pressure can reduce the growing of populations of micro-organisms. This dependency affects a higher effectiveness of the process of pasteurisation. In the common process of pasteurisation, a temperature-range from 60 °C up to 90 °C is necessary, but with a pressure of 4,000 [bar] up to 10,000 [bar], the necessary temperature-range is only 10 °C up to 30 °C. [5]

pH-value
The optimal pH-value for, the growth of micro-organisms is in the neutral magnitude around 7 and light alkaline >7. [3]

aw-value or Activity of Water
Micro-organisms like all organisms need water. In the absence of water, the metabolisms of the organisms end. The term aw-value represents the availability of water inside of the media. Thus, this term represents one of the most important growth-conditions. [6] The activity of water is defined as the quotient of the partial-pressure of water-steam above the media (p) and the partial-pressure of-water-steam above clear water (p0) at a certain temperature.

\[ a_W = \frac{p}{p_0} \]

A lack of water can effect a reduction of the growing-process and can also – in the case of damageable organisms-cause the end of the population. The majority of micro-organisms have their optimum of growing at an aw-value of about 0,98 up to 1. But there are also organisms which need only an aw-value of only 0,6. [7]

The measurement of the reduction of bacteria
Log-reduction
The log-reduction represents the effectiveness of technologies to reduce the number of micro-organisms. The reduction of populations of micro-organisms can be described in log-steps; this means the reduction of the exponent of the basis 10. The definition of the log-reduction can be ideally described with an example. A population has got \( N_0 = 10^6 \) individuals the reduction of 1 log represents the reduction of the exponent 6-1 = 5. The “new” population has got \( N_1 = 10^3 \) individuals. The percentage of the reduction equals 90 %. In the case of pasteurization, a log-reduction of 5 is generally demanded. This reduction equals a reduction of 99,999 %. The number of living micro-organisms at the beginning of the process is 1,000,000 and goes down to 10 at the end of the process.

In other words, a 1-log-reduction equals a 10-fold (10^1) reduction, a 2-log reduction equals a 100-fold (10^2) and a 3-log-reduction equals a 1000-fold (10^3) reduction. The diagram above shows also the effect of an 0,3-log-reduction, which causes a bisection of the individuals.

Cleaning-processes by the use of the media-flow
The cleaning process by the use of a media-flow can be separated into three steps.
– The first step is the destabilisation of the deposit of micro-organisms; this can occur with the aid of mechanical, thermal, and chemical devices respectively media.
– The generation of a more or less constant velocity in respect of the transport of the organisms must be reached in the second phase.
– In the last phase a steady state of transport with a constant velocity must be achieved.

In terms of an optimal cleaning by the use of the mechanical possibilities the media-flow is self-evidence, the suitable solution. In this case the cleaning process is a function of the velocity of the media e.g. water, because the velocity influenced the form of the flow and thus the stress which affects the movement of the deposits. It is also desirable to get a uniform as possible flow, to minimize the acceleration losses and losses based on the deceleration of the media. In the case of a liquid media it is also necessary to take the stage of the media into consideration. Because when the velocity of the flow is locally high, the pressure-loss can also be very high. This particular pressure-loss can cause a shortfall of the pressure below the vapour-pressure of the media. The achievement of that stage can effect partially, or more drastically the complete vapourisation, this follows to an increase of the velocity of the flow up to the acoustic-velocity.

It is essential to avoid such conditions, because media in this stage can cause shocks and shock-waves and this can damage and destroy devices and the equipments. [9] The following parts of the text will show formulas to discuss the effectiveness of the blow-out procedures.

Reynolds-number
One of the most important factors to describe the principles of the transport of particles is the Reynolds number. The Reynolds-number combines 3 significant properties of the flow and the fluid: velocity, density and viscosity.

\[ Re = \frac{cd}{v} \]

c = Velocity [m/s]  
d = Diameter [m]  
v = Viscosity [m²/s]

The flow-rate is the most interesting factor, because it is the easiest to influence and mostly the only influenceable factor. A Reynolds number – in the case of circular pipes – of 2320 or less indicates a flow in a laminar mode while a number larger than 2320 indicates a more turbulent flow. [10]

Laminar-sublayer
The laminar-sublayer is the part of the boundary-layer of the flow with a direct contact to the wall of the pipe. As the result of the influence of the viscosity and the adherence condition at the wall the forces of the turbulent flow of the main flow disappear. The turbulent flow changes to the laminar mode at the wall and the effectiveness of the turbulent main flow concerning the removal of bacteria or other particles...
disappear. Inside of the sublayer there are only "Newtonian frictional-forces". These forces affect a kind of damping of the turbulent movements outside of the area of the laminar-sublayer. The measurement respectively the thickness of the laminar-sublayer is, next to the flow rate, the most important impact concerning the removal of micro-organisms, because the border of the laminar-sublayer represents the border of the effectiveness of the turbulent flow. But the interactions between the flow and micro-organisms are much more complicated. On the other hand, the transport process based essentially on the turbulent flow, because this form of flow represents a kind of vibrations effected by movements across and against the mainstream. These movements can overcome the adhesive-force, weight-force and the friction-force of the micro-organisms. And amongst others, the releasing of bacteria out of their interconnection is the main problem, because the form of the accumulation of the particles influenced the firmness of the whole bacteria structure drastically. On the other hand, represents the thickness of the laminar-sublayer the maximal/minimal removable sediments in respect of their diameters. This fact is well known regarding the calculation of friction losses inside of pipes. Schlichting develops equations which make it calculable, whether the surface is hydraulic smooth, in a transition state from the laminar to a turbulent friction, or completely turbulent. The calculation of the laminar-sublayer inside of pipes – which is also called viscose-sublayer based on an equation derived by Prandtl.

\[
\delta_L \approx \frac{50}{Re^{0.675} R}
\]

Like shown before, the thickness of the layer in ratio of the thickness of the deposit (bacteria) is essential. The knowledge of the measurement of bacteria gives a hint concerning the necessary flow-rate to get a removal-effect. It is important to stress out that this approach does not take the roughness of the pipe and other factors into consideration. But if the diameter respectively height of a bacteria is approximately 1/1000 [mm] the velocity to minimise the sublayer to the same magnitude, the flow-rate would reach unrealistic and impossible rates. Next to the energy-costs it is also fundamental to take other points into consideration like the different wears, oscillations [9] and the loudness. The theoretical description of the sublayer inside of pipes displays the principle problem to clean pipes generally.

An example with water (ϑ = 20 [°C]) as cleaning-media with an inner diameter of the pipe of 0.025 [m] combined with the variation of the flow-rate between 1 [m/s] up to 5 [m/s] makes the influence of the media-flow clearer. The results of the calculations are shown in the diagram below. The curve represents the ratio between the laminar sublayer and the "thickness" of the bacteria.

At the velocity of approximately 3.5 [m/s] the factor \(\delta_r\) has the value of 30 [-] this represents the distance between both layers. In other words, the thickness of the laminar sublayer is 30-fold higher as the "thickness" of the bacteria. Therefore, the velocity has to reach extreme high values to reduce the sublayer to the magnitude of micro-organisms. The cleaning with water is not practical. The description of the fluid-conditions shows the problem to remove bacteria and with the knowledge of the growing process of bacteria-populations the problems and the importance of cleaning-techniques are clearer. The way to use this approach, to describe the problems of removing of micro-organisms based on the point that this process is relatively easy to visualize. The cleaning process is more complicated, but a detailed analyse of this process would not reach the purpose to point out the problems. The following part will show an approach to minimise and even the avoiding of the generation of bacteria inside of pipes and also on gaskets and other equipments.

**Silver as additive to polymers**

Metallic silver, which presently has a real renaissance, is very effective against bacteria. An important pre-requrement for this application is the necessary know-how and the right formulation to make such products.

Elementary silver, which is in this case also called colloidal silver, can be introduced.
Thus silver in extremely fine distribution can be compounded into polymer formations leading to new nano-composite materials. Since also the silver can be distributed more homogeneously in the product quality and security are enhanced. Chemically, the production process is a pure physical one, the resulting material behaves very homogeneously. There is no need for further purification steps so that the nanosilver can be applied immediately. Given the right formulation silver ions are set free sufficient charged of electrons to kill bacteria on the surface of e.g. a gasket. To avoid unwanted toxic side effects the silver dosage can be lowered to the product – or application – specific optimum. A company-owned method for measuring the anti-infective properties of materials offered unique advantages. [11]

Effects of colloidal silver in respect of micro-organisms

Colloidal-particles are the smallest particle-sizes in which material can be divided without leaving their individual properties. The next stage would be the size of atoms.

These particles have the same electrical negative or positive charge; for this reason the particles balance each other. All processes inside of cells based on the stage of colloidal materials. [12]

One way to reduce the growing of micro-organisms is the use of toxically chemicals which application can generally harm or contaminate e.g. drinking-water and consequently the health of people. Another way to minimise or avoid the growth of micro-organisms is – e.g. on surfaces – the use of the so called nano silver respectively colloidal silver. Intensive analyses of colloidal silver show the effectiveness of this metal in respect of the micro-organisms.

The most interesting result of the studies is the magnitude of the effectiveness of colloidal silver in polymers. A fraction of 50 up to 1,000 [ppm] ([ppm = parts per million]) is sufficient to avoid the growth of bacteria, fungi, and algae. [13] In the medicine, silver is often use to disinfect something. Silver-ions can hinder the growth of bacteria, but furthermore they can bring the existence of micro-organisms to an end like mentioned above.

The process of the deactivation can be analyses in to three steps.

– The bacteria come closer to the surface which contains silver-ions.
– The ions pass a charge of positive nanoload to the bacteria.
– The transfer of this charge has an effect like a lighting to the cell, in which a positive charge of electrons will be transferred into the cell. The intensity of that transfer is so slight that it can not be recognised. The bacteria become inactive, because the metabolism will hinder.
– The bacteria become inactive and consequently they are not still able to exist longer. [14]

Conclusion and outlook

Branches with high quality consciousness would like to avoid any step that might support the further spreading of antibiotic resistance, which is why antibiotics are not a sustainable solution to this problem.

The increase of a population of bacteria like shown in the first part of this paper and problems of cleaning-which was exemplary described concerning a media-flow – shows the necessity to find a new way. The application of nano-silver needs the knowledge of optimised spreading and the generation of very little particles. The use of nano-silver is in principle possible in a lot of different applications, but only with a close cooperation with specialized firms. [15] The appearance of biofouling can be reduced with the application of nano-silber and also in the cases of applications in the biogeo-technology and the steam generators.
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**Literature**


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